The Fetters of the Sib: Weber Meets Darwin

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Abstract

We analyze the effects of family ties - "the fetters of the sib" - on the incentives for productive effort. A family is here modelled as a pair of mutually altruistic siblings. Each sibling exerts effort, or makes an investment, to produce output under uncertainty, and siblings may transfer output to each other. We show that altruism has a non-monotonic effect on effort. Equilibrium effort decreases (increases) with altruism at low (high) levels of altruism. We study how this effect depends on "climate," the magnitude and volatility of returns to effort. We also analyze the evolutionary robustness of family ties and how this robustness depends on climate. We find that family ties will be stronger in milder climates than in harsher climates, and that the evolutionarily robust degree of altruism is positive but less than one half. Decreased protection of property rights increases the evolutionarily robust degree of altruism.

Keywords: altruism, family ties, moral hazard, evolutionary robustness.
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1 Introduction

Disparities in physical endowments and environmental and climatic constraints, as well as differences in human capital may explain much of the persisting differences in wealth and productivity between countries, see, e.g. Landes (1999), Diamond (1997) and Glaeser et al. (2004). Other researchers have pointed out that institutions, such as the protection of property rights, matter (North, 1990), and several empirical studies provide support for this view, see Mauro (1995), Hall and Jones (1999) and Acemoglu, Johnson and Robinson (2001). Yet other researchers have devoted attention to the effect of culture and beliefs, such as trust (Fukuyama, 1995, Knack and Keefer, 1997, La Porta et al., 1997), religion (Barro and McCleary, 2003), respect for others and confidence in self-determination (Tabellini, 2005). Already early on, it was argued that individualism was an important force behind the industrial revolution in England (Macfarlane, 1978). Thus, Max Weber (1951) wrote that "the great achievement of [...] the ethical and ascetic sects of Protestantism was to shatter the fetters of the sib [the extended family]. These religions established [...] a common ethical way of life in opposition to the community of blood, even to a large extent in opposition to the family" (p.237).[1] In Weber's view, a strong sense of solidarity within the extended family, coupled with a hostile attitude towards strangers, promotes a culture where nepotism may thrive and counter the development of efficient markets. Likewise, Banfield (1958) thought that the "amoral familism" that he observed in certain parts of Italy was an impediment to economic development.[2] More recently, using the World Values Survey to construct an indicator for the strength of family ties Alesina and Giuliano (2007) find that the strength of family ties has significant effects on various economic outcomes, such as labor market participation, the extent of home production, and geographic mobility.

Motivated by these observations that family ties vary in strength across cultures and that this may have significant economic effects, we pursue the line of thought suggested by Weber, by analyzing the effects of family ties on incentives and risk-sharing. We all face

[1] A recent empirical investigation conducted by Becker and Woessmann (2006) suggests that the improvements in literacy that followed from the Protestant obligation to read the Bible, also contributed significantly to enhancing economic development.

[2] The potential effects of other cultural traits or values, such as trust and religion, on economic outcomes have been investigated elsewhere. See, for instance, Putnam (1993), Huntington (1996), Landes (1999), Knack and Keefer (1997), Inglehart and Baker (2000), Barro and McCleary (2003), and Guiso, Sapienza and Zingales (2006).

risk, and risk may lead individuals to pool resources and thereby mitigate adverse income shocks at the individual level. Such risks can sometimes be alleviated by way of insurance markets or social security systems. However, these formal institutions may face severe moral hazard problems and hence only provide partial or no insurance at all (see, e.g., Helpman and Laffont, 1975, and Arnott and Stiglitz, 1988). Furthermore, insurance markets have not always been well-developed and are still not well-developed everywhere. In regions and countries where markets are poorly developed, the extended family tends to be an important source of insurance (for a discussion of evidence, see section 6). If family members with higher earnings give transfers to those with lower incomes (and are willing and expected to do so), what is the effect of such family ties on incentives to exert productive effort or make productive investments? How does this effect depend on the returns to effort and the riskiness of the return, or, in short, on the environment or "climate"?[3]

In order to study this question, we here develop a simple model in which two risk-averse siblings each choose a costly risk-reducing action, "effort," that determines the probability distribution over output levels.[4] We model the motive for intra-family transfers as altruism, modelled in the usual way as a positive weight placed on other family members' welfare. Once both siblings' outputs have been realized, these are observed by both, and each sibling chooses whether to share some of his or her output with the other, if at all. Most of our analysis is focused on the case of loglinear preferences over own consumption and effort.[5] This game has a unique perfect Bayesian equilibrium outcome.

