Interdependent Preference Formation[¤]

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Abstract

A standard assumption in the economic approach to individual decision making is that people have independent preferences, that is, they care only about their absolute (material) payo¤s. We study equilibria of the classic common pool resource extraction and public good games when some of the players have negatively interdependent preferences (in the sense that they care not only about their absolute payo¤s but also about their relative payo¤s) while the remainder have independent preferences. It is shown that at any equilibrium, those with interdependent preferences earn strictly higher absolute payo¤s than do players with independent preferences. If the population composition evolves in accordance with any payo¤ monotonic evolutionary selection dynamics, then all players will have interdependent preferences in the long run. Similar (but weaker) results obtain for some other economically important classes of games in strategic form. The robustness of our …ndings with respect to other preference formation mechanisms such as myopic and rational socialization is also discussed.

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1 Introduction

A standard assumption in the economic modeling of human behavior is that people have independent preferences. Given a choice between two income distributions, they will prefer that in which their own income is higher, regardless of their rank or relative standing in the two distributions. Changes in the incomes of others, provided that their own material circumstances remain unchanged, leave them neither better nor worse o¤, and they are consequently unwilling to sacri…ce any portion of their own material well-being in order to enhance or to diminish the well being of others.

The usual methodological defence of independent preferences is made on evolutionary grounds: units which maximize their own material payo¤s will prosper and thrive, while those that do not will be outperformed and driven to eventual extinction (Friedman, 1953). This evolutionary argument is compelling in the context of perfectly competitive environments, in which individual units are powerless to a¤ect the payo¤s of other units. However, in strategic settings in which a …nite group of individuals interact, the evolutionary argument is by no means self-evident. It is at least conceivable that in some strategic environments, individuals who care about their relative payo¤s as well as their absolute (material) payo¤s (that is, in the terminology of the present paper, agents with interdependent preferences) will have an advantage over those who are concerned exclusively with their absolute payo¤s. This advantage can then translate, somewhat paradoxically, into higher equilibrium absolute payo¤s for those who are not absolute payo¤ maximizers. Our purpose in the present paper is to identify environments of economic importance that give rise to this phenomenon. We …nd that in a variety of commonly studied settings including common pool resource extraction and public good games, absolute payo¤ maximizers earn strictly lower absolute payo¤s in equilibrium than do players with interdependent preferences. We argue that this disparity in equilibrium payo¤s has far-reaching implications for the theory of preference formation.

There are two quite distinct strands in the existing literature on endogenous preferences. The evolutionary approach views preference formation as the unplanned outcome of genetic and/or cultural transmission mechanisms. Transmission may be 'vertical', as when children inherit their preferences directly from their parents, or 'oblique', as when they inherit their preferences through the emulation and imitation of other individuals to whom they are exposed (Cavalli-Sforza and Feldman, 1981, Boyd and Richerson, 1985).[1] Alternatively, the rational socialization approach to preference formation is based on the postulate that altruistic and forward looking parents deliberately inculcate preferences in their children with

[1] This approach has been applied to explain the evolution of altruism among siblings (Bergstrom, 1995), time preference (Rogers, 1994), risk-aversion (Rubin and Paul, 1979, Robson, 1996), systematic errors in expectations (Waldman, 1994), and a variety of other tastes and behavioral traits (Hirshleifer, 1987, Frank, 1987, Hansson and Stuart, 1990, Güth and Yaari, 1992).

a view to enhancing what they, as parents, perceive to be the children's future well-being. Along these lines, Rubin and Somanathan (1996) have recently considered the inculcation of honesty, and Bisin and Verdier (1996a) the emergence of preferences for social status.

It is typically assumed in the evolutionary approach that the selection dynamics are (absolute) payoff monotonic, i.e., higher material payoffs to a heritable trait typically lead to more rapid replication of that trait over time. Consequently, our finding that in a variety of strategic settings of economic importance, the material rewards to those with interdependent preferences strictly exceed the rewards to those with independent preferences leads directly to the implication that evolution will favor the emergence of interdependent preferences. If the population is initially heterogeneous, our results imply that at least in environments that are well represented by common property and public good games, any payoff monotonic evolutionary selection dynamics will lead in the long run to a population that consists exclusively of individuals with interdependent preferences. These results are obtained when each member of the population interacts simultaneously with every other member, which is the usual assumption in common property and public goods contexts. We also consider the case in which members of the population interact on the basis of pairwise random matching to play an arbitrary 2×2 game. Somewhat milder results are obtained in this context, with a heterogeneous population composition typically prevailing in the long run. Except in relatively uninteresting cases where cooperative behavior is strictly dominant for all players, in none of the strategic settings studied in this paper does the evolutionary approach entail a monomorphic population composed only of agents with independent preferences.

When preferences are acquired as a result of deliberate socialization efforts by altruistic, forward looking parents, the implications of the strategic advantage held by those with interdependent preferences are less obvious. Even if it is true that at any given population composition those with interdependent preferences obtain strictly higher material payoffs, it may not be in the interest of a forward-looking parent with independent preferences to inculcate interdependent preferences in her child. The reason is that such an act would alter the population composition and induce a different equilibrium in the subsequent generation, and although the child at this equilibrium would do better than those with independent preferences, this payoff may be less in absolute terms than that which could have been earned had the child been inculcated with independent preferences. Intuitively, there are efficiency losses associated with the inculcation of interdependent preferences, and if these are sufficiently large, such inculcation may lead to a decline in absolute payoffs despite the increase in relative standing in the society. In spite of this complication, we show that in some common pool resource extraction and public good games, socialization by forward-looking parents also leads in the long run to a uniform population in which all individuals have interdependent preferences.

The general problem of preference formation can, of course, be studied within the context of any strategic environment. Our focus on the common pool resource extraction and public good games is motivated by the fact that these environments have been a perennial feature of human societies from the earliest times. Traditional societies even in the present day rely heavily on commonly owned fisheries, grazing lands, and forest areas for their subsistence. Similarly, throughout human history, a large number of essential activities have required collective action of one kind or another, ranging from the hunting of large animals and the construction of housing to the provision of irrigation, harvesting, and defence against encroachment or attack by competing groups. If such environments favor the emergence of interdependent preferences, then the standard assumption of independent preferences in economic models should be made with considerably greater caution and circumspection.[2]

2 An Analytical Framework

Consider an overlapping generations economy in which each person lives for two periods, and has some finite (possibly zero) number of children in the second period of her life. Let N_t denote the size of the adult population in period t. In the first period of their lives, preferences are acquired in a manner that is left unspecified for the moment. In the second period of life, the adult members of the population interact with one another in a manner that we represent by a symmetric strategic form game with complete information.[3] Each adult i selects an action x_i from a given set of available actions A. The resulting action profile $x = (x_1, x_2, \ldots, x_N)$ then determines the absolute payoff $\pi_i(x) \geq 0$ obtained by each adult. The adult population in any given generation consists of two distinct groups, which are heterogeneous with respect to their preferences over payoff distributions. A number $k_t \in \{1, 2, \ldots, N_t - 1\}$ of individuals are absolute payoff maximizers in the standard sense; they are said to be independent agents. These individuals always prefer payoff distributions in which their own material payoff is higher, and are left unaffected by changes in the payoffs

[2] The importance and plausibility of interdependent preferences has, of course, been noted in the literature (Duesenberry, 1949, Easterlin, 1974, Frank, 1987, and Cole, Mailath and Postlewaite, 1992), and is supported by ample empirical and experimental evidence (see Tomes, 1986, Clark and Oswald, 1996, Saijo and Nakamura, 1995, Levine, 1996, and references cited therein). It is also well known that the introduction of interdependent preferences into economic models has non-trivial implications in that many conventional results have been either overturned or significantly modified in the presence of such preferences (see, among others, Boskin and Sheshinski, 1978, Oswald, 1983, Frank, 1984, Akerlof and Yellen, 1990, and Ito, Saijo and Une, 1995). However, to the best of our knowledge, the existing literature falls short of providing an analysis of the evolution of interdependent preferences.

[3] The symmetry postulate is very common in evolutionary approaches to economics and, as will become apparent shortly, it is particularly reasonable in our context. The assumption of complete information is, on the other hand, much more problematic, and will be relaxed in future work.

of others. The remainder of the population consists of individuals who are concerned not only with the value of their absolute payoff but also with their payoff relative to the average payoff in the population. We say that these individuals have (negatively) interdependent preferences which are represented by an objective function

$$p_i(x) = F\left(\pi_i(x); \frac{\pi_i(x)}{\bar{\pi}(x)}\right); \quad i \in \{k_t + 1; \ldots; N_t\} \tag{1}$$

where F is an arbitrary strictly increasing function on R^2 and $\bar{\pi}(x)$ is the mean payoff at the outcome x in the population at large. (We refer to such individuals in the sequel simply as interdependent.) This way of representing the (negatively) interdependent preferences has recently been proposed and axiomatically characterized by Ok and Koçkesen (1997). In particular, the preferences represented by (1) can be interpreted as a compromise between the standard case where the individual is assumed to care only about her absolute payoff π_i, and the extreme case where she is concerned exclusively with her relative payoff in the game, i.e., with $\pi_i/\bar{\pi}$ (the latter case corresponds to Duesenberry's relative income hypothesis.) The analysis of the present paper is conducted in terms of an essentially arbitrary strictly increasing F function. Thus the class of interdependent preferences we consider here is quite rich, and incudes great many specifications used elsewhere.[4]

Given the formulation above, the actual strategic interactions of the individuals in period t are modeled by the normal form game where the ith player's action space is A and her objective function is either π_i (if $i \in \{1; \ldots; k_t\}$) or p_i (if $i \in \{k_t + 1; \ldots; N_t\}$). Let us denote a generic game of this sort by $G(k_t; N_t)$.[5] An equilibrium of this game is an action profile at which, given their preferences, no player has an incentive to deviate. Formally, at any equilibrium action profile $\hat{x}$ in period t;

$$\pi_i(\hat{x}) \geq \pi_i(y_i; \hat{x}_{-i}) \qquad \text{for all } i \in \{1; \ldots; k_t\} \tag{2}$$

and

$$p_i(\hat{x}) \geq p_i(y_i; \hat{x}_{-i}) \qquad \text{for all } i \in \{k_t + 1; \ldots; N_t\} \tag{3}$$

for all $y_i \in A$; where $\hat{x}_{-i}$ represents the actions of all players other than player i at action profile $\hat{x}$.[6] Given a game $G(k_t; N_t)$, let the set of Nash equilibrium action profiles be denoted by $NE(k_t; N_t)$. The first question of interest is the following: are there economically

[4] One interesting special case of our specification is the objective function $p_i = \pi_i(\pi_i/\bar{\pi})^\theta$ where $\theta \geq 0$ can be interpreted as the degree of interdependence; see Ok and Koçkesen (1997) for a detailed discussion of individual preferences that can be represented by objective functions of form (1). Moreover, we note that the entirety of our findings would remain intact under an even more general class of functional forms where $p_i = F_i(\pi_i; \pi_i/\bar{\pi})$ with F_i not necessarily equal to F_j; $i \neq j$.

