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Research paper

Strategy assortativity and the evolution of parochialism

Ennio Bilancini [a,*], Leonardo Boncinelli [b], Alessandro Tampieri [c]

[a] *IMT School for Advanced Studies, Piazza S. Francesco 19, 55100 Lucca, Italy*
[b] *Department of Economics and Management, University of Florence, Via delle Pandette 9, 50127 Florence, Italy*
[c] *Department of Economics and Management, University of Florence, and CREA, University of Luxembourg, Via delle Pandette 9, 50127 Florence, Italy*

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ABSTRACT

This paper investigates the role of strategy assortativity for the evolution of parochialism. Individuals belonging to different groups are matched in pairs to play a prisoner's dilemma, conditioning their choice on the identity of the partner. Strategy assortativity implies that a player is more likely to be matched with someone playing the same strategy. We find that, if the degree of strategy assortativity is sufficiently high, then parochialism (i.e., cooperate with your own group and defect with others) spreads over a group, while egoism (i.e., defect with everyone) emerges otherwise. Notably, parochialism is more likely to emerge in smaller groups.

1. Introduction

Assortative matching refers to the fact that individuals are more likely to be matched with people similar to them in some relevant respect. This property of matching processes has been a subject of interest in connection with the evolution of prosocial behavior.[1]

In many analyses explicitly considering assortative matching, similarities refer to belonging to the same cultural group, the same social or ethnic group, or the same religion (McPherson et al., 2001). We refer to this kind of matching as "type assortativity". However, assortative matching can be driven by similar behaviors, irrespective of the cultural, ethnic or social group of the individuals. In this latter case, assortativity may emerge indirectly when a specific behavior causes individuals to frequent the same locations, even if they come from different social groups. Assortativity in behaviors can be illustrated through various historical examples where individuals from different backgrounds united due to shared ideals or actions. For instance, consider the Civil Rights Movement, the anti-Apartheid movement in South Africa, the Suffragette movement in the early 1900s, the "Underground Railroad", and the activism surrounding HIV/AIDS.[2] In all these cases, interactions were not based on social or ethnic similarities, but rather

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* Corresponding author.
E-mail addresses: ennio.bilancini@imtlucca.it (E. Bilancini), leonardo.boncinelli@unifi.it (L. Boncinelli), alessandro.tampieri@unifi.it (A. Tampieri).

[1] For a detailed review of assortativity in evolutionary game theoretical models see Section 3 of Newton (2018).

[2] In the Civil Rights Movement, which took place in the United States during the 1960s, people from diverse racial and socio-economic backgrounds came together in a concerted effort to fight for equal rights and end racial segregation; such a movement saw a coalition of individuals, both black and white, who were united in their opposition to the Apartheid regime. The Suffragette movement fought for women's voting rights, also demonstrating assortativity in behavior; women from various ethnic and social origins joined forces in a collective struggle for gender equality. The "Underground Railroad" was a network in the United States before the Civil War, where individuals, both black and white,worked together to help slaves escape to freedom. The activism surrounding HIV/AIDS included medical professionals, patients, artists, and activists who, regardless of their background, were united in their efforts to raise awareness, promote research, and fight the stigma associated with the disease.

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on behaviors held for pursuing a common goal. In addition, assortativity in behaviors allows a few extreme cases, albeit socially relevant, where some individuals may dislike or devalue their own cultural group. This is the case of "cultural cringe" (Phillips, 2006): the desire to get along with individuals belonging to different cultures, a common phenomenon now in, e.g., Australia, Canada and Brazil. Assuming assortativity by groups makes it hard to account for these social phenomena.

In this paper we investigate the evolution of cooperation considering assortative matching driven by the behavior code, to which we refer as "strategy assortativity". Along this concept, individuals are more likely to be matched together if their behavior code is similar, regardless of their social group. We emphasize that strategy assortativity differs from "action assortativity": in strategy assortativity, individuals are more likely to be paired together solely if they adhere to the same strategy, with no consideration given to the degree of similarity between these strategies. In practice, this can occur when individuals deliberately choose to gather at a specific location, driven by a universally shared behavioral code among all attendees.

Specifically, we consider a setting where individuals belong to one of many social groups and are drawn to play a prisoner's dilemma in pairs. With many social groups, there are several possible strategies for a generic member of each social group, which can be summarized in the following: cooperation with everyone (cooperation), cooperation only with the own group (parochialism), cooperation only with the own group and some other (semi-parochialism), cooperation only with all other groups (anti-parochialism), cooperation only with some of the other groups (semi anti-parochialism) and defection with everyone (egoism).

In the context where individuals hang out into different places, strategy assortativity may arise because preferences determine where they gather. An example might be handy to get the idea. Consider a population of Christians and Muslims who have heterogeneous preferences about with whom to cooperate. People who want to cooperate with Christians but not with Muslims tend to go to a church, people who want to cooperate with Muslims but not with Christians tend to go to a mosque, people who want to cooperate with everybody tend to go to non-religious volunteering associations, and people who do not want to cooperate with anyone tend to go to bars, clubs or the like. Importantly, people going in the same place are more likely to interact, irrespective of their type.

We find that, while equilibria of cooperation or anti-parochialism are always selected against – no matter how strong is assortativity – an egoist equilibrium might be eroded over time by parochialism. This is consistent with recent experimental evidence, showing that parochialism is ubiquitous in 42 nations (Romano et al., 2021).

In addition, when strategy assortativity is strong enough, parochialism is always favored by evolution. These results may be explained as follows. In a cooperative equilibrium, mutant parochialists of the same group have an advantage with respect to cooperators of any group since, in assortative matchings, they receive all the benefits of cooperation as cooperators do while, in random matchings, they save on the costs of cooperation when interacting with cooperators belonging to other groups. For the same argument, the advantage is even greater in an anti-parochial equilibrium. In an egoist equilibrium, mutant parochialists of the same group have an advantage with respect to egoists of any group, if strategy assortativity – and so the chance that a mutant meets another mutant – is strong enough. Indeed, in case of assortative matching, the mutants cooperate with each other obtaining a greater benefit than egoists do, which might be greater than the cost of cooperating in case of random matching with a member of the mutants' group. These results have an interesting consequence: when strategy assortativity is strong enough to induce the emergence of parochialism, it also leads *de facto* to type assortativity.