It is well-known in the economics literature that the family is particularly vulnerable to the Samaritan's dilemma (Buchanan, 1975). This dilemma arises due to an altruist's

[3] In a companion sequel paper, Alger and Weibull (2007), we analyze these questions in a setting in which family transfers are socially coerced rather than, as here, voluntary, and there we also compare the outcomes with those in perfectly competitive insurance markets.

[4] Other researchers take the risk as given and focus on the enforceability of transfers within families; see, e.g., Coate and Ravallion (1993), Foster and Rosenzweig (2001), Genicot and Ray (2003), and Bramoullé and Kranton (2006).

[5] This particular game has not been studied before. Most of the literature on altruism, starting with Becker (1974), assumes one-sided altruism (see also, e.g., Bruce and Waldman, 1990, Chami, 1998, and Lindbeck and Nyberg, 2006). In models with two-sided altruism, typically only one of the players choose an effort (see Laferrère and Wolff, 2006, for a recent survey), or there is no risk (Lindbeck and Weibull, 1988 study the effect of two-sided altruism on savings, and Chen and Woolley, 2001, the intrahousehold allocation of income on private and public goods).

inability to commit not to help a person in need. See Becker's (1974) so-called "rotten kid theorem," according to which an altruistic parent can neutralize a selfish child's selfish acts. In a similar vein, Lindbeck and Weibull (1988) analyze the intertemporal inefficiency that altruism (one-sided as well as mutual) may cause in the form of suboptimal savings (see also Bruce and Waldman, 1990), and Coate (1995) analyzes why poor individuals tend to underinsure. However, to the best of our knowledge, we are the first to model the effect of mutual intra-family altruism on work effort (or investment) in a risky environment, and to analyze how such altruism interacts with "climate".[6]

We perform a number of comparative-statics experiments that show how equilibrium effort, income and expected utility depend on the degree of altruism and the harshness of climate, represented by two parameters, one parameter reflecting the riskiness of the environment, the other the marginal cost of reducing this riskiness. The qualitative features of the model are the following. If the two siblings' outputs are distinct, the "rich" individual transfers some of his or her output to the other, "poor" sibling, granted the potential donor is sufficiently altruistic. The anticipation of receiving a transfer when poor has a negative effect on a sibling's incentive to exert effort. This free-rider effect is well-known from other analyses of altruism. However, in our model altruism also has a positive effect on a sibling's incentive to exert effort, since an altruistic sibling may exert more effort in order to have more to give the other sibling, an effect we call the "empathy effect" of altruism on effort.

In a family with equally altruistic siblings, the free-rider effect outweighs the empathy effect when altruism is of intermediate strength: the equilibrium effort decreases as a result of an increase in altruism from low to intermediate. By contrast, if the common degree of altruism is strong, the empathy effect is more pronounced and the equilibrium effort is then increasing in altruism. Thus, altruism mitigates the moral hazard that arises when a sibling anticipates that he may be helped out. In fact, if the riskiness of the environment is low, highly altruistic siblings make greater efforts than selfish siblings. Despite the non-monotonicity of effort in the common degree of altruism, a sibling's expected material utility is highest for fully altruistic individuals, that is, siblings who give the same weight to the

[6]Coate (1995) investigates whether a poor individual, who anticipates to be helped out by two rich individuals, has an incentive to underinsure, and to what extent government intervention may mitigate this problem. In his model, altruism is one-sided and the main analysis does not include an endogenous risk-reducing effort. Persson and Weibull (2003) ask whether the incentive to underinsure would still exist in a model with a large number of individuals. However, their model does not feature an endogenous risk-reducing effort.

other's material utility as to their own. In particular, it is higher than for selfish siblings. The intuition is straightforward: an individual who attaches the same weight to the other's material utility fully internalizes the external effects of his or her own effort.