[5] Of course, even when k_t; N_t and π_is are specified, the game is not completely determined due to its parametric dependence on the function F. For simplicity, however, we do not use a notation that makes this dependence explicit.

[6] As usual, $(y_i; x_{-i}) \in R^N$ stands for the vector $(x_1; \ldots; x_{i-1}; y_i; x_{i+1}; \ldots; x_N)$.

important classes of games for which, at any population composition and size $(k_t; N_t)$, and any equilibrium action profile $\sigma \in NE(k_t; N_t)$, the absolute payoff to each player with interdependent preferences exceeds the payoff to any player with independent preferences? We shall give an affirmative answer to this question in Section 3 where we demonstrate that two widely studied models, the common pool resource and public good games, yield this inequality strictly under very general conditions. In other words, at any equilibrium of these games, the worst performing player with interdependent preferences (who obviously does not target the maximization of absolute payoffs) obtains an absolute payoff that is strictly higher than that of the best performing player with independent preferences.

This observation has interesting implications for the theory of preference formation. Consider first the case in which preferences are acquired by children directly from their parents, either by imitation and emulation within the home, or by genetic transmission. In this case the population composition will evolve on the basis of differences in the number of surviving children across the two groups of individuals, which in turn are likely to depend on material payoffs in a systematic way. If the dynamics of the population composition are payoff monotonic, as is commonly assumed, the finding that agents with interdependent preferences obtain higher material payoffs than do independent players in a variety of economic environments will imply a long run population composition in which some, if not all, individuals have interdependent preferences. These implications are derived and discussed in Section 4.

Alternatively, preference acquisition may be a result of conscious socialization efforts on the part of parents. In this case, children may have preferences that differ from those of their parents, if parents consider it best for the child to be inculcated with preferences other than their own. Parents may socialize their children on the basis of the payoffs received in the current generation, or they may be forward-looking, taking full account of the effects of their own actions on the population composition in the subsequent generation. This specification may result in population dynamics that differ from those that obtain under evolution. The implications of parental socialization are discussed in Section 5, where it is shown that at least for some common pool resource and public goods environments, all parents will inculcate interdependent preferences in their children.

We now turn to examining the nature of equilibria in a number of strategic environments (of the sort described above) for a given population composition and size.

3 Strategic Environments

3.1 Common Pool Resource Extraction

The following model of common pool resource extraction (Dasgupta and Heal, 1979) has been in widespread use for some time. Consider a population consisting of N individuals, each of whom has access to a common pool resource. Let $x_i \geq 0$ denote the extraction effort chosen by individual i, while $X = \sum x_i$ denotes the aggregate extraction effort. Total product is given by a differentiable real function f such that $f' > 0$ and $f'' < 0$. It is natural to assume that $f(0) = 0$, so without extractive effort there is no product. There is an opportunity cost $w \geq 0$ per unit of extractive effort and each member of the population receives a share of the total product that is proportional to her share of aggregate extractive effort. The value, to the individual, of a unit of the resulting product is given by a nonnegative function P, of the total output, on $\mathbb{R}_+$ with $P' \leq 0$. The payoff to player i is thus given by

$$\pi_i(x) = \frac{x_i}{X} P(f(X)) f(X) - x_i w = x_i (R(X) - w) \qquad (4)$$

where $R(X) = P(f(X))f(X)/X$ denotes the average value of the extraction effort and $x \in \mathbb{R}_+^N$ is the vector of extraction efforts.[7] To guarantee an interior solution, we shall assume throughout that f is bounded from above (otherwise equilibrium extractive effort would be unbounded), and that $P(0)f'(0) > w$ (otherwise no extraction would occur in equilibrium). As is well known, if all players are payoff maximizers with independent preferences, then the equilibrium vector of extraction effort is unique, interior, symmetric, and inefficient.

Rather than assuming that all agents who have access to the common pool resource are concerned only with the maximization of their absolute payoffs, we consider the following scenario. Of the N members of the population, $k \in \{1, \ldots, N-1\}$ are standard payoff maximizers with independent preferences. The remainder have interdependent preferences, and are concerned with their relative as well as absolute payoffs. Specifically, a player $i \in \{k+1, \ldots, N\}$ seeks to maximize a payoff function p_i of the following form:

$$p_i = \begin{cases} F(\pi_i, \pi_i/\bar{\pi}), & \text{if } \pi_i \neq 0 \\ F(0, 0) & \text{if } \pi_i = 0 \end{cases} \qquad (5)$$

[7] The above formulation, which closely follows Cornes, Mason and Sandler (1986), is general enough to encompass a variety of institutional settings. For instance, if the output is for agents' own use and a labor market does not exist (as in pre-market societies) one would interpret w as the opportunity cost of the extraction effort in terms of other useful activities and P as the intrinsic value of the good for the individual. If, on the other hand, the good is exchanged or sold in a market and a labor market exists (as in contemporary societies), w can be interpreted as the foregone outside wage and P as the price of the product. In the latter case, if the output market is perfectly competitive P is a constant function, whereas if it is imperfectly competitive P represents a downward sloping inverse demand function.

$F : \mathbb{R}^2 \to \mathbb{R}$ is any differentiable function with $F_1, F_2 > 0$.[8] Furthermore, we assume that F satisfies the following natural boundary condition: for any $z_1, z_2 \in \mathbb{R}$,

$$F(0, z_1) > F(z, z_2) \quad \text{whenever} \quad z < 0. \tag{6}$$

That is, an agent with interdependent preferences becomes concerned with her relative payoff only when her absolute payoff is positive; indeed the relative payoff concept runs into obvious difficulties when the absolute payoffs are negative (While (6) is quite reasonable, we will require it to hold only in the present section.)

Henceforth, we shall refer to the strategic form game defined above as a common pool resource game. An equilibrium of this game is an action profile x which satisfies, for any $y \in \mathbb{R}_+$, the conditions (2) and (3) (with $k = k_t$ and $N = N_t$). Our main question can then be stated as follows. In a given equilibrium of a common pool resource game, which of the two groups has a higher average absolute payoff? The following result provides an unambiguous answer to this question.[9]

Proposition 1 In any equilibrium of any common pool resource game, absolute payoff maximizing individuals obtain strictly lower absolute payoffs than do individuals who have interdependent preferences.

To illustrate the intuition behind this proposition, we plot in Figure 1 the reaction curves for independent and interdependent players in a two player commons game with the independent and interdependent payoff functions given by $\pi_i(x) = x_i(1 - X)$ and $p_i = \pi_i^2/\Pi$, respectively.[10] If both of the players had independent preferences, the unique equilibrium of the game (represented by point b in Figure 1) would be symmetric where both players choose the action 0.33. However, player 2's reaction curve when she has interdependent preferences is everywhere above the one she would have, had she possessed independent preferences. Consequently, she chooses a higher action and hence obtains a higher payoff than does the first player at the new equilibrium (point a in Figure 1).

The main driving force behind this result appears to be the potential value of commitment in strategic environments. In this particular case, the commitment by the interdependent player arises out of her concern about the share of the aggregate payoff she obtains. Consequently, she is willing to extract more of the common resource at every choice of extraction level by the independent player (player 1), even if that means a reduction in the absolute

[8] We use the convention of setting $p_i(x) = F(0, 0)$ whenever $\pi_i(x) = 0$ to avoid the difficulty of evaluating indeterminate form $\frac{0}{0}$.

[9] All proofs which do not appear in the main text are found in the appendix.

[10] We thus choose $w = 1$, $F(t_1, t_2) = t_1 t_2$, and $P(t) = 1$ for all $t_1, t_2, t \geq 0$, and $f(X) = 2X - X^2$ for $X \in [0, 1]$ and $f(X) = 1$ for $X \geq 1$. (The violation of the assumption that $f' > 0$ everywhere is readily observed to be inconsequential.)