We then investigate the role played by group size. We find that it is more likely that parochialism emerges as a globally asymptotically stable state in a small group. This can be explained with the fact that parochialism is more costly for individuals belonging to a larger group. On the one hand, the costs and benefits are independent of group size in case of assortative matching. On the other hand, the benefits do not depend on own group size — they only depend on the fraction of individuals who cooperate with members of such group. Therefore, the probability to pay the cost of cooperation is larger for the parochial members of larger groups.

Next, we focus on the analysis of average cooperation in the entire population. In this case, we focus on an increase of relative size of one group that determines a corresponding decrease in relative size of another group. We find that average cooperation is larger for higher levels of strategy assortativity. The impact of the relative population size between the two groups is more articulated. In case where strategy assortativity is sufficiently high, and parochialism in all groups is a globally asymptotically stable strategy, average cooperation is larger for greater differences in size between the two groups. If the level of strategy assortativity is such that the globally asymptotically stable strategy is parochialism in one group and egoism in the other, consistently with the results above, then the parochial group is the minority. Hence, average cooperation increases with the size of the minority group, as this is the group that pushes cooperation.

The remainder of the paper is organized as follows. Section 2 briefly summarizes the relevant literature and the connection with this work. Section 3 describes the framework, while Section 4 shows our main results. Section 5 focuses on the analysis of cooperation in the case with a majority and a minority. Section 6 concludes by discussing our results and sketching future research lines. All proofs are relegated in Appendix.

2. Literature

The present paper contributes to the literature on parochialism, which is the tendency to collaborate with individuals of the same group and not with others. Parochialism has been analyzed from different perspectives. One strand analyzes parochialism in the context of between-group cooperation (see Dyble, 2021, Garcia and van den Bergh, 2011 and Choi and Bowles, 2007, among others). A different approach focuses on cooperation in frameworks where the strategy depends on spatial interaction and geographical proximity between players (see Berg et al., 2021, Bowles and Gintis, 2004a, Bowles and Gintis, 2004b, McElreath et al., 2003 and Eshel et al., 1998, among others). In the present paper, we abstract away from both group selection and distance: parochialism emerges as a social outcome, given a sufficiently high degree of strategy assortativity.

This paper also contributes to the stream of literature on strategy assortativity. The seminal contribution in this strand is Bergstrom (2003), who introduces an index of assortativity in a prisoner's dilemma, which is given by the difference between the probability that a cooperator meets a cooperator and the probability that a defector meets a cooperator. In a later contribution, Bergstrom (2013) discusses assortativity in relation to different matching processes: first, the two-pool assortative matching, where an individual matches with some probability from an "assortative pool" consisting only of one's own type, and with the complementary probability from a "random pool"; second, the strangers-in-the-night matching, where individuals meet randomly, and they accept the match with similar partners with higher probability. Among recent contributions on strategy assortativity, Nax and Rigos (2016) and Wu (2016) analyze the evolution of endogenous action assortativity through democratic consensus in social dilemmas and coordination games, respectively. Xu et al. (2019) analyze strategy assortativity among investors in financial markets. A general approach to assortativity is put forward by Van Veelen (2011), which generalizes the findings in Van Veelen (2009) regarding the validity of Hamilton's rule (Hamilton, 1964), allowing for matching among more than two individuals. We note that our findings on the evolution of parochialism with strong strategy assortativity collapse into established results on the evolution of cooperation within a single cultural group (Bergstrom, 2003 and Van Veelen, 2011, among others).

The starting point of the present analysis is Bilancini et al. (2018). They assume that interacting among members of different cultures is costly, because of culture-related norms or habits. To do so, they consider two exogenous cultures, where individuals face a cost of cultural intolerance if they have to interact with someone belonging to the different culture. Unlike Bilancini et al. (2018), we abstract away from cultural intolerance, whose presence would in fact reinforce our findings but limit their generality. Rather, we argue that cultural intolerance may arise as an outcome. In addition, we focus on "strategy" rather than "action" assortativity, that is, a more nuanced concept that allows assortativity from individuals of different cultures but similar behavior. Finally, our analysis covers both cases of two and more than two groups.

The analysis of assortative matching based on group affiliation or cultural traits has developed in at least two important directions: individuals may match assortatively because they are willing to do so, or because they interact with neighbors and neighbors are similar to them. The first reason points to homophily, i.e., *love of the same*, which is a well-documented phenomenon in social life (Currarini et al., 2009). The second reason points to family ties, in that individuals tend to interact often with relatives, and relatives are more likely to have one's own type (Bergstrom, 1995; Alger and Weibull, 2010; Lehmann et al., 2015; Alger et al., 2020).

Alger and Weibull (2013, 2016) deserve a specific discussion. In their framework, assortativity is preference-based: different individuals may have different preferences, and individuals having the same preferences are more likely to interact together. The domain of preferences encompasses the actions to be played: hence, individuals may exhibit different "moral preferences", yielding a different willingness to cooperate. In this context, they find that, under incomplete information, moral preferences allow cooperation to spread in the population and to resist to invasions. Newton (2017) embeds the evolution of assortativity into Alger and Weibull (2013)'s model, showing that their results do not extend to this setting. In our paper we assume different cultural groups, but we consider assortativity taking place only on strategies. While we do not explicitly consider preferences over strategies, strategy adoption may be explained as the result of preferences. Differently from Alger and Weibull (2013), we focus on the evolution of strategies only, keeping types fixed. We stress that types are public information, implying that behaviors are conditional on type. In this setting, we endogenously obtain the evolution of type assortativity and parochialism.