The second question that we seek to answer in this paper is: What determines the strength or absence of family ties? More specifically, if family ties are subject to social or biological evolutionary forces, will family ties tend to be stronger or weaker in harsher climates? We use the above equilibrium predictions to address this question. Early proponents of evolutionary theory, including Darwin, were puzzled by the occurrence of altruism in nature: how can a behavior or trait whereby the individual gives up resources for the benefit of others survive? Biologists have proposed several evolutionary theories of altruism, such as kinship altruism (Hamilton, 1964), reciprocal altruism (Trivers, 1971), and multilevel selection theory (Sober and Wilson, 1998). Starting with Becker (1976) economists have also made contributions. Bergstrom (1995, 2003) enriched Hamilton's kinship selection theory by allowing for more complex strategic interactions between kin. Inspired by Bergstrom's (1995, 2003) approach, and using material utility as a measure of fitness, we develop a notion of local evolutionary robustness and apply this to altruistic family ties.

We show, by way of numerical simulations, that neither complete selfishness (no concern for one's sibling) nor full altruism (equal concern for one's sibling as for oneself) is evolutionarily robust in any climate. In light of "Hamilton's rule" (Hamilton, 1964) for kinship altruism, one might have expected the evolutionarily robust degree of altruism to equal one-half, irrespective of climate, since on average half of an individual's genes are shared with his or her sibling. This would hold in our model if intra-family altruism did not affect the level of risk-reducing effort. However, our model suggests that the endogeneity of the risk-reducing effort pushes the evolutionarily robust degree of altruism down to a value below one-half, and that that this value is lower in harsher climates.[7]

Our model is similar to that in Arnott and Stiglitz (1991). They model "family insurance" as transfers within pairs of *ex ante* identical individuals and they allow for an endogenous, risk-reducing effort taken by these individuals. They address a different question, however. They ask whether, in the presence of insurance markets, supplemental informal insurance within the family improves welfare. Moreover, whereas in our model transfers within the family are driven by altruism, in their model family transfers are the outcome of a joint

[7] The idea that cultural features and attitudes may be related to climate dates back at least to Montesquieu (1748).

agreement. In particular, if family members can observe each other's effort, the joint agreement in their model specifies that total family income should always be split equally and (in the case of observable effort) the agreement specifies the effort to be taken. Mathematically, this is equivalent to the special case in our model of maximal family altruism (when members attach the same utility weight to other's welfare as to their own).

Technically, our model is very similar to that in Lindbeck and Nyberg (2006). They analyze altruistic parents' incentive to instill a work norm in their children. The incentive stems from parents' inability to commit not to help their children if in financial need. If the children feel a strong social norm to work hard, then this reduces the risk that the children will be in need, which is good for the altruistic parents. However, the parents will suffer with their children if these work hard and fail. The parents instill just enough of the social work norm in their children so that these two effects are optimally balanced. While their model is asymmetric—parents are altruistic and move first and children are selfish and move last—our model is symmetric in two senses: the two siblings move simultaneously and may (but need not) be equally altruistic towards each other. Moreover, they do not make an evolutionary analysis, and do not ask whether the work ethic could depend on the climate. Nevertheless, the issues dealt with are related, the models are similar in structure and the utility from consumption and effort is parametrized the same way as in their model.

The remainder of the paper is organized as follows. In the next section we set up the model, beginning with the case of a selfish atomistic individual and then introducing family ties in terms of a two-stage game between two mutually altruistic siblings. In section 3 we show that this game has a unique equilibrium and Section 4 is devoted to a comparative-statics analysis of the equilibrium outcome. In Section 5 we develop a notion of local evolutionary robustness of family ties and apply this to numerical simulations of the model. Section 6 briefly discusses evidence on family ties and Section 7 concludes. All mathematical proofs have been relegated to an appendix.

2 The model

2.1 Atomistic and selfish individuals

Consider a selfish individual who feels no wish or social pressure to help others, living in an environment where insurance is not available. The individual chooses an *effort* level $x \in \mathbb{R}_+$

that determines the probability distribution over the possible returns, or *output* levels. The output is either high, $y^H > 0$, or low, $y^L = y^H/\rho$, where $\rho > 1$, the ratio between the high and low output levels, represents the *riskiness* of the environment; this is the fraction by which output is reduced in the "bad" outcome. We think of y^H as the *richness* of the environment. The probability $p \in [0, 1]$ for the high output level is increasing in the individual's effort, $p = \psi(x)$, where the disutility function ψ is continuously differentiable with $\psi' > 0$ and $\psi'' < 0$. The resulting expected utility is