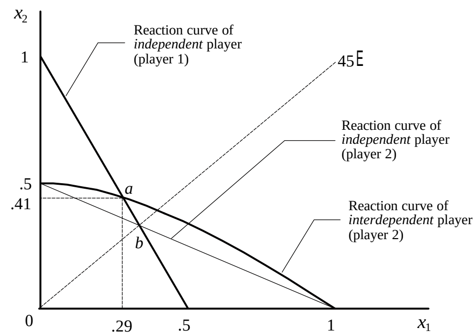

Figure 1: A Two Player Common Pool Resource Game

payoffs she would receive. The best response of player 1 who knows the behavioral disposition of the interdependent player leads us to an asymmetric equilibrium at which she chooses a strictly lower extraction effort than that of player 2. Given the structure of π_i; this leads to a higher level of absolute payoff for the interdependent player than for the independent player.[11]

3.2 Private Provision of Public Goods

In this section, we examine interdependent preferences within the context of the private provision of a public good (cf. Bergstrom, Blume and Varian, 1986, and Cornes and Sandler, 1996). This model is widely used in studying the infamous "free rider" problem, and is one of the major workhorses in the field of public economics.

Consider an N-person economy in which there is one public good the quantity of which is denoted by X; and one private good which is interpreted as a Hicksian composite good. For the purposes of symmetry, we assume that each individual is endowed with an identical level of private good denoted by $\omega > 0$: The preferences of individuals are represented by a twice differentiable utility function U on R^2_+ such that $U_1 > 0$; $U_2 > 0$; $U_{11} \leq 0$; and

[11] One possible extension of this analysis would be to examine the strategic advantage of interdependent preferences in common pool resource games where individuals can engage in costly sanctions against other players once extraction levels have been observed. Such sanctions are an important and prevalent feature of common property institutions (Ostrom, Walker and Gardner, 1992, Sethi and Somanathan, 1996).

$U_{12} \geq 0$.[12]

Let $X = \sum x_i$ represent the sum of the individual contributions, where $x_i \in [0; \omega]$ stands for the contribution of individual i. It is commonplace to postulate that the quantity of public good is defined as the sum of (voluntary) contributions of individuals which are paid out of their endowments. However, this production technology is not sufficiently general to cover the wide variety of collective choice problems with which societies have historically been confronted. For instance, as noted by a number of authors, if X stands for the protection of a military front, it seems more reasonable that the technology should be modelled as $X = \min\{x_1; \ldots; x_N\}$ (the so-called weakest-link technology, cf. Hirshleifer, 1983).[13] Since we wish to incorporate here a sufficiently general public good provision model that would include examples like the provision of irrigation and national defence (which are all significant collective action problems that may well have contributed to the shaping of individual preferences through evolution), we consider a broader class of technologies than the usual summation technology. Following Cornes (1993), therefore, we postulate that the public good in question is produced by a quasi-concave CES production function of the form

$$X = \left(\sum_{i=1}^{N} x_i^{\rho} \right)^{1/\rho} \quad \text{for some } \rho \leq 1.$$

This specification incorporates all public goods which can be produced by a technology that falls between the weakest-link and the summation technologies (since $\lim_{\rho \to -\infty} (\sum x_i^{\rho})^{1/\rho} = \min\{x_1; \ldots; x_N\}$).

If she contributes x_i to the production of the public good, individual i would clearly be left with an amount $c_i = \omega - x_i$ of the private good. We may, therefore, write the absolute payoff of person i as a function of the profile of the contributions as follows:

$$\pi_i(x) = U(\omega - x_i; (x_i^{\rho} + X_{-i})^{1/\rho}) \tag{7}$$

where $x \in [0; \omega]^N$ and $X_{-i} = \sum_{j \neq i} x_j^{\rho}$.

As in the previous subsection, we shall assume in what follows that only a certain number $k \in \{1; \ldots; N-1\}$ of the individuals recognize π_i as their objective function. The rest of the

[12] Since the present study is concerned with material payoffs, we interpret U as a money metric utility function in what follows. All of the assumed regularity conditions are standard (with the possible exception of $U_{12} \geq 0$). Among the examples of commonly used functional forms for U that satisfy these postulates are $U(c; X) = c^{\alpha} X^{\beta}$; $U(c; X) = cV(X)$ and $U(c; X) = c^{\alpha} + V(X)$ where $0 < \alpha \leq 1$; $\beta > 0$; and V is a differentiable real function on $\mathbb{R}_+$ such that $V' > 0$.

[13] As noted by Cornes and Sandler (1996, p. 55), "the Allied defenses in 1940 were only as strong as their weakest point, the Maginot line." For other interesting collective action problems which necessitate a different public good production technology than that which is usually assumed, we refer the reader to Hirshleifer (1983), Cornes (1993), and Cornes and Sandler (1996).

society targets the maximization of an objective function which is defined by (1) for some differentiable F such that $F_1, F_2 > 0$. (Clearly π_i is defined by (7) for these people, and $\bar{\pi} = \frac{1}{N} \sum U(\omega - x_i, X)$.) In what follows, we shall refer to the resulting class of strategic form games as public good games.

Defining the notion of equilibrium again via (2) and (3), we now ask the same question we asked in the previous section, this time for public good games. How do the absolute payoffs of the individuals, as defined by (7), compare in the equilibrium? The answer is again unambiguous:

Proposition 2 In any interior equilibrium of any public good game, absolute payoff maximizing individuals obtain strictly lower absolute payoffs than do individuals with interdependent preferences. In any boundary equilibrium of any public good game, all independent agents obtain (weakly) lower payoffs than all interdependent agents, and if $\lim_{X \to 0} U_2(\omega; X) > U_1(\omega; 0)$, then at least one independent agent obtains a strictly lower payoff than all interdependent agents.

The intuition behind this result is similar to that discussed in the common pool resource game. Here, a concern about one's relative payoff shifts the reaction curve inward and leads to a lower equilibrium contribution for the interdependent player as compared to the contribution of the independent player. Although the mechanisms through which the interdependent player obtains a higher payoff than does the independent player are different in the two games, both are the result of the strategic advantage an interdependent player derives from her particular behavioral disposition.

3.3 Other Strategic Environments

In Sections 3.1 and 3.2 we have considered games in which strategic interaction of the agents takes place at the population-wide level: each member of the population interacts simultaneously with every other member and is thereby 'playing the field.' An alternative and commonly used specification is that of 'pairwise contests,' in which members of the population are randomly matched in pairs to play a 2×2 game. As a prelude to the evolutionary analysis of such environments, we provide an exhaustive analysis in this section of all symmetric 2×2 games in which one of the players has independent preferences while the other has interdependent preferences.[14]

Take any symmetric 2×2 game where the action space of both individuals is $\{H, D\}$. The (absolute) payoff bimatrix of such a game must necessarily be of the form portrayed in Table 1.

	Player 2	
Player 1	H	D
H	$(a; a)$	$(b; c)$
D	$(c; b)$	$(d; d)$

Table 1

[14] Güth and Yaari (1992), whose focus is on the evolution of reciprocity, conduct a similar analysis for a particular class of 2×2 games.

Since the game at hand is a two-person game, the only non-degenerate case of interest is when one of the agents, say player 1, is independent, and the other (i.e. player 2) is interdependent. Consequently, by (1), the game that is actually played between the agents is the one reported in Table 2, where F is any strictly increasing function. Once again, the question we ask is: how do the absolute payoffs of the players (reported in Table 1) fare given that they are in fact playing the game depicted in Table 2?

	Player 2	
Player 1	H	D
H	$(a, F(a, 1))$	$\left(b, F\left(c, \frac{2c}{b+c}\right)\right)$
D	$\left(c, F\left(b, \frac{2b}{b+c}\right)\right)$	$(d, F(d, 1))$

Table 2

To address this question, we shall use the following well-known classification of symmetric 2×2 games (Weibull, 1995, pp. 28–30).

Category I: $(a < c$ and $b < d)$ or $(a > c$ and $b > d)$

Category II: $a > c$ and $b < d$

Category III: $a < c$ and $b > d$

These categories exhaust all generic examples of symmetric 2×2 games. For instance, the Prisoner's Dilemma, coordination games (e.g. Stag Hunt), and the Hawk-Dove game belong to categories I, II and III, respectively. In what follows, by a game of type i, we mean a game represented by the payoff bimatrix of Table 2 (for some strictly increasing F), provided that the corresponding game of the form given in Table 1 belongs to category i, $i = I, II, III$.

The set of all games of type I, II and III is quite rich, and contains games with remarkably different inherent structures. Consequently, it is not surprising that one cannot obtain exact analogues of Propositions 1 and 2 for the class of all such games. Nevertheless, it is possible to show that interdependent agents still hold the upper hand against independent agents in the majority of such games. Indeed, it turns out that in any game of type I, II or III, there exists an equilibrium (defined by (2) and (3)) at which the interdependent player obtains at least as much absolute payoff as the independent agent. Moreover, if there exists a unique asymmetric equilibrium in any such game, then at that equilibrium the level of absolute payoff of interdependent player 2 must strictly exceed that of player 1. More precisely, we have the following:

Proposition 3 (a) In any game of type I, either (D, D) (or (H, H)) is the unique equilibrium, or there exists another unique equilibrium at which the interdependent agent obtains strictly higher absolute payoffs than the independent agent.

(b) Any game of type II is degenerate in the sense that at any equilibrium of any such game the absolute payoffs of the interdependent and independent agent are the same.[15]

(c) In any game of type III, either (H, D) and (D, H) are both equilibrium outcomes, or the equilibrium is unique and the interdependent agent obtains strictly higher absolute payoff than the independent agent in this equilibrium.

Proof To see part (a), take any game of type I in which $a < c$ and $b < d$, and assume that (D, D) is not an equilibrium of this game. Since $b < d$, we must thus have $F(d, 1) < F\left(b, \frac{2b}{b+c}\right)$ which implies that $c < b$ since F is strictly increasing in both of its arguments. But given that $a < c < b$, it is immediately observed that (D, H) is the only pure strategy Nash equilibrium of the game at hand, and we have $\pi_2(D, H) = b > c = \pi_1(D, H)$. (The case where $a > c$ and $b > d$ is analyzed analogously.)