Finally, our paper may be related to the literature on the cultural transmission of values. Relevant examples are Cavalli-Sforza and Feldman (1981), Boyd and Richerson (1988), and Bisin and Verdier (2001) (see Cheung and Wu, 2018 for a continuous-trait extension of the binary-trait model). More recently, Wu and Zhang (2021) have shown the crucial role played by assortativity on the dynamics of cultural transmission. Our model differs from those in this stream of literature in that, if we interpret types as cultural groups (as done in Bilancini et al., 2018), then culture is exogenously given (possibly, due to a relatively short time horizon of the analysis), while only behaviors are allowed to evolve over time.

3. The model

3.1. Population

We study a large population, with mass normalized to 1, composed by individuals belonging to one of many cultural groups, which are public information. We often refer to the cultural group as the "type" of an individual. Cultural groups are likely to be observable in the real world: they are recognizable through various cues such as ethnic traits, names, residential locations, language style, manners, clothing, and more. We denote by G the set of cultural groups, by g a generic group, with $g \in G$, and by β^g the share of population belonging to group g, with $0 < \beta^g < 1$ and $\sum_{g \in G} \beta^g = 1$.

3.2. Stage game

Individuals are matched in pairs to play a prisoner's dilemma with additive payoffs. In each match, the possible actions are "cooperate" (C) or "defect" (D): C pays a benefit b to the partner at an individual cost of c, while D is costless but pays nothing to the partner. The following payoff matrix summarizes: (see Table 1).

Table 1
Stage game. b: benefit from the partner's cooperation; c: cost of the player's cooperation.

	C	D
C	$b-c, b-c$	$-c, b$
D	$b, -c$	0,0

3.3. Strategies

Individuals can condition the action played in the stage game to the partner's cultural group. In particular, an individual follows a strategy that is a function $x : G \to \{C, D\}$, mapping the partner's cultural group into either cooperation or defection. We denote by X the set of all possible strategies, which is the same for every player. We denote by $x^{-1}(C)$ the set of groups whom one cooperates with according to strategy x, i.e, $x^{-1}(C) \equiv \{\hat{g} \in G : x_{\hat{g}} = C\}$. Analogously, we denote by $x^{-1}(D)$ the set of groups whom one defects with according to strategy x, i.e, $x^{-1}(D) \equiv \{\hat{g} \in G : x_{\hat{g}} = D\}$. For the sake of exposition, we introduce the following terminology.

Definition 1. For group g, strategy x is:

- semi-parochial if $\{g\} \subset x^{-1}(C) \neq G$;
- parochial if $x^{-1}(C) = \{g\}$;
- cooperative if $x^{-1}(C) = G$;
- semi-antiparochial if $\{g\} \subset x^{-1}(D) \neq G$;
- antiparochial if $x^{-1}(D) = \{g\}$;
- egoistic if $x^{-1}(D) = G$.

We point out that the categories in Definition 1 are a partition of the strategy set, meaning that each strategy belongs to one and only one of these categories.

3.4. States

We denote by s^g_x the fraction of individuals of group g playing strategy x. Hence, we have that:

$$\sum_{x\in X} s^g_x = 1.$$

A state is denoted by the vector $s = (s^g)_{g\in G}$ where $s^g = (s^g_x)_{x\in X}$. The set of all possible states is denoted by S.

Given its relevance in the following analysis, we denote the fraction of individuals coming from group $g \in G$ among all those who play strategy $x \in X$ in state $s \in S$ as:

$$\eta_{g|x}(s) = \frac{\beta^g s^g_x}{\sum_{g'\in G} \beta^{g'} s^{g'}_x}.$$

3.5. Matching process

The main feature of this model is *strategy assortativity*: individuals are more likely to be matched together if they follow the same strategy x.

The random matching follows the two-pool assortative matching process with uniform assortativity (Cavalli-Sforza and Feldman, 1981): with probability $p \in (0, 1)$ an individual is matched with someone who adopts the same strategy x (i.e., drawn from an assortative pool), while with probability $1-p$ he is matched with a random partner (i.e., drawn from the pool of all the agents who do not match assortatively). The draws determining whether an individual enters the assortative or random pool are independently and identically distributed across individuals.

3.6. Expected payoffs

We denote the expected payoff of an agent belonging to group $g \in G$ who adopts strategy x in state s by $\pi^g_x(s)$. We notice that:

$$\pi^g_x(s) = p\left(\mathbb{1}\{g \in x^{-1}(C)\}b - c\sum_{g'\in x^{-1}(C)} \eta_{g'|x}(s)\right) + \\ + \quad (1-p)\left(b\sum_{g'\in G}\beta^{g'}\sum_{x' : g\in x'^{-1}(C)} s^{g'}_{x'} - c\sum_{g'\in x^{-1}(C)}\beta^{g'}\right). \tag{1}$$

The expected payoff is composed of two parts: one in case assortative matching occurs, with probability p, and the other in case of random matching, with probability $1-p$. In the former part, the benefit b is fully obtained if strategy x prescribes to cooperate with group g, while nothing is obtained otherwise (the indicator function captures this). Also, the cost of cooperation c is paid to the extent that individuals playing x come from groups which x prescribes to cooperate with (η captures this). In the latter part, the benefit b comes from the groups cooperating with g, while again the cost c is paid depending on the overall share of individuals belonging to groups which x prescribes to cooperate with (β captures this).

3.7. *Asymptotic stability*

We focus on dynamics where strategies evolve over time satisfying payoff monotonicity (Weibull, 1995) and keeping group sizes fixed. This is consistent with Bilancini et al. (2018), where the horizon is sufficiently long such that selection operates on strategies but not so long that it also operates on cultural types. Time is continuous and denoted by t, with $s(t)$ indicating the state of the system at time t.