$$\kappa\psi(x)\, u(x, y^H) + [1 - \kappa\psi(x)]\, u(x, y^L), \tag{1}$$

where the von Neumann-Morgenstern utility function u is twice differentiable with $u_1', u_1'' < 0$, $u_2' > 0$ and $u_2'' < 0$. The first argument of u is thus effort and the second argument the disposable *income* or *consumption*. The factor κ, where $0 < \kappa \leq 1$, represents *institutional quality*. With probability κ an individual who has obtained the high output level, y^H, can keep this, while with probability $1 - \kappa$ such an individual is robbed, where robbery brings down a "rich" individual's wealth to that of a "poor" individual, from y^H to y^L. (Poor individuals are not robbed.) Thus $\kappa = 0$ represents the lowest possible institutional quality (no protection of private property above the lowest level) and $\kappa = 1$ the highest possible one (full protection).

An interior solution for the choice of effort satisfies the first-order condition

$$\kappa\psi'(x)\left[u(x, y^H) - u(x, y^L)\right] + \kappa\psi(x)\, u_1'(x, y^H) + [1 - \kappa\psi(x)]\, u_1'(x, y^L) = 0. \tag{2}$$

Although much of the subsequent analysis turns on this first-order condition, we will henceforth focus on the analytically more convenient special case when the success probability is an exponential function of effort,

$$\psi(x) = 1 - e^{-\theta x}, \tag{3}$$

for some $\theta > 0$, and the utility function is log-linear in consumption and effort,

$$u(x, y) = \ln y - \beta x \tag{4}$$

for some $\beta > 0$. The parameter θ represents the ease by which effort increases the probability of high output, an environmental factor that we will sometimes refer to as *the return to effort*, while β represents the individual's (discomfort from or) *dislike of effort*. In this special case of *exponential success probability* and *log-linear utility*, the expected utility (1) may conveniently be written as a function of the success probability p:

$$\ln y^H - (1 - \kappa p)\ln\rho + \frac{\beta}{\theta}\ln(1 - p) \tag{5}$$

and the first-order condition (2) can be explicitly solved in terms of the optimal success probability. In this special case the ratio of the dislike of effort, β, and the returns to effort, θ, may be interpreted as *the marginal cost of increasing the success probability* p. To save on notation we will write γ for the ratio β/θ. For an atomistic and selfish individual, the general solution is

$$p^0 = \max\left\{0, 1 - \frac{\gamma}{\kappa \ln \rho}\right\}. \tag{6}$$

In particular, $p^0 > 0$ if and only if:

$$\gamma < \kappa \ln \rho. \tag{7}$$

Only if this condition is met is it worthwhile for the individual to exert effort in autarky. In this case we have

$$p^0 = 1 - \frac{\gamma}{\kappa \ln \rho} > 0 \tag{8}$$

and thus

$$x^0 = -\frac{1}{\theta} \ln\left(\frac{\beta}{\theta \kappa \ln \rho}\right) > 0.$$

In sum: the optimal effort level, when positive, is independent of the richness of the environment, y^H, higher in a riskier environment (with higher ρ), when the marginal cost of increasing the success probability is lower (i.e., either when the returns θ to effort are higher, or when the dislike of effort, β, is lower), and and in societies with higher institutional quality κ.

We finally note that this model may be interpreted as a two-period investment model in which the investor has an initial endowment of one unit and decides how much of this, $p \in [0, 1]$, to invest in a given risky project. The remaining share of the endowment, $1 - p$, is consumed in period one. The investor discounts second-period consumption by the factor $1/\gamma$ and has Cobb-Douglas von Neumann-Morgenstern utility, $u = \ln c_1 + \frac{1}{\gamma} \ln c_2$ from consumption in periods one and two. If the amount p is invested, then second-period consumption is either high, y^H, with probability κp, or low, $y^L = y^H/\rho$, with probability $1 - \kappa p$, where the factor $\kappa \in [0, 1]$ is the probability that the excess return, $y^H - y^L$, is not taken away (stolen or taxed) from the investor.