To see part (b), take any game of type II, and assume that (H, H) is not an equilibrium. Since $a > c$ in this case, we must then have $1 < 2c/(b + c)$. But then $1 > 2b/(b + c)$, and hence (D, D) must be an equilibrium.

Finally, to prove part (c), take any game of type III, and assume that either (H, D) or (D, H) is not an equilibrium. W.l.o.g., let us assume that (H, D) is not an equilibrium. But then we readily obtain that $2c/(b + c) < 1$ so that $b > c$. This, in turn, guarantees that (D, H) is the unique equilibrium, and we are done. QED

The potential value of commitment once again appears to be the driving force behind Proposition 3. This is particularly clear for Proposition 3c which covers the Hawk-Dove game (in which $a < c < d < b$); if the difference between absolute payoffs to playing hawk against dove and dove against hawk (i.e. between b and c in Table 1) is large enough, playing H becomes a dominant strategy for the interdependent player so that she credibly commits to hawkish behavior. The best that the independent player can do in response is then to retreat to dove-like behavior.[16]

This completes our static analysis of the potential strategic advantages of interdependent preferences. The implications of our results for the dynamics of the population composition

[15] Interestingly, if we consider the mixed strategy extension of games of type II, this category too ceases to be degenerate. Indeed, one can show that if an interior mixed strategy Nash equilibrium of a game of type II exists, at this equilibrium the expected absolute payoff of player 2 is strictly higher than that of player 1. Since we focus on pure strategies in this paper, we omit the proof of this assertion which is of course available from the authors upon request.

[16] For a detailed discussion of the motivation for and properties of the Hawk-Dove game, see Maynard Smith (1982).

are explored in the sections to follow.

4 Preference Evolution

We consider in this section a model of preference evolution based on vertical transmission: children inherit the preferences of their parents and the population composition evolves in accordance with an absolute payoff monotonic evolutionary selection dynamic.

4.1 Playing the Field

First consider the case in which the preferences of children are identical to those of their parents. This could occur either because preferences are transmitted genetically or, more plausibly, through 'vertical' cultural transmission as children observe and emulate their parents. Under this mechanism, it is assumed that any conscious efforts on the part of parents to inculcate preferences in their children are motivated only by a desire to raise their children to be like themselves, and not with a view to engineering their children's preferences in order to enhance their prospective well-being in the subsequent period.

The principal ingredient of analysis is the assumption that the number of surviving children that each parent leaves behind is an increasing function of the material payoffs that they earn in their adult life. This is a common assumption in evolutionary models in general (see, for instance, Rubin and Paul, 1979 and Robson, 1996). The argument is that greater access to resources gives rise to a larger number of mates and a higher probability of survival to maturity, thereby resulting in greater number of surviving children (Waldman, 1994, p. 489).[17]

We begin by assuming that, during any period t, the population composition and size $(k_t; N_t)$ is historically determined, and a particular game $G(k_t; N_t)$ is played. Suppose that the adult members of the population locate an equilibrium action profile $\hat{x}_t \in NE(k_t; N_t)$ and receive their corresponding payoffs. Propositions 1 and 2 imply that for any common property and public good games, regardless of which equilibrium is played, and regardless of the population composition and size in period t, we have $\pi_j(\hat{x}_t) \geq (>)\ \pi_i(\hat{x}_t)$ for all (some) $i \in \{1; \ldots; k_t\}$ and all $j \in \{k_t + 1; \ldots; N_t\}$. That is, in such games, any individual with

[17] It is interesting to note that the classical theory of wages developed by Adam Smith, Malthus and Ricardo was based on the postulate, considered self-evident only a century and a half ago, that increases in incomes would, by lowering infant mortality rates, give rise to an increase in population growth and eventually in labor supply: "poverty, though it does not prevent the generation, is extremely unfavorable to the rearing of children. The tender plant is produced, but in so cold a soil, and so severe a climate, soon withers and dies. It is not uncommon, I have been frequently told, in the Highlands of Scotland for a mother who has borne twenty children not to have two alive." (Smith, 1776, p. 88)

interdependent preferences earns a greater material payoff than at least one independent player, and no less than any of them. If the number of surviving children of each adult is a strictly increasing function of material payoffs, then the population composition in the subsequent generation must satisfy the following recursive inequality:

$$\frac{k_{t+1}}{k_t} < \frac{N_{t+1} - k_{t+1}}{N_t - k_t}.$$

Let $s_t = k_t/N_t$ denote the population share in period t of those adults having independent preferences. The above inequality then implies that

$$\frac{s_{t+1}}{s_t}\left(\frac{N_{t+1}}{N_t}\right) < \frac{1 - s_{t+1}}{1 - s_t}\left(\frac{N_{t+1}}{N_t}\right)$$

which in turn yields $s_{t+1} < s_t$. Hence, as long as $k_t > 0$, the population share of those with independent preferences will decline monotonically. If, in addition, there is some upper bound which the total population cannot exceed, then we can say more:

Proposition 4 Consider any common pool resource or public good game, and suppose that there is an upper bound which the total population cannot exceed in any generation. For any given initial population composition and size (k_0, N_0) such that $k_0 \in \{0, \ldots, N_0 - 1\}$, any (absolute) payoff monotonic dynamics with vertical transmission entails that the population consists exclusively of interdependent agents after finitely many generations.

The above result hinges on the assumption that the number of surviving offspring increases with material well-being. It must be noted that this assumption appears less innocuous in view of the demographic changes that have taken place over the past century. Significant improvements in public health and widespread immunizations have led to a decline in death rates among the poor, while the spread of contraceptive practices among the more affluent has allowed their birth rates to fall. Nevertheless, it is unlikely that so short a period of time would have significantly altered the distribution of preferences in the population as it existed prior to these demographic changes. Furthermore, as we shall see in Section 5.1, taking into account the possibility of (myopic) parental socialization allows us to make a case for the emergence and persistence of interdependent preferences that does not rely on differential rates of population growth.

4.2 Pairwise Contests

We now turn to the analysis of symmetric 2×2 games within the confines of (absolute) payoff monotonic dynamics with vertical cultural transmission. Since there are quite a number of distinct games in this class, here we shall focus only on one particularly interesting subclass of symmetric 2×2 games, namely on games of Hawk-Dove type. The corresponding results for other sorts of symmetric 2×2 games will only be mentioned briefly.

The evolutionary scenario that we describe in this subsection is that of "pairwise contests" wherein we assume that population is finite but large, and that each individual is randomly matched with another member of this society in order to play a certain game. Three types of possible pairings are possible: both players independent, both interdependent, and one player of each type. Given the population composition and size $(k_t; N_t)$ in period t, the probabilities of being matched with an independent or interdependent type are objectively determined for each player. Furthermore, corresponding to each of the three types of pairings is a set of equilibria; we assume that players are able to coordinate on one of these. The manner in which players solve the equilibrium selection problem is not addressed, and the results that we report do not depend on the choice of any particular equilibrium. Given the choice of equilibria, the expected (absolute) payoff to each type of agent, and the mean expected (absolute) payoff in the population at large are determined as functions of the population composition $s_t = k_t/N_t$. Let $\pi_{indep}(s_t)$ and $\pi_{inter}(s_t)$ denote the expected average (absolute) payoff of independent and interdependent agents respectively. The dynamics of the population composition may be represented by a difference equation

$$s_{t+1} = g(s_t); \tag{8}$$

where $g : [0;1] \to [0;1]$ is continuous, and $g(s_t) = s_t$ if $s_t \in \{0;1\}$ (a homogeneous population remains homogeneous.) It is assumed, as before, that the dynamics are payoff monotonic, so for $s_t \in (0;1)$, we have

$$\pi_{indep}(s_t) \gtreqless \pi_{inter}(s_t) \quad \text{if and only if} \quad g(s_t) \gtreqless s_t:$$

Finally, we make the unrestrictive assumption that if $s_t \in (0;1)$, then $g(s_t) \in (0;1)$. This states simply that the population composition cannot jump in a single generation from an interior to a boundary point, though of course it can converge asymptotically to one of the boundaries. Note that in order for an interior state $s \in (0;1)$ to be a rest point of the above dynamics, the expected payoffs of the two player types must be equal.

Given this evolutionary setting, we wish to study games of Hawk-Dove variety, that is, those 2×2 games represented in Table 1 with $a < c < b < d$. Recall that when both players are independent, this game has two pure strategy equilibria $\{(H;D);(D;H)\}$. If both of these profiles remain equilibria when one (or both) of the players is interdependent, there is nothing we can say about the long run population composition without addressing explicitly the issue of equilibrium selection. Although it is unambiguously clear that, in pairwise contests involving only independent or only interdependent agents, the average payoff accruing to the players will be $(b + c)/2$, this is not the case in contests involving both types of players due to the presence of multiple equilibria. Therefore, we are not able to rank the average payoffs obtained by independent and interdependent types in an unambiguous way, and hence cannot derive definitive results regarding the long run population composition in this case.

A more interesting case obtains if the interdependent behavior of an agent alters the set of equilibria to the singleton $\{(D, H)\}$, which occurs if and only if $F(a, 1) > F(c, 2c/(b+c))$, that is, when player 2 is sufficiently interdependent. In this case, H is a strictly dominant strategy for interdependent players regardless of whether their opponent is independent. Consequently, they reap the benefits of their aggressive nature in games they play against independent players. Yet, when matched against another interdependent agent, an interdependent player suffers, since (H, H) is then the unique equilibrium. As a result, no monomorphic population of either kind can be stable. A large population that is composed of only independent agents will be vulnerable to an invasion by a sufficiently small number of interdependent mutants, since the likelihood that two interdependent types will be matched with each other is then negligible. Since a similar reasoning applies to a large population that is composed of only interdependent agents, we must conclude that both types of individuals must be present in a society with a stable population composition (if such a composition exists at all).[18] This intuition underlies the following proposition.