In a payoff monotonic dynamic, a pure strategy with a higher payoff always has a higher growth rate than a pure strategy with a lower payoff. In the following definition, $\dot{s}^g_x$ denotes the time derivative of the fraction of agents in group g playing strategy x.

Definition 2 (*Payoff Monotonicity*)**.** A dynamic is payoff monotone if for $g \in G$ and $x \in X$, $\dot{s}^g_x / s^g_x > \dot{s}^g_{x'} / s^g_{x'}$ if and only if $\pi^g_x(s) > \pi^g_{x'}(s)$.

In the remaining of the paper, we will rely on global asymptotic stability for stating our results (see Sandholm, 2010, for a thorough review of stability concepts in dynamic systems). A state is globally asymptotically stable if any trajectory in the interior of the state space eventually converges to the same equilibrium point. We denote by $\widehat{S}$ the interior of the state space, i.e., $\widehat{S} = \{s \in S : s^g_x > 0$ for all $g \in G$ and all $x \in X$ $\}$.

Definition 3 (*Global Asymptotic Stability*)**.** A state s^* is globally asymptotically stable if, for any $s \in \widehat{S}$, we have $s(t) \to s^*$ as $t \to \infty$.

4. Results

We start by showing that the egoistic strategy performs always better that any other strategy that defects with own group but cooperates with all other groups (antiparochial strategy) or with only some other groups (semi-antiparochial strategy).

Lemma 1. *For group g, the antiparochial strategy and any semi-antiparochial strategy is strictly dominated in S by the egoistic strategy.*

The intuition behind Lemma 1 is the following. Let us first consider potential benefits coming from partners. When matching is assortative, an individual is in any case matched with someone defecting, because all the strategies under consideration prescribe defection with group g. When matching is random, the individual can be matched with a defecting or cooperative opponent, but this only depends on own group identity and not on the strategy chosen.

Let us now turn to costs. If an individual adopts a strategy that is antiparochial or semi-antiparochial, such individual pays the cost of cooperation in some cases happening with positive probability, at least in random encounters, while the cost of cooperation is never paid in case of the egoistic strategy is adopted. Overall, the payoff granted by the egoistic strategy is always larger than that granted by any antiparochial or semi-antiparochial strategy.

From Lemma 1, we are able to introduce the following restriction of the set of states: $\widetilde{S} = \{s \in S : s^g_x = 0$ if x is antiparochial or semi-antiparochial for group g$\}$. This allows us to state the next result: the parochial strategy is always better than any other strategy that cooperates with own group and also all other groups (cooperative strategy) or some other groups only (semi-parochial strategy), once we restrict attention to the states that remain after eliminating antiparochial or semi-antiparochial strategies, i.e., $\widetilde{S}$.

Lemma 2. *For group g, the cooperative strategy and any semi-parochial strategy is strictly dominated in $\widetilde{S}$ by the parochial strategy.*

The intuition behind Lemma 2 is the following. Let us first consider potential benefits coming from partners. When matching is assortative, an individual is in any case matched with someone cooperating, because all strategies under consideration prescribe cooperation with group g. When matching is random, as already stressed in the discussion of Lemma 1, the action taken by partners only depends on own group identity and not on the strategy chosen.

Let us now turn to costs. When matching is assortative, if an individual adopts a strategy that is cooperative or semi-parochial, such individual can pay a smaller cost of cooperation than in case of parochial strategy, despite the fact that he is cooperating with a larger set of types: this can happen depending on the relative size of individuals of other groups playing antiparochial or semi-antiparochial strategies. If we restrict to $\widetilde{S}$, however, this does not happen and we have that the whole cost of cooperation is always paid. When matching is random, as before, the cost of cooperation is paid more frequently if the individual plays a cooperative or semi-parochial strategy than in case the parochial strategy is played. Overall, the payoff granted by the parochial strategy is always larger that granted by any cooperative or semi-parochial strategy.

We are ready to state our main result, about global asymptotic stability: in the globally asymptotically stable state, if the degree of assortativity is below a certain threshold, which is group specific, then the individuals in such group adopt the egoistic strategy, while they adopt the parochial strategy if the degree of assortativity is above the group specific threshold.

Proposition 1. *The globally asymptotically stable state s is such that $s^g_x = 1$, with:*

- *x parochial for group g, if $p > \hat{p}^g$,*
- *x egoistic for group g, if $p < \hat{p}^g$,*

where

$$\hat{p}^g \equiv \frac{c\beta^g}{b - c(1-\beta^g)}.$$

Lemmas 1 and 2 allow us to focus on the comparison between the egoistic strategy and the parochial strategy. Intuitively, the parochial strategy performs better in case of assortative matching, granting a payoff of $b - c$ instead of 0, which is what is obtained with the egoistic strategy. The parochial strategy performs worse in case of random matching, because sometimes the cost of cooperation is paid, while that never happens with the egoistic strategy. The former effect prevails over the second one if and only if the degree of assortativity is large enough.

Proposition 1 shows that parochialism is globally asymptotically stable in a group if the degree of strategy assortativity is strong enough. The intuition is simple: with a higher strategy assortativity, the parochial strategy of a generic member of group g yields a higher expected payoff because a higher p amounts to having a higher chance of meeting a partner adopting the same strategy, who will hence cooperate with g's individuals. The effect of an increase in the degree of strategy assortativity on the payoff of the egoistic strategy is, if any, negative, in that it implies a higher chance of meeting a partner adopting the same strategy, who will hence defect.