2.2 Individuals with family ties

Now assume that these individuals still work individually but belong to families in which the members have altruistic feelings towards each other. In case of unequal individual output levels between siblings, those who obtained higher output may prefer to share some of their output with members who obtained lower outputs.[8]

More precisely, assume now that each individual i has one sibling, denoted i', and each such pair interacts over two periods, along the lines of the model in the preceding section.[9] Thus, in the first period, both siblings simultaneously choose their individual efforts. Let $\mathbf{x} = (x_i, x_{i'})$ be the effort vector and let $p_i = \psi(x_i)$ be the associated success probability for individual i. The output y_i of individual i is realized at the end of the first period. Furthermore, an individual with a high output gets to keep it with probability κ, but loses it — e.g. due to theft — with probability $1-\kappa$. Thus, at the end of the first period, an individual's disposable output is high with probability $p_i\kappa$ and low with probability $1-p_i\kappa$. For the sake of notational and analytical convenience, we take the two siblings' disposable outputs y_i^d and $y_{i'}^d$ to be statistically independent random variables.[10]

The vector $\mathbf{y} = \left(y_i^d, y_{i'}^d\right)$ is observed by both siblings at the beginning of the second period. A sibling's effort may or may not be observed by the other sibling (these may live in different villages or countries). In the first case, the *state* at the beginning of period two is the vector pair $\omega = (\mathbf{x}, \mathbf{y})$. In the second case, the state at the beginning of period two is only the vector $\omega = \mathbf{y}$. In both cases, let Ω denote the state space. Having observed the state $\omega \in \Omega$, both individuals simultaneously choose whether to make a transfer to the other, and if so, how much. After these transfers have been made, each individual's *disposable income*, or *consumption*, therefore equals his output plus any transfer received from the sibling minus any transfer given to the sibling.[11]

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[8] As will be shown below, an alternative interpretation is that family members are selfish but can sign contracts on conditional transfers.

[9] The prime sign thus denotes a reflexive "sibling operator," where $(i')' = i$.

[10] This independence assumption can easily be relaxed. Positively correlated outputs simply decrease the probability for unequal outputs and thus diminish the scope for altruistic transfers between them. For instance, suppose that both individuals' output is exposed to the same exogenous hazard that may reduce each high output to the low output level. If the probability for this common hazard to hit is $\lambda \in [0,1]$, then the probability for the output pair $\left(y^H, y^H\right)$ is $(1-\lambda)\, p_i p_{i'}$, that for $\left(y^H, y^L\right)$ is $(1-\lambda)\, p_i \left(1-p_{i'}\right)$, that for $\left(y^L, y^H\right)$ similarly is $(1-\lambda)\left(1-p_i\right) p_{i'}$, and that for $\left(y^L, y^L\right)$ is the residual probability. For $\lambda = 0$, this is precisely the current model, while for $\lambda > 0$ the probability for unequal outputs is lower.

[11] Arnott and Stiglitz (1991) study a model similar to ours, where two individuals jointly choose a pair of efforts, which determine the probability distribution over output states, as well as the pair of transfers conditional on the realized state. As we will see below this is mathematically equivalent to a special case

We analyze this interaction as a two-stage game, denoted G, in which a pure strategy for individual i is a pair $s_i = (x, \tau_i)$, where $x \in \mathbb{R}_+$ is the effort and $\tau_i : \Omega \to \left[0, y^H\right]$ is a function that specifies what transfer i gives to i' in each state ω. Each strategy profile $\mathbf{s}$ determines the *total utility* to sibling i in each state:

$$u(x, y_i - \tau_i(\omega) + \tau_{i'}(\omega)) + \alpha_i u(x, y_{i'} - \tau_{i'}(\omega) + \tau_i(\omega)), \tag{9}$$

where the disposable output vector $\mathbf{y} = \left(y_i^d, y_{i'}^d\right)$ is defined by the state ω, the function u is the same as in the preceding section, and $\alpha_i \in [0,1]$ represents the degree of true *altruism* of i towards i'.

We will call the function u the *material* utility function. An individual i with $\alpha_i = 0$ will be called *selfish* and an individual with $\alpha_i = 1$ *fully altruistic*. We solve the two-stage game G by way of backward induction. Since we allow for the possibility that siblings may not observe each others' efforts, the game G may be a game of imperfect information. As solution concept we will use *perfect Bayesian equilibrium* in pure strategies, that is, each individual selects a pure strategy that is sequentially rational under expectations that are correct on the equilibrium path, and, if efforts are unobserved, each sibling (in the lack of counter-evidence) believes that the other sibling has made her equilibrium effort.[12]

3 Equilibrium

Let $\omega \in \Omega$ be the state at the beginning of the second stage. Sibling i wants to make a transfer to sibling i' if and only if i believes his own marginal material utility from consumption to be lower than his sibling's when the latter is weighted by i's degree of altruism. In order to make his transfer decision, individual i also has to figure out whether his sibling i' is simultaneously planning to give a transfer to him, i. All that matters to each sibling is the *net* transfer to the other.