Proposition 5 Consider any game of the Hawk-Dove type and any strictly increasing F with $F(a, 1) > F(c, 2c/(b+c))$. Let the population size N be finite (but large), and consider the pairwise contests scenario along with an arbitrary (absolute) payoff monotonic dynamics with vertical transmission. For any $k_0 \in \{1, ..., N-1\}$, there exists some strictly positive number θ such that, except for some finite number of initial generations, the population composition contains at least a share θ of each player type.

The above result states that convergence to the boundaries cannot occur under the dynamics (8). It is amply possible, even for simple specifications such as the widely used replicator dynamics, for stable limit cycles and more complex dynamics to occur in this model so the population composition may not converge at all. What the result implies, however, is that if convergence does occur, it will be to an interior state.

Propositions 4 and 5 draw markedly different pictures of the long run population composition of the society even though they both use vertical transmission mechanisms and payoff

[18] This finding is very much in the same spirit as that of Banerjee and Weibull (1995), who consider a population consisting of three types: (irrational) hawks, (irrational) doves, and optimizers, with the latter playing a best response against whichever opponent they meet. In this setting the only stable composition is a mixture of hawks and optimizers. Our independent types are identical to Banerjee and Weibull's best responders, while the behavior of our interdependent types (if they are sufficiently interdependent) is indistinguishable from that of their (irrational) hawks.

monotonic evolutionary dynamics, and even though the commitment of the interdependent players always pays off against independent agents in the games under consideration. It appears therefore that the evolution of preferences is likely to yield different outcomes under selection dynamics of the playing the field variety as compared with dynamics based on pairwise contests. To reiterate, the main reason behind this difference is that in pairwise contests it is possible for two interdependent agents to be paired, which may thus result in absolute payoff losses that do not affect the independent players in the society. Therefore, if the share of interdependent agents in the population increases sufficiently, the frequency with which this occurs rises, and thus the expected average payoff of the interdependent types becomes smaller than that of the independent types. This possibility simply does not exist in the playing the field framework, for, at least in common pool resources and public good games, emergence of a polymorphic population composition always guarantees a higher absolute payoff to all interdependent agents.[19]

5 Parental Socialization

In this section we consider two models of parental socialization: myopic and "rational". In the case of myopic socialization parents attempt to socialize their children on the basis of the current payoff distribution, and children are either successfully socialized or simply inherit the preferences of their parents. In the case of forward-looking (rational) socialization, parents take full account of the effects of their actions on the future population composition.

5.1 Myopic Socialization

In order to examine the effects of myopic socialization, we proceed under the assumption that each generation has the same population size N and that each adult has exactly one child. As before, let $NE(k_t; N)$ denote the set of Nash equilibria corresponding to the population composition and size at time t. Having observed the payoff distribution, adults must decide whether to inculcate independent or interdependent preferences in their children. It is assumed that parents are altruistic, but that they are able to judge different payoff distributions only in the light of their own preferences. (Bisin and Verdier, 1996b, refer to this

[19] In passing, we note how Proposition 5 would be altered, under the basic evolutionary scenario we examined above, if we replaced the games of Hawk-Dove variety with other symmetric 2×2 games. In games of Category I, either any initial population composition is stable (as in Prisoner's Dilemma), or the population is composed of only independent agents (the latter case being observed only for relatively uninteresting games where cooperative behavior is strictly dominant strategy for all players.) In Category II type games, on the other hand, we again face the multiple equilibrium problem and thus are unable to reach to unambiguous conclusions.

as partial empathy.) A parent with independent preferences will therefore wish to inculcate preferences in her child which yield the highest absolute payoff. A parent with interdependent preferences, on the other hand, will wish to inculcate preferences in her child which yield the highest value for the objective function defined by (1). Even if parents had static expectations regarding the behavior of other parents, a forward looking parent who chooses to instill preferences that differ from her own will expect to influence the population composition and hence the set of equilibria that will emerge in the subsequent generation. This complicates the decision problem faced by parents quite substantially, in a manner that is briefly explored in Section 5.2. For the moment, however, suppose that parents ignore this effect of their actions, and myopically use the current payoff distribution to determine which of the two preference types yields a higher value for their objective function. Propositions 1 and 2 imply that for any common property and public good games, regardless of which equilibrium is played, and regardless of the population composition and size in period t, we have $\pi_j(\hat{x}_t) \geq (>)\ \pi_i(\hat{x}_t)$ for all (some) $i \in \{1, \ldots, k_t\}$ and all $j \in \{k_t + 1, \ldots, N\}$. Since interdependent parents obtain greater absolute as well as relative payoffs than do independent parents, they will certainly choose to inculcate interdependent preferences in their children. Independent parents, on the other hand, will choose to inculcate interdependent preferences in their children, imploring them to "do as I say, not as I do!"

Of course, the parent's socialization efforts may not be successful, in which case we assume that the child simply inherits her parent's preferences. Let us assume then that there is an exogenously given probability, σ, with which the socialization effort is successful, and refer to the resulting preference formation mechanism as myopic socialization with probability σ. The long run implications of this mechanism can be summarized as follows:

Proposition 6 Fix a population size $N \geq 2$, and consider any common pool resource or public good game. For any given initial number of independent players $k_0 \in \{0, \ldots, N-1\}$, any myopic socialization mechanism with probability $\sigma > 0$ entails that the long run population will be composed entirely of interdependent agents.

We note, however, that if the population initially consists exclusively of independent types, it will continue to do so in each subsequent generation, for in that case there is no possibility that an independent parent will have an interdependent child. However, if we add to the model the possibility of errors, trembles, or mutation in the process of preference adoption, then the resulting stationary distribution will have full support $\{0, \ldots N\}$, and as the mutation rate gets vanishingly small, the stationary distribution of the process converges (with probability 1) to the homogeneous distribution which is again comprised of only the interdependent agents.[20]

[20] For brevity, we omit the proof of this assertion which is available upon request. The issue at hand is

Finally, we consider the games of the Hawk-Dove type in the light of the present myopic socialization mechanism. Given Proposition 5, the following observation is not surprising:

Proposition 7 Consider any game of the Hawk-Dove type and any strictly increasing F with $F(a; 1) > F(c; 2c/(b + c))$. Let the population size N be finite (but large), and consider the pairwise contests scenario along with any myopic socialization mechanism with probability $\sigma > 0$. For any $k_0 \in \{1, \ldots, N - 1\}$, the expected population share of independent agents in the long run is strictly smaller than 1, that is, the long run population is polymorphic in expectation.[21]

As expected, Propositions 6 and 7 yield different conjectures for the long run composition of the society as determined by myopic socialization. Yet, it is striking that in each of these results (and those of previous section) we find no evidence supporting the presence of populations that are composed entirely of independent agents.

5.2 Rational Socialization

Finally, consider the case in which parents are forward looking and deliberately shape the preferences of their children in order to increase what they perceive, in the light of their own preferences, as the child's well-being. In terms of the framework used here, a rational, forward-looking parent with independent preferences will choose to inculcate interdependent preferences in her child if it enhances the child's absolute payoff. Similarly, a parent with interdependent preferences will choose to inculcate independent preferences in her child if, by doing so, they can induce an action profile in the subsequent generation which yields her child a higher value of the parent's interdependent objective function.

Since parents are forward looking, the dynamics of the population composition will, in general, depend on the expectations held by each parent regarding the behavior of other parents. As before, assume that each parent has only one child, so that the population is stationary at N. In period t there are $k_t \in \{1, \ldots, N\}$ independent individuals. Denote by $k^e_{i,t}$ the expectations of parent i in period t regarding the number of other parents who will socialize their children with independent preferences. In deciding whether to transmit independent or interdependent preferences to her child, an independent parent i compares the absolute payoff to an independent player in a society with $k^e_{i,t} + 1$ independent players with the absolute payoff to an interdependent player when there are $k^e_{i,t}$ independent players. If the latter is higher, then the parent chooses to inculcate interdependent preferences in her

analogous to the double limit problem studied by Young (1993), Kandori, Mailath and Rob (1993), and Vega-Redondo (1996).

[21] Of course, if the population is initially composed of only interdependent (independent) agents, so will it be in every period.

offspring. Similarly, an interdependent parent i compares the interdependent payoff to an independent agent in a society with $k^e_{i;t} + 1$ independent players with the interdependent payoff to an interdependent agent in a society with $k^e_{i;t}$ independent agents. If the latter is higher she chooses to inculcate interdependent preferences in her child.

If parents have static expectations regarding the behavior of other parents, then $k^e_{i;t} = k_t$ for all interdependent parents and $k^e_{i;t} = k_t - 1$ for all independent parents. At any steady state of the dynamics under static expectations, parents' expectations will be self-fulfilling. Static expectations will not, however, be self-fulfilling whenever the population composition is changing from one period to the next. In this case one might wish to explore the properties of trajectories along which parents have rational or self-fulfilling expectations at all times. With rational expectations, the dynamics of the population composition may be indeterminate: from any initial population composition there may exist multiple paths which satisfy the parents' optimality conditions and in which expectations are self-fulfilling. In the case to be considered below, however, not only is the rational expectations path determinate, it yields precisely the same trajectory as the hypothesis of static expectations.

When the population size N is large, dynamics under static expectations will be closely approximated by the dynamics under myopic socialization. The only difference between myopic socialization and forward-looking socialization with static expectations is that the latter requires that parents take into account the possible changes in the population composition induced by their own socialization efforts. Therefore, when the relative share of a single parent is negligibly small in a population, these two notions of socialization coincide. In particular, the results one would obtain in terms of myopic and rational socialization with static expectations would be virtually identical for games of Hawk-Dove variety that are played in pairwise contests in finite but large populations. Similarly, Proposition 6 would remain intact in the present framework if N is sufficiently large.