Since the thresholds $\hat{p}^g$ are group specific, we notice that we can have a globally asymptotically stable where the individuals in some groups are egoistic and the individuals in other groups are parochial. In particular, $\hat{p}^g$ depends on the group size in a way that can be understood by taking the derivative with respect to β, as simply stated as follows:

Corollary 1. *The larger the size of group g, the larger the threshold $\hat{p}^g$.*

Corollary 1 reveals that the outcome in case of an intermediate degree of strategy assortativity is such that parochialism emerges in the smallest group, and defection in the largest group. The reason why parochialism is more likely to emerge in the smallest group is that the cost of parochialism is lower the smaller the group size. This is due to the fact that, when matching occurs randomly, the probability to meet an individual of own type is given by the relative group size. This, in turn, determines the frequency, and hence the cost, of cooperation in case of parochialism.

5. Analysis of cooperation

Given the importance of cooperation for the success of our societies, it is crucial to relate our findings to the observed extent of cooperation. Specifically, in this section, we focus on how group size influences the average level of cooperation that emerges in our model.

We restrict attention to the case with two groups only. This allows us to speak about majority and minority and the role played by their relative size over the average cooperation in the population, allowing a clear-cut comparative statics exercise that can suggest directions for policy interventions. With more than two groups, indeed, a variation in the size of one group may be combined with a variety of changes in the sizes of the other groups.

We begin by focusing on a single group. Proposition 1 shows that evolution favors the emergence of cooperation among the members of a certain group g provided that the level of strategy assortativity p is sufficiently high, i.e., greater than the threshold $\hat{p}^g$. Importantly, cooperation is not unconditional towards everybody, but it only comes in the form of parochialism, meaning that the members of g only cooperate with other members of g. Hence, for $p > \hat{p}^g$, average cooperation for members of g is:

$$\bar{C}^g = p + \beta^g(1-p). \tag{2}$$

Intuitively, with probability p an individual from g is matched with another individual from g, and both cooperate. With probability $(1-p)$ instead, the matching is random and, hence, cooperation occurs only if another member of g is met, which occurs with probability β^g. Average cooperation of individuals in g changes according to variations of group size and the degree of strategy assortativity. Differentiating (2) with respect to both β^g and p we get, for $p > \hat{p}^g$:

$$\frac{\partial \bar{C}^g}{\partial \beta^g} = (1-p) > 0, \tag{3}$$

$$\frac{\partial \bar{C}^g}{\partial p} = 1 - \beta^g > 0. \tag{4}$$

An increase of both the size of the group and the degree of strategy assortativity increase average cooperation of group g, as it raises the chance of being matched with one member of group g, but for different reasons. By (3), a larger group g implies a higher probability to be randomly matched with one belonging to g. By (4), a higher degree of strategy assortativity increases the probability that a matching is assortative in strategy rather than random and hence, by the nature of the equilibrium from Proposition 1, also assortative in type.

However, for $p < \hat{p}^g$, we have $\bar{C}^g = 0$ and $\partial \bar{C}^i / \partial \beta^g = \partial \bar{C}^g / \partial p = 0$. When strategy assortativity is low no cooperation emerges and, hence, little differences in group size or strategy assortativity are not going to affect group cooperation.

The next step is to look at average cooperation of the whole population. In particular, we consider the case in which the increase in the relative size of one group, say group i, determines a reduction in the relative size of only one other group, say group j.

We assume that $\beta^i > \beta^j$. In the case in which there are only these two groups, i and j can be interpreted as the majority and the minority, respectively. Depending on the level of both $\hat{p}^i$ and $\hat{p}^j$, three qualitatively different cases are possible. In the first, $p > \hat{p}^i > \hat{p}^j$ so that members of both groups cooperate when they meet another member of their own group. In the second case, $\hat{p}^i > p > \hat{p}^j$ so that only members of group j, the smaller group, cooperate among themselves. In the last case, $\hat{p}^i > \hat{p}^j > p$ so that nobody cooperates. For $p > \hat{p}^i > \hat{p}^j$ average cooperation in the population is given by:

$$\bar{C} = \beta^i \left[p + \beta^i (1-p)\right] + \left(1-\beta^i\right)\left[p + \left(1-\beta^i\right)(1-p)\right], \tag{5}$$

which, differentiating with respect to β^i, gives:

$$\frac{\partial \bar{C}}{\partial \beta^i} = 2(1-p)\left(2\beta^i - 1\right) > 0. \tag{6}$$

Intuitively, a greater size of the larger group leads to more cooperation on average because the random pairs are more likely to be formed by members of the same group, who hence cooperate with each other. By contrast, differentiating (5) with respect to p yields:

$$\frac{\partial \bar{C}}{\partial p} = 2\left(1-\beta^i\right)\beta^i > 0, \tag{7}$$

in line with the effect of p on the average cooperation for each single group. These findings are summarized by the following Proposition 2, with no need of additional proofs.

Proposition 2. *For $p > \hat{p}^i > \hat{p}^j$, average cooperation is larger the larger is the difference in size between the two groups $\beta^i - \beta^j$. In addition, average cooperation is larger the larger the level of strategy assortativity p.*

Consider next the case where $\hat{p}^i > p > \hat{p}^j$. In this case, average cooperation amounts to

$$\bar{C} = \bar{C}^j = \left(1-\beta^i\right)\left[p + \left(1-\beta^i\right)(1-p)\right]. \tag{8}$$

Differentiating with respect to β^i we get:

$$\frac{\partial \bar{C}}{\partial \beta^i} = \frac{\partial \bar{C}^j}{\partial \beta^i} = 2\beta^i - 2\beta^i p + p - 2 < 0.$$

Since cooperation only occurs by members of group j, an increase in the proportion of group i, where no cooperation at all occurs, necessarily decreases average cooperation. Moreover, differentiating with respect to p we get:

$$\frac{\partial \bar{C}}{\partial p} = \frac{\partial \bar{C}^j}{\partial p} = (1-\beta^i)\beta^i > 0.$$

Average cooperation increases with p since a greater p increases the frequency of interactions between members of group j who only cooperate among themselves. These findings are summarized by the following Proposition 3, with no need of additional proofs.