In order to sort this out, let $\hat{\tau}_i : \Omega \to \left[0, y^H\right]$ be the function that defines, for every state $\omega \in \Omega$, the transfer that individual i would like to make to his or her sibling *if* the latter makes *no* transfer to i. Let $\mathbf{y} = (y_i, y_{i'})$ be the output pair in state ω, and let $\mathbf{x} = (x_i, x_{i'})$ be

of our model (see footnote 16). Arnott and Stiglitz use their model to analyze whether informal insurance, within families, on top of formal insurance, may be welfare-enhancing.

[12] Of course, i will know that i' has made a positive effort if $y_{i'}^d = y^H$.

the (actual or expected) effort pair. Then $\hat{\tau}_i(\omega) = 0$ if $u_2'(x_i, y_i) \geq \alpha_i u_2'(x_{i'}, y_{i'})$, otherwise the optimal transfer $\hat{\tau}_i(\omega)$ is positive and equates i's marginal material utility to that of his sibling's when weighted by i's degree of altruism:

$$u_2'(x_i, y_i - \hat{\tau}_i(\omega)) = \alpha_i u_2'(x_{i'}, y_{i'} + \hat{\tau}_i(\omega)). \tag{10}$$

In general, the desired transfer, $\hat{\tau}_i(\omega)$, thus depends on both outputs and efforts. However, when the material utility function is separable, as under log-linear material utility (4), only outputs matter. We henceforth focus on the special case of log-linear material utility and exponential success probabilities (3).

For each state $\omega \in \Omega$, let $G(\omega)$ denote the continuation game from the beginning of stage two on. This is a two player simultaneous-move game in which each player's strategy is his or her transfer to the other sibling. It is straightforward to prove the following lemma, which says that except for the case when both individuals are fully altruistic, $\alpha_i = \alpha_{i'} = 1$, there exists a unique Nash equilibrium in each continuation game $G(\omega)$. Moreover, in this equilibrium, at most one sibling makes a positive transfer to the other. Should both siblings be fully altruistic, equilibrium is not unique, but the net transfers, and hence consumption levels are uniquely determined.

Lemma 1 *For each $\omega \in \Omega$, the transfer pair $(\hat{\tau}_i(\omega), \hat{\tau}_{i'}(\omega))$ constitutes a Nash equilibrium of $G(\omega)$. If $\alpha_i \alpha_{i'} < 1$, then this equilibrium is unique. If $\alpha_i = \alpha_{i'} = 1$, then there is a continuum of Nash equilibria, all resulting in equal sharing of the total output.*

As noted above, transfers do not depend on efforts under log-linear material utility and exponential success probabilities. Thus, the equilibrium outcome is the same whether or not the siblings observe each others' efforts. It is easily verified from the first-order condition (10) that the transfer from i to i' is positive if and only if i obtains the high output and i' the low, and, moreover, i is sufficiently altruistic in the precise sense that $\rho\alpha_i > 1$. Hence, the lower bound on altruism for a transfer to be given from i when "rich" to i' when "poor" is $1/\rho$. Moreover, if a transfer is given by a rich individual i to a poor sibling i', then this transfer, $\hat{\tau}_i(y^H, y^L)$, satisfies the first-order condition:

$$\frac{1}{y^H - \hat{\tau}_i(y^H, y^L)} = \frac{\alpha_i}{y^L + \hat{\tau}_i(y^H, y^L)},$$

or

$$\hat{\tau}_i(y^H, y^L) = \frac{\alpha_i - 1/\rho}{1 + \alpha_i} y^H. \tag{11}$$

In sum, if we denote by t_i^* the share of her high income y^H that a rich individual i gives in equilibrium to her poor sibling i', we have:

$$t_i^* = \max\left\{0, \frac{\rho\alpha_i - 1}{\rho\alpha_i + \rho}\right\}. \tag{12}$$

As expected, this share is non-decreasing in the rich sibling's degree of altruism, α_i, and in the riskiness ρ of the environment (recall that the riskiness is the ratio between the low and high outputs).