If the influence of a single parent on the population composition is not negligible, then it is conceivable that the implications of rational socialization (with static or rational expectations) will be substantially different than those of myopic socialization. Due to the potential efficiency losses induced by the inculcation of interdependent preferences, the absolute payoff of an independent individual can be larger than the absolute payoff she would have earned had she acquired interdependent preferences instead, even though it remains true that for a given population composition, interdependent agents earn greater payoffs. Consequently, in small populations, rational socialization may act against the evolutionary forces that favor the spread of interdependent preferences. We find, however, that rational socialization need not always go against the evolutionary selection processes (such as vertical cultural transmission) even in small societies. In fact, depending on the particular characteristics of the strategic environment under consideration, it may well act just like a payoff monotonic

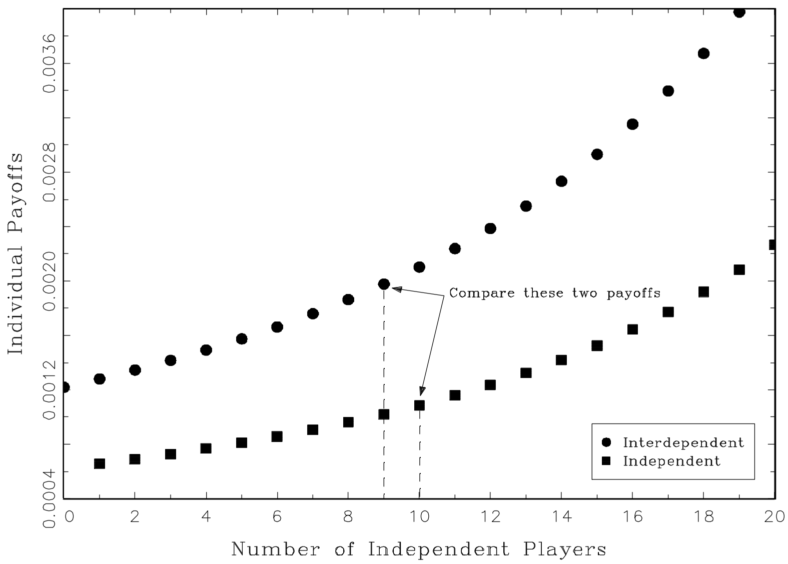

Figure 2: Rational Socialization in the Commons Game

selection dynamics. We conclude the present study with a demonstration of this possibility.

Fix an arbitrary N, and consider the common pool resource game with $w = 1$, $P(z) = 1$ for all $z \geq 0$, and

$$f(X) = \begin{cases} 2X - X^2; & \text{if } 0 \leq X \leq 1 \\ 1; & \text{if } X > 1 \end{cases}$$

Therefore, the objective function of an independent agent is $\pi_i(x) = x_i(1 - X)$ for all $x \in \mathbb{R}^N_+$; and $p_i = \pi_i^2/\bar{\pi}$ for all $i \in \{k+1, \ldots, N\}$. It is easy to check that the equilibrium of this game (for any $k \in \{0, \ldots, N\}$) is interior and intra-group symmetric (i.e., all independent (and interdependent) agents choose the same level of extraction effort in the equilibrium). Unfortunately, the algebra involved in comparing the relevant payoffs at arbitrary (k, N) tuples turns out to be quite complicated. Consequently, we have chosen to simulate these equilibrium payoffs for a variety of N levels (including $2, 3, 10, 20, 50, 100$). The simulation results for the case $N = 20$ are typical and are plotted in Figure 3. The striking observation is that an independent parent will choose to inculcate interdependent preferences in her child, regardless of their expectations concerning the behavior of other parents.[22] In particular,

[22] It is enough to analyze the decision making process of only the independent parents because that of the interdependent parents is symmetrical, i.e., if an independent parent chooses to transmit interdependent preferences so does an interdependent parent (since domination in absolute payoffs implies domination in interdependent payoffs).

this occurs under both static and self-ful…lling expectations. As in the case of vertical cultural transmission, rational socialization too gives rise in this example to a monomorphic population composed only of interdependent agents. From any initial composition, the population will become completely interdependent in a single generation.[23]

6 Conclusions

The …ndings reported in this paper give some support to the hypothesis of interdependent preferences on theoretical grounds. Our results do not allow us to conclude that interdependent preferences are the only possible outcome of evolutionary selection, nor do we claim that independent preferences can never be sustained in evolutionary equilibrium. We do feel justi…ed in concluding, however, that there are su¢cient theoretical grounds for considering the hypothesis of negatively interdependent preferences to be an important and reasonable alternative to the more standard postulate of independent preferences at least in some economic contexts.

There are a number of directions in which we believe the present research could be fruitfully extended. It will be interesting to know the extent to which our results generalize to include additional, broader classes of games. In Koçkesen, Ok and Sethi (1997) we address this question for classes of supermodular and submodular games, and provide conditions under which players with interdependent preferences do no worse (and sometimes better) than those with independent preferences. One might also investigate how our …ndings would be modi…ed when the model is extended to include the presence of private information with respect to the extent of one's interdependence. Another possible direction for future research pertains to the implications of our results for managerial behavior in oligopolistic markets. The payo¤ structure in the common pool resource game resembles that in Cournot oligopoly, and the conditions under which rational socialization predicts the inculcation of interdependent preferences are likely to be related to those in which a pro…t seeking shareholder (principal) will instruct the manager (agent) of her …rm to pursue objectives other than the maximization of absolute pro…ts. This issue has already been explored for duopolistic markets with linear demand by Fershtman and Judd (1987) but our …ndings suggest that the phenomenon will arise much more generally. A third possible extension involves the application of the present framework to study certain anomalies frequently observed in experimental games. It appears particularly well suited to explain behavior in ultimatum bargaining games, in which a concern for relative standing would predict the rejection of highly skewed o¤ers and entail fear of retaliation on the part of the …rst movers (cf. Bolton,

[23] The same result was obtained for a variety of public good games, including the case $U(c; X) = cX$, and for several other examples of common pool resource games, details of which are available upon request.

1991, Saijo and Nakamura, 1995, and Levine, 1996). Furthermore, the ultimatum bargaining environment is one in which responders with interdependent preferences will earn higher payoffs than those with independent preferences, so that evolution operating in this environment is likely to select against the latter. These and other questions arising from the present work are left for future research.

Appendix

Proof of Proposition 1

Let $\hat{x} \in \mathbb{R}^N_+$ be an equilibrium of an arbitrary common pool resource game. Strict concavity of f, together with the assumption that $f(0) = 0$, implies that $\frac{d}{dX}\left(\frac{f(X)}{X}\right) < 0$ for all $X \geq 0$. Given that $P' \leq 0$, therefore, we have $R' < 0$. From this observation, boundedness of f (which implies that $\lim_{X\to\infty} f'(X) = 0$), and the hypothesis that $R(0) = P(0)f'(0) > w$, it follows that there exists a unique $X_o > 0$ such that $R(X_o) \gtreqless w$ whenever $X \lesseqgtr X_o$.

Suppose that $\hat{X} = \sum \hat{x}_i \geq X_o$. Then, $\hat{x}_i = 0$ for all $i \in \{1, \ldots, k\}$, for otherwise $\pi_i(\hat{x}_i - \epsilon, \hat{x}_{-i}) > \pi_i(\hat{x}_i, \hat{x}_{-i})$ for any $\epsilon \in (0, \hat{x}_i)$. We next claim that $\hat{x}_j = 0$ for all $j \in \{k+1, \ldots, N\}$ as well. So, assume for contradiction that $\hat{x}_j > 0$ for some $j \in \{k+1, \ldots, N\}$. If $\hat{X} > X_o$, then $\pi_j(\hat{x}) < 0$ so that by (5) and (6),

$$p_j(0, \hat{x}_{-j}) = F(0, 0) > F\left(\pi_j(\hat{x}), \frac{\pi_j(\hat{x})}{\bar{\pi}(\hat{x})}\right) = p_j(\hat{x}),$$

contradicting that $\hat{x}$ is a Nash equilibrium. On the other hand, if $\hat{X} = X_o$, then $\pi_j(\hat{x}) = 0$ and we have, by (5),

$$p_j(\hat{x}_j - \varepsilon, \hat{x}_{-j}) = F\left(\pi_j(\hat{x}_j - \varepsilon, \hat{x}_{-j}), \frac{\pi_j(\hat{x}_j - \varepsilon, \hat{x}_{-j})}{\bar{\pi}(\hat{x}_j - \varepsilon, \hat{x}_{-j})}\right) > F(0, 0) = p_j(\hat{x})$$

for all $\varepsilon \in (0, \hat{x}_j)$. (Here the strict inequality follows from the fact that F is strictly increasing.) Therefore, $\hat{x}_i = 0$ must hold for all $i \in \{1, \ldots, N\}$ whenever $\hat{X} \geq X_o$, and this contradicts $X_o > 0$. We thus conclude that $\hat{X} < X_o$ holds and we have $R(\hat{X}) > w$.