Proposition 3. *For $\hat{p}^i > p > \hat{p}^j$, average cooperation is smaller the larger is the difference in size between the two groups $\beta^i - \beta^j$. In addition, average cooperation is larger the larger the level of strategy assortativity p.*

Propositions 2 and 3 show that the effect of a change in the population size of group i on cooperation depends on whether the group i is cooperating or not, given that the minority group j is cooperating. When only group j is cooperating, then an increase of $\beta_i - \beta_j$ leads to a decrease in the proportion of parochialists in favor of defectors, thereby reducing average cooperation. If, instead, both groups i and j are cooperating, then an increase of $\beta_i - \beta_j$ increases the frequency of interactions within the same group, thereby increasing average cooperation.

Fig. 1 illustrates these results, with arrows indicating the increase in average cooperation. For a level of strategy assortativity p above $\frac{c}{b}$, average cooperation reaches its maximum when $\beta^i = 1$: for such a high level of strategy assortativity, the majority group is always parochial, even when its relative size tends to 1 (consider p_2 in Figs. 1 and 2). For any level of p in between $\frac{c}{2b-c}$ and $\frac{c}{b}$, the level of β that reaches maximum cooperation is the highest β such that both groups are parochial (consider p_1 in Figs. 1 and 2). Finally, for any level of p lower than $\frac{c}{2b-c}$, the level of β that reaches maximum cooperation is the lowest β such that the minority is parochial (consider p_0 in Figs. 1 and 2).

6. Discussion

We have studied the evolution of cooperation when individuals are assortatively matched according to their strategies rather than their social groups. We have considered a framework where individuals differ in their social groups and can adopt their actions (either cooperate or defect) conditional on the partner's group. As a consequence, the available strategies in the prisoner's dilemma can exhibit different patterns of the relationship between behavior and partner's group, ranging from parochialism (cooperate only with own group) to antiparochialism (defect only with own group), going through intermediate strategies, called semi-parochial and semi-antiparochial, and where cooperation and egoism (i.e., cooperate with everyone or no one, respectively) are special cases.

Our results have shown that antiparochialism and semi-antiparochial strategies are always dominated by egoism and that, once we restrict attention to undominated strategies, cooperation and semi-parochial strategies are dominated by parochialism. Indeed,

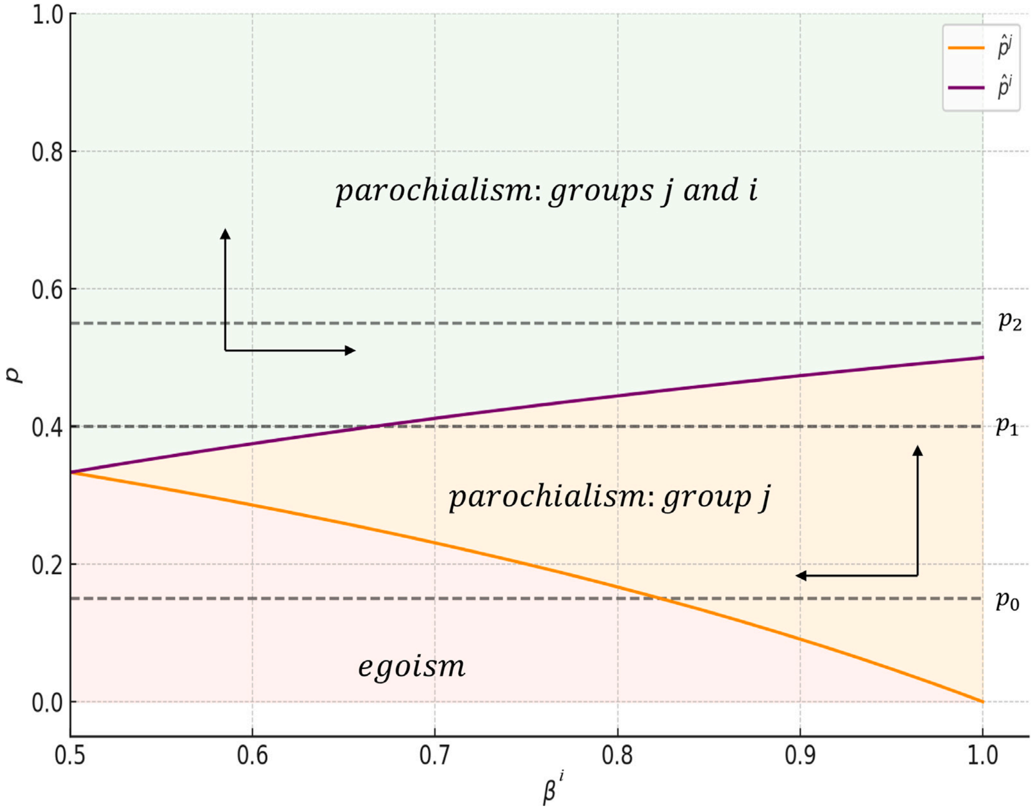

Fig. 1. Regions of parochialism adoption based on the degree of strategy assortativity p and the size of the majority group β^i, for $b = 2$ and $c = 1$, and considering two groups only, i and j, so that $\beta^j = 1 - \beta^i$. In the green region both groups are parochial; in the yellow region only the minority group is parochial; in the pink region both groups are egoist. The arrows indicate the direction of increasing average cooperation in the population. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

egoists perform better that antiparochialists and semi-antiparochialists because they all get the same expected benefits but the former pay a smaller cost of cooperation. Analogously, parochialists perform better that cooperators and semi-parochialists because, once we restrict to undominated strategies, they all get the same expected benefits but the former pay a smaller cost of cooperation.

Moreover, parochialism performs better than egoism when strategy assortativity is sufficiently strong, while the opposite applies if strategy assortativity is sufficiently weak. This happens because, with strong assortativity, parochialists of the same group often cooperate with each other, yielding a benefit which more than offsets the higher cost sustained in random matching.