In the first period, each individual independently chooses an effort level. In the special case of exponential success probability (3) and log-linear material utility (4), the *(ex ante) expected total utility* for individual i can be expressed as a function of the two success probabilities:

$$\begin{aligned} U_i(p_i, p_{i'}) = {} & (1+\alpha_i)\ln y^H - (1-\kappa p_i)(1-\kappa p_{i'})(1+\alpha_i)\ln\rho \\ & + \kappa p_i(1-\kappa p_{i'})[\ln(1-t_i^*) + \alpha_i \ln(1/\rho + t_i^*)] \\ & + \kappa p_{i'}(1-\kappa p_i)[\ln(1/\rho + t_{i'}^*) + \alpha_i \ln(1-t_{i'}^*)] \\ & + \gamma\ln(1-p_i) + \alpha_i\gamma\ln(1-p_{i'}). \end{aligned} \tag{13}$$

The pair $(U_i, U_{i'})$ of payoff functions defines a simultaneous-move game G^* in which a pure strategy for each player i is his or her success probability $p_i \in [0,1]$. With exponential success probabilities and log-linear utility, each player in G^* has a unique best reply to the other's strategy. Straight-forward calculations show that i's best reply, p_i^*, to any probability $p_{i'} \in [0,1)$ that the sibling may choose is increasing in i's altruism, α_i, *ceteris paribus.* Since effort is monotonically related to the success probability, an increase in an individual's degree of altruism also means an increased effort. The motive is twofold: first, to increase the chance to have something to give in case one's sibling will receive the low output, and, secondly, to decrease the risk that one's sibling will need to give a transfer.[13] Hence, a more altruistic individual not only gives a larger transfer, as noted above (see (12)), but also makes a bigger effort to obtain the high output level. However, this is true for both siblings. Hence, an increase of one sibling's degree of altruism reduces the other's effort—since the other sibling is more likely to obtain the high output and give help if need be. We call the first, positive, effect of true altruism the *empathy effect* (from own altruism) and the second, negative, effect the *free-riding effect* (from one's sibling's altruism).

[13] The sibling's transfer is voluntary, but it is better for the sibling to be in a position in which both siblings receive the high output.

Suppose that both siblings are equally altruistic: $\alpha_i = \alpha_{i'} = \alpha$. It follows from equation (12) that when this common degree of altruism is sufficiently small, $\rho\alpha \leq 1$, no transfer takes place. It is as if each sibling then lived in autarky. By contrast, if $\rho\alpha > 1$ then each sibling, if rich, gives a transfer to the other, if poor. In general, equation (12)) determines the common transfer share t^*:

$$t^* = \max\left\{0, \frac{\rho\alpha - 1}{\rho\alpha + \rho}\right\}. \tag{14}$$

Given this, it is not difficult to show that G^* has a unique Nash equilibrium, that this is symmetric, and to give it a characterization in terms of the parameters of the model:

Proposition 2 *Suppose that the two siblings are ex ante identical with log-linear material utility (4), exponential success probability (3) and a common degree of altruism α. The game G^* has a unique Nash equilibrium, (p^*, p^*). If $\alpha \leq 1/\rho$, then the common success probability p^* is the same as in autarky, $p^* = p^0$. If $\alpha > 1/\rho$ and $\kappa \ln \rho \geq \gamma$, then p^* is the unique solution in $(0,1)$ of the equation*

$$\kappa\left(1 - \kappa p - \kappa\alpha p\right)\ln\left(\frac{1+\rho}{\rho\alpha+\rho}\right) + \kappa\left(\alpha - \kappa p - \kappa\alpha p\right)\ln\left(\frac{\alpha+\rho\alpha}{1+\alpha}\right) + \kappa\ln\rho = \frac{\gamma}{1-p}. \tag{15}$$

4 Comparative statics

Proposition 2 shows that the equilibrium success probability, and hence effort, is a function of α, ρ, and γ (but is independent of y^H). Recalling that $\gamma = \beta/\theta$, we see in equation (15) that the equilibrium effort is increasing in the riskiness ρ of the environment, decreasing in the dislike of effort, β, and increasing in the returns to effort, θ. For given riskiness, dislike of and returns to effort, how does the equilibrium effort depend on the common degree of altruism α? Figure 1 plots the equilibrium success probability p^* against the degree of altruism α