Now pick any $i \in \{1, \ldots, k\}$ and $j \in \{k+1, \ldots, N\}$. Given that $\hat{X} < X_o$, it is easily seen that $\hat{x}_i > 0$. Thus,

$$\frac{\partial \pi_i}{\partial x_i} = R(\hat{X}) - w + \hat{x}_i R'(\hat{X}) = 0 \tag{9}$$

and

$$\frac{\partial p_j}{\partial x_j} = \frac{\partial \pi_j}{\partial x_j} F_1 + \frac{1}{\bar{\pi}}\left[1 - \frac{\pi_j}{\sum \pi_r}\right]\frac{\partial \pi_j}{\partial x_j} F_2 - \frac{1}{\bar{\pi}}\left(\frac{\pi_j}{\sum \pi_r}\right)\left(\sum_{r \neq j} \frac{\partial \pi_r}{\partial x_j}\right) F_2 \leq 0$$

where all the derivatives are evaluated at $\hat{x}$. It is easily verified that $\sum_{r \neq j} \partial \pi_r / \partial x_j < 0$ and $\pi_j / \sum \pi_r \leq 1$. Hence, since $F_1, F_2 > 0$, we must have $\partial \pi_j(\hat{x}) / \partial x_j < 0$, that is, $R(\hat{X}) - w + \hat{x}_j R'(\hat{X}) < 0$. Combining this inequality with (9), we obtain

$$(\hat{x}_j - \hat{x}_i) R'(\hat{X}) < 0.$$

The proposition then follows from (4) and the fact that $R' < 0$. QED

Proof of Proposition 2

Let $\hat{x} \in [0, \omega]^N$ be an equilibrium of an arbitrary public good game. Proposition 2 is an immediate consequence of the following two claims.

Claim 1. If there exists a $j' \in \{k+1, \ldots, N\}$ such that $\hat{x}_{j'} > 0$, then $U(\omega - \hat{x}_j; \hat{X}) > U(\omega - \hat{x}_i; \hat{X})$ holds for all $(i, j) \in \{1, \ldots, k\} \times \{k+1, \ldots, N\}$.

Proof of Claim 1. Note that by (7), we have

$$\frac{\partial \pi_i(\hat{x})}{\partial x_i} = -U_1(\omega - \hat{x}_i; \hat{X}) + \hat{x}_i^{\rho - 1}(\hat{x}_i^{\rho} + \hat{X}_{-i})^{(1/\rho) - 1} U_2(\omega - \hat{x}_i; \hat{X})$$

where $\hat{X} = (\sum \hat{x}_i^{\rho})^{1/\rho}$. Now take an arbitrary $i \in \{1, \ldots, k\}$, and assume that $\hat{x}_i < \omega$. Therefore, $\partial \pi_i(\hat{x})/\partial x_i \le 0$ so that

$$-U_1(\omega - \hat{x}_i; \hat{X}) + \hat{x}_i^{\rho - 1}(\hat{x}_i^{\rho} + \hat{X}_{-i})^{(1/\rho) - 1} U_2(\omega - \hat{x}_i; \hat{X}) \le 0. \tag{10}$$

(Clearly, strict inequality holds in (10) only if $\hat{x}_i = 0$.)

Next take any $j \in \arg\max_{j' \in \{k+1, \ldots, N\}} \hat{x}_{j'}$, and note that $\hat{x}_j > 0$ by hypothesis. Then $\partial \pi_j(\hat{x})/\partial x_j \ge 0$, and hence

$$\frac{\partial \pi_j}{\partial x_j} F_1 + \frac{1}{\bar{\pi}} \left[1 - \frac{\pi_j}{\sum \pi_r}\right] \frac{\partial \pi_j}{\partial x_j} F_2 - \frac{1}{\bar{\pi}} \left(\frac{\pi_j}{\sum \pi_r}\right) \left(\sum_{r \neq j} \frac{\partial \pi_r}{\partial x_j}\right) F_2 \ge 0. \tag{11}$$

But for all $r \neq j$, given that $\rho \le 1$ and $U_2 > 0$,

$$\frac{\partial \pi_r}{\partial x_j} = \hat{x}_j^{\rho - 1}(\hat{x}_r^{\rho} + \hat{X}_{-r})^{(1/\rho) - 1} U_2(\omega - \hat{x}_i; \hat{X}) > 0.$$

(Notice that $\hat{x}_r^{\rho} + \hat{X}_{-r} > 0$, for we have assumed above that $\hat{x}_j > 0$.) Therefore, (11) implies that $\partial p_j/\partial x_j > 0$ so that we have

$$-U_1(\omega - \hat{x}_j; \hat{X}) + \hat{x}_j^{\rho - 1}(\hat{x}_j^{\rho} + \hat{X}_{-j})^{(1/\rho) - 1} U_2(\omega - \hat{x}_j; \hat{X}) > 0$$

Combining this inequality with (10) and recalling that $\hat{x}_j^{\rho} + \hat{X}_{-j} = \hat{x}_i^{\rho} + \hat{X}_{-i}$, we find that

$$-U_1(\omega - \hat{x}_j; \hat{X}) + \hat{x}_j^{\rho - 1} U_2(\omega - \hat{x}_j; \hat{X}) > -U_1(\omega - \hat{x}_i; \hat{X}) + \hat{x}_i^{\rho - 1} U_2(\omega - \hat{x}_i; \hat{X}). \tag{12}$$

Now suppose that $\hat{x}_j \ge \hat{x}_i$. Then $U_{11} \le 0$ implies that $U_1(\omega - \hat{x}_j; \hat{X}) \ge U_1(\omega - \hat{x}_i; \hat{X})$ so that by (12)

$$\hat{x}_j^{\rho - 1} U_2(\omega - \hat{x}_j; \hat{X}) > \hat{x}_i^{\rho - 1} U_2(\omega - \hat{x}_i; \hat{X}).$$

But this is a contradiction, for since $\rho \le 1$ and $\hat{x}_j \ge \hat{x}_i$, we must have $\hat{x}_j^{\rho - 1} \le \hat{x}_i^{\rho - 1}$, and since $U_{12} \ge 0$, we must have $U_2(\omega - \hat{x}_j; \hat{X}) \le U_2(\omega - \hat{x}_i; \hat{X})$. Therefore, we may conclude that $\hat{x}_j < \hat{x}_i$ for all $i \in \{1, \ldots, k\}$ such that $\hat{x}_i < \omega$. But then by the choice of j, it follows that $\alpha_{j'} < \alpha_i$ for all $i \in \{1, \ldots, k\}$ and all $j' \in \{k+1, \ldots, N\}$. Claim 1 then follows from the hypothesis that $U_1 > 0$.

Claim 2. If $\alpha_j = 0$ for all $j \in \{k+1, \ldots, N\}$, then $U(\omega - \alpha_j, \hat{\alpha}) \geq U(\omega - \alpha_i, \hat{\alpha})$ holds for all $(i, j) \in \{1, \ldots, k\} \times \{k+1, \ldots, N\}$ and $U(\omega - \alpha_j, \hat{\alpha}) > U(\omega - \alpha_i, \hat{\alpha})$ for at least one $i \in \{1, \ldots, k\}$ and all $j \in \{k+1, \ldots, N\}$.

Proof of Claim 2. Given that $\alpha_j = 0$ for all j and $U_1 > 0$, the first part of the claim is obvious. In fact, the payoff level of any interdependent player would then obviously be strictly greater than any independent player with $\alpha_i > 0$. But since $\lim_{X \to 0} U_2(\omega, X) > U_1(\omega, 0)$, we must have $\alpha_i > 0$ for some $i \in \{1, \ldots, k\}$, and we are done. QED

Proof of Proposition 4

Letting N^* stand for an upper bound for N_t, we have

$$s_t \in S = \bigcup_{N=2}^{N^*} \left\{ \frac{k}{N} : k \in \{1, \ldots, N-1\} \right\} \qquad \text{for all } t = 0, \ldots.$$

Since S is finite, and $s_{t+1} < s_t$ whenever $s_t > 0$, there must exist a $T \leq \#S$ such that $s_t = k_t = 0$ for all $t \in \{T, T+1, \ldots\}$. QED

Proof of Proposition 5

By appealing to the assumption of "large" population, we may assume that the probability that a given person is matched with an independent agent is s_t in period t. Consequently, for any t,

$$\pi_{\text{indep}}(s_t) = s_t \left(\frac{b+c}{2} \right) + (1 - s_t)c \quad \text{and} \quad \pi_{\text{inter}}(s_t) = s_t b + (1 - s_t)a.$$

By using payoff monotonicity, therefore, we have

$$\pi_{\text{indep}}(s) \gtreqless \pi_{\text{inter}}(s) \quad \Leftrightarrow \quad s \lesseqgtr s^* \quad \Leftrightarrow \quad g(s) \gtreqless s \tag{13}$$

where $s^* = \frac{2(c-a)}{b+c-2a}$. By using (13), one can easily verify that either $s^* \in \arg\max_{s \in [0, s^*]} g(s)$ or $s^* \in \arg\min_{s \in [s^*, 1]} g(s)$ implies that $\lim_{n \to \infty} g^n(s) = s^*$ for all $s \in (0, 1)$, which in turn establishes the proposition trivially.[24] In what follows, therefore, we assume that neither of these conditions hold.

Define

$$\overline{\mu} = \sup g^{-1} \left(\max_{s \in [0, s^*]} g(s) \right) \qquad \text{and} \qquad \underline{\mu} = \inf g^{-1} \left(\min_{s \in [s^*, 1]} g(s) \right)$$

(see Figure 3). By continuity of g, $\underline{\mu}$ and $\overline{\mu}$ are well-defined. Moreover, since g is continuous,

[24] For any positive integer n, we let g^n stand for the nth iterate of g; that is, $g^n = g \circ \cdots \circ g$ where the composition operator is applied n times.