We notice that, when parochialism is the prevailing strategy, the average cooperation in a group increases with both the group relative size and with strategy assortativity. However, while strategy assortativity can increase for all groups, increasing the relative size of one group necessarily decreases the relative size of another group, which triggers contrasting effects on the average cooperation in the whole population. In a setting with two groups only, the relative group size plays a rather articulated role according to whether parochialism is the prevailing strategy in one group or both. If only one group is parochial, which occurs for an intermediate degree of strategy assortativity, this is the small one, while the large one is egoist. As a consequence, average cooperation increases with the size of the minority group. If strategy assortativity is sufficiently high, so that parochialism emerges in both groups, then average cooperation increases with the difference in size between the two groups.

As stressed in the Introduction, our model considers a setting with no degree of assortativity between strategies that are similar but not identical. Buy doing so, we are able to highlight the relevance of strategy assortativity to drive parochialism. Considering nuanced versions of assortativity, where similar strategies imply a higher probability of interaction, we expect that the quality of our results is unaffected, as long as the level of assortativity is the highest in case of strategies that are exactly the same. Further research may better characterize the relevant thresholds in such scenarios.

A possible limitation of the analysis is the relatively short time horizon considered, under which group sizes can be reasonably assumed to be fixed. In a longer time horizon, group size may evolve in response to average payoff of the group. Phenomena such as cultural assimilation could also be embedded in the model, leading to a change over time of the relative group size.

Our paper helps answering the following general question: is parochialism socially desirable or not? The answer depends on the counterfactual: it is worse than cooperation but better than egoism. In our model, full cooperators are always wiped out over time, and parochialism is the best we can aim at. To obtain this result, a crucial role is played by the assumption of strategy assortativity.

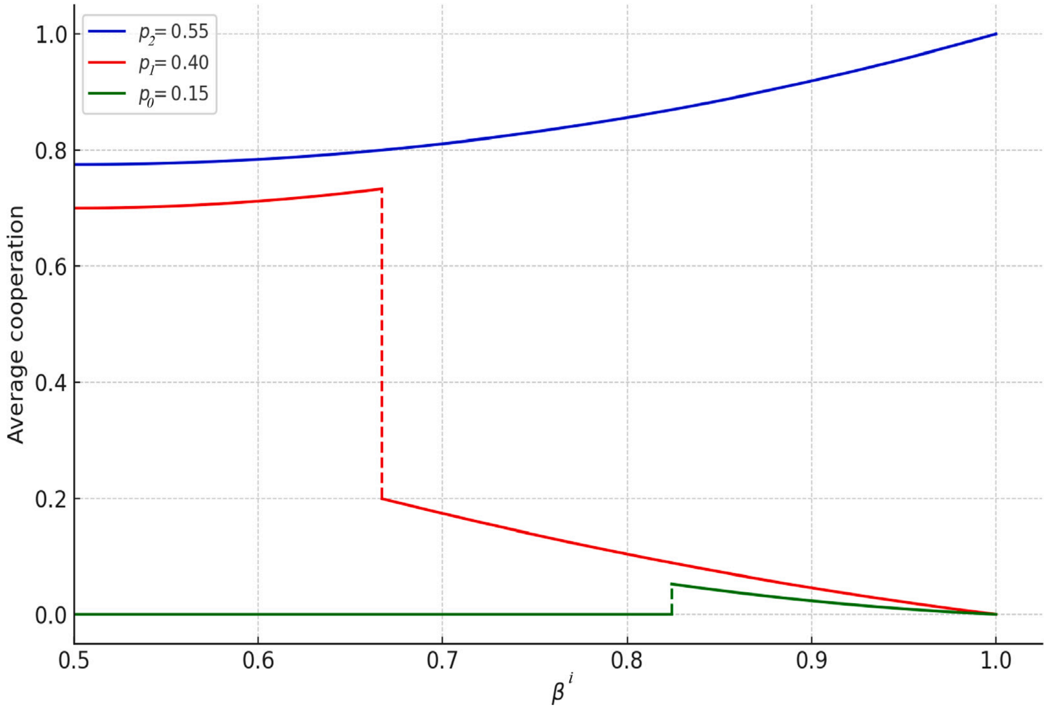

Fig. 2. Average cooperation with two groups as a function of relative group size when $b = 2$ and $c = 1$ for three values of p: $p_0 = 0.15$, $p_1 = 0.4$, $p_2 = 0.55$.

If we replace such an assumption with action assortativity, then full cooperation is a viable outcome, occurring for sufficiently high levels of action assortativity, even in the presence of direct cost of interacting with an individual of a different type (Bilancini et al., 2018). This observation calls for an inquiry of the type of assortativity that is prevalent in our societies, what determines it and, from a policy perspective, how we can affect such determinants.

Another question that our results help tackling concerns the social desirability of multi-culturalism in a society. As noticed by Kuran and Sandholm (2008), there is a trade-off between multiculturalism and social integration, and while the former advocates for policies designed to preserve the cultural features of some social groups or minorities, the interaction among different communities might erode specific cultural features and promote a hybridization of the population. In our setting, think of the case where the degree of strategy assortativity is intermediate, so that parochialism has established only in the minority group. Suppose the majority group is now divided into subgroups, so that strategy assortativity occurs at a finer level: each subgroup has a smaller size than the original group, and this may allow the subgroup threshold to fall below the current degree of strategy assortativity. If this happens, then the average cooperation in society increases.

Suppose, instead, that the minority group is divided into subgroups. Each subgroup would still be parochial, but average cooperation would fall because, when matching occurs randomly, it is less likely to meet someone of own group. Therefore, our results suggest that sub-cultures can enhance average cooperation in large groups but not in small groups. From a different perspective, sub-cultures are more likely to enhance average cooperation when the degree of strategy assortativity is low. This is so because most groups will be made of egoists. In case of a high degree of strategy assortativity, instead, most groups will me be made of parochialists, hence a finer partition of groups is likely to reduce average cooperation.