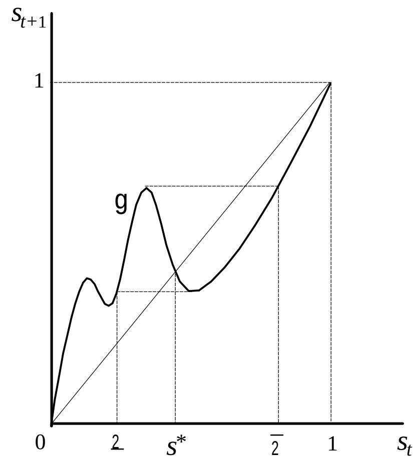

Figure 3: Construction of the interval $[\underline{\theta}, \overline{\theta}]$

$g(0) = 0$, $g(1) = 1$ and $g(s) \in (0,1)$ for all $s \in (0,1)$, we have $0 < \underline{\theta} < s^* < \overline{\theta} < 1$. Finally, we define $\theta = \min\{\underline{\theta}, 1 - \overline{\theta}\}$. Proposition 5 is then an immediate consequence of the following Claims 2 and 3.

Claim 1. If $s \in (0, s^*)$, then $g(s) < \overline{\theta}$, and if $s \in (s^*, 1)$, then $g(s) > \underline{\theta}$.

Proof of Claim 1. We only prove the first assertion, the second one is proved similarly. Take any $s \in (0, s^*)$ and suppose that $g(s) \geq \overline{\theta}$. Then since g is continuous and $g(1) = 1$, the choice of $\overline{\theta}$ implies that $g(g(s)) \geq g(\overline{\theta})$ (otherwise, it follows from the intermediate value theorem that there exists a $\theta' > \overline{\theta}$ such that $g(\theta') = g(\overline{\theta})$). But since $g(s) > s^* > s$, by (13) and the definition of $\overline{\theta}$,

$$g(g(s)) < g(s) \leq \max_{s' \in [0, s^*]} g(s') = g(\overline{\theta}),$$

contradiction.

Claim 2. If $s \in [\underline{\theta}, \overline{\theta}]$, then $g^n(s) \in (\underline{\theta}, \overline{\theta})$ for any positive integer n.

Proof of Claim 2. Let $s \in [\underline{\theta}, s^*)$. By Claim 1, $g(s) < \overline{\theta}$ and by (13), $g(s) > s \geq \underline{\theta}$. The claim then follows by induction. The case where $s \in (s^*, \overline{\theta}]$ is established similarly.

Claim 3. For any $s \in (0, \underline{\theta}) \cup (\overline{\theta}, 1)$, there exists a positive integer M such that $g^M(s) \in (\underline{\theta}, \overline{\theta})$.

Proof of Claim 3. W.l.o.g., we only study the case where $s \in (0, \underline{\theta})$. Suppose for contradiction that $g^n(s) \leq \underline{\theta}$ for all $n \geq 1$. This means that $\underline{\theta}$ is an upper bound for the sequence $g^n(s)$ which is, by (13), strictly increasing. Therefore, there exists an $\hat{s}$ such that

$0 < \lim_{n\to\infty} g^n(s) = \hat{s} \leq \underline{\theta}$. But then $\hat{s}$ must be a fixed point of g, for by continuity of g,

$$\hat{s} = \lim_{n\to\infty} g^{n+1}(s) = \lim_{n\to\infty} g(g^n(s)) = g\left(\lim_{n\to\infty} g^n(s)\right) = g(\hat{s}).$$

By (1), therefore, $\underline{\theta} \geq \hat{s} = s^* > \underline{\theta}$, contradiction. Consequently, there exists a positive integer M such that $g^M(s) > \underline{\theta}$. Let M be the smallest such integer. Then $g^{M-1}(s) \in (0, s^*)$, and by Claim 1, we also have $g^M(s) < \overline{\theta}$. Proof is then complete. QED

Proof of Proposition 6

The myopic socialization with probability σ entails the discrete time Markov chain with the transition matrix $\Pi \in [0,1]^{(N+1)\times(N+1)}$ where

$$\Pi_{rp} = \mathrm{Prob}[k_{t+1} = p \mid k_t = r]$$
$$= \begin{cases} \begin{cases} \dfrac{r!}{p!\,(r-p)!}(1-\sigma)^p \sigma^{r-p}, & \text{if } p \leq r \\ 0, & \text{if } p > r \end{cases}, & \text{if } r < N \\ \begin{cases} 1, & \text{if } r = p \\ 0, & \text{if } r \neq p \end{cases}, & \text{if } r = N. \end{cases}$$

Let, for any positive integer n, Δ_n denote the n-dimensional unit simplex (i.e., the set of all probability distributions on a set of cardinality n), and let e_n^i denote the ith unit vector in Δ_n. We wish to show that $\lim_{t\to\infty} e_{N+1}^i \Pi^t = e_{N+1}^1$ for all $i \in \{1, \ldots, N\}$. (Notice that e_{N+1}^1 is the degenerate probability distribution that corresponds to the state $k_t = 0$.) Clearly, Π represents a reducible chain with states 0 and N being absorbent. Define $\hat{\Pi} \in [0,1]^{N\times N}$ by $\hat{\Pi}_{rp} = \Pi_{rp}$ for all $r, p \in \{0, \ldots, N-1\}$. Given that the unique essential class of $\hat{\Pi}$ is composed only of the aperiodic state 0, there exists a unique invariant distribution of $\hat{\Pi}$.[25] But since $\hat{\Pi}$ is lower triangular, it is easily observed that $x\hat{\Pi} = x$ implies that $x = e_N^1$. So, the unique stationary distribution of the chain $\hat{\Pi}$ must be e_N^1. By using the ergodic theorem, therefore, we obtain

$$\lim_{t\to\infty} (x, 0)\,\Pi^t = \lim_{t\to\infty} (x\hat{\Pi}^t, 0) = e_{N+1}^1$$

for all $x \in \Delta_N$, and the proposition follows. QED

Proof of Proposition 7

Let $k^* = N\left(\frac{2(c-a)}{b+c-2a}\right)$. Notice that if $k_t = k^*$ (or 0, or N), we have $k_t = k_{t+1} = \cdots$. On the other hand, if $k_t > k^*$, then the probability of $k_{t+1} > k_t$ is zero, and there is a probabilistic

[25] State i is essential, if any state j is accessible from i, then i is accessible from j. See Bhattacharya and Waymire (1990, Theorem 7.1(i), p. 134.)

tendency for k_t to shrink. More precisely, the myopic socialization with probability σ yields the discrete time Markov chain with the transition matrix $\Pi \in [0,1]^{(N+1)\times(N+1)}$ where

$$
\begin{aligned}
\Pi_{rp} &= \text{Prob}\,[k_{t+1} = p \mid k_t = r] \\
&= \begin{cases}
\begin{cases} \dfrac{r!}{p!\,(r-p)!}(1-\sigma)^p \sigma^{r-p}, & \text{if } r \geq p \\ 0, & \text{if } r < p \end{cases}, & \text{if } N \neq r > k^* \\
\begin{cases} \dfrac{(N-r)!}{(N-p)!\,(p-r)!}(1-\sigma)^{N-p} \sigma^{p-r}, & \text{if } r \leq p \\ 0, & \text{if } r > p \end{cases}, & \text{if } 0 \neq r < k^* \\
\begin{cases} 1, & \text{if } r = p \\ 0, & \text{if } r \neq p \end{cases}, & \text{if } r \in \{0, k^*, N\}.
\end{cases}
\end{aligned}
$$

(Notice that k^* may or may not be a state in this chain. W.l.o.g., however, we shall assume in what follows that it is.)[26]

Now choose any e^i, $i \in \{1, N+1\}$. Proposition 7 will be established if we can show that $\lim_{t\to\infty} e^i \Pi^t \in \{e^1, e^{N+1}\}$. If $i = k^* + 1$, the claim is trivial, so let $i \neq k^* + 1$. Since any state r is aperiodic (i.e., $\Pi_{rr} > 0$) and since the mean recurrence rate of state k^* is 1, by the generalized ergodic theorem for Markov chains (Grimmett and Stirzaker, 1992, Theorem 6.4.21), we have

$$\lim_{t\to\infty} \Pi^t_{rk^*} = \sum_{t=1}^{\infty} \text{Prob}\,[k_1 \neq k^*, \ldots, k_{t-1} \neq k^* \text{ and } k_t = k^* \mid k_0 = r].$$

That is, $\lim_{t\to\infty} \Pi^t_{rk^*}$ is equal to the probability that the chain ever visits k^* given that it starts from $r \notin \{0, k^*, N\}$. But the latter probability is obviously nonzero since all states other than 0 and N communicate to k^*. Consequently, the (k^*+1)th entry of $e^i \lim_{t\to\infty} \Pi^t$ is nonzero, and we are done.[27] QED

[26] It is not difficult to show that all states of this chain other than 0, k^* and N are transient. It follows that if $x \in \Delta_{N+1}$ is a stationary distribution, then $x_i = 0$ for all $i \notin \{1, k^*+1, N+1\}$. Given that 0, k^* and N are absorbent states, therefore, $\text{co}\{e^1, e^{k^*+1}, e^{N+1}\}$ is the set of all stationary distributions of Π. (Here $\text{co}(\cdot)$ stands for the convex hull operator, and e^i denotes the ith unit vector in Δ_{N+1}.)

[27] Now suppose k^* is not a state of the chain. Since by the "large" population hypothesis, we can assume that $\frac{2(c-a)}{b+c-2a} < \frac{N-1}{N}$, i.e., $k^* < N-1$, state 0 is accessible from all states other than N. Thus, again by the generalized ergodic theorem, $\lim_{t\to\infty} \Pi^t_{r0} > 0$ for all $r \neq N$. Hence, $\lim_{t\to\infty} e^i \Pi^t \neq e^{N+1}$. Similarly, one can show that the invariant distribution of the chain is not equal to e^1. (In fact, when k^* is not a state, we have $\lim_{t\to\infty} e^i \Pi^t \in \text{int}(\text{co}\{e^1, e^N\})$.)

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