An avenue for future research regards the investigation of the determinants of the degree of strategy assortativity. In particular, we can ask ourselves which effects are likely to be results of technological progress, as time goes on, on p. Honestly, we do not see a clear-cut answer to the question. Telecommunications have already created significant room for remote interaction, and future developments in digital communication will further reduce the role of geographical considerations in constraining interactions. So the question becomes whether the interactions on the internet are characterized by more or less strategy assortativity than physical interactions. Public regulation of web activity can affect the answer.

A potentially interesting line for future research is related to the concept of identity (Akerlof and Kranton, 2000). If we think of assortativity as defined on identity, rather than on types or preferences/strategies, a relevant question arises regarding the determinants of identity: is the individual self-image mostly generated by the belonging to some ethnic or religious group, or rather by actual behaviors? Such a question probably requires an empirical answer, which may help understand the relative prominence, case-by-case, of type-assortativity and strategy-assortativity.

Another route to explore is related to the possibility of individuals to deceive others by strategic mimicry of other types, e.g., adopting a different dress code to conceal group membership and appear as someone different. This could be done along the lines of Heller and Mohlin (2019), who study how deception and preferences might co-evolve together.

Following the insights resulting from the analysis of cooperation, we would like to conclude with a comment on implications concerning migration policies. Similar models have been employed to analyze the impact of government programs in regulating immigrants' behavior (see, for instance, Pin and Rogers, 2015). A larger quota of the minority group, which may result from a higher immigration flow, may generate an increase of average cooperation. This is what happens in our model for an intermediate degree of strategy assortativity, when only the minority group is comprised of parochialists, while the majority group is comprised by egoists. Even if the benefits from parochialism will be reaped only by the minority group (immigrants) these may be addressed to the whole society through appropriate redistributive policies.

Declaration of competing interest

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Appendix. Proofs

Proof of Lemma 1

Let x be the egoistic strategy and x' any strategy that is antiparochial or semi-antiparochial.

$$\pi^g_x(s) - \pi^g_{x'}(s) = p \sum_{\hat{g} \in x'^{-1}(C)} \eta_{\hat{g}|x'} c + (1-p) \sum_{\hat{g} \in x'^{-1}(C)} \beta^{\hat{g}} c$$

In the above expression, the first term is ≥ 0 and the second term is > 0. Hence $\pi^g_x(s) - \pi^g_{x'}(s) > 0$. Since this holds for any $s \in S$, it is proven that any strategy that is antiparochial or semi-antiparochial is strictly dominated in $\hat{S}$ by the egoistic strategy.

Proof of Lemma 2

Let x be the parochial strategy and x' any strategy that is semi-parochial or cooperative.

$$\pi^g_x(s) - \pi^g_{x'}(s) = p \left(\sum_{\hat{g} \in x'^{-1}(C)} \eta_{\hat{g}|x'} - \sum_{\hat{g} \in x^{-1}(C)} \eta_{\hat{g}|x} \right) c + (1-p) \left(\sum_{\hat{g} \in x'^{-1}(C)} \beta^{\hat{g}} - \sum_{\hat{g} \in x^{-1}(C)} \beta^{\hat{g}} \right) c$$

In the above expression, the first term can have any sign in $\hat{S}$, but it is surely ≥ 0 in $\widetilde{S}$. Since the second term is > 0, we obtain that $\pi^g_x(s) - \pi^g_{x'}(s) > 0$, proving that any strategy that is semi-parochial or cooperative is strictly dominated in $\widetilde{S}$ by the parochial strategy.

Proof of Proposition 1

The proof follows the argument in Samuelson and Zhang (1992).

Let x be the egoistic strategy and x' a strategy that is antiparochial or semi-antiparochial. Considering $s \in \widehat{S}$, we know from the proof of Lemma 1 that

$$\pi^g_x(s) - \pi^g_{x'}(s) > (1-p) \sum_{\hat{g} \in x'^{-1}(C)} \beta^{\hat{g}} c \tag{9}$$

By continuity and payoff monotonicity, we have that:

$$\frac{\dot{s}^g_x}{s^g_x} - \frac{\dot{s}^g_{x'}}{s^g_{x'}} > \varepsilon, \text{ for some } \varepsilon > 0. \tag{10}$$

By (10), we observe that $s^g_x / s^g_{x'}$ increases over time unboundedly. Since s^g_x cannot exceed 1, we conclude that $s^g_{x'}$ must tend to zero as time goes on.

Following Fudenberg et al. (1998), once we know that antiparochial and semi-antiparochial strategies wipe out over time, we can restrict attention to $\widetilde{S}$. Let $\overline{x}$ be the parochial strategy and $\overline{x}'$ a strategy that is semi-parochial or cooperative. Then, by Lemma 2 we have that

$$\pi^{g}_{\bar{x}}(s) - \pi^{g}_{\bar{x}'}(s) > (1-p) \sum_{\hat{g} \in \bar{x}'^{-1}(C)} \beta^{\hat{g}} c \tag{11}$$

and the same argument applies, showing that also $s^{g}_{\bar{x}'}$ must tend to zero as time goes on.

We are left with only egoism and parochialism as possibly surviving strategies in the long run. Hence, following again Fudenberg et al. (1998), we restrict attention to states where only egoism and parochialism occur in the comparison between them:

$$\pi^{g}_{\bar{x}}(s) - \pi^{g}_{x}(s) = p(b-c) - (1-p)\beta^{g} c.$$

Therefore, parochialism pays strictly more than egoism if $p > \hat{p}^{g}$, with

$$\hat{p}^{g} \equiv \frac{c\beta^{g}}{b - c(1-\beta^{g})},$$

while the inverse holds if $p < \hat{p}^{g}$, which completes the proof.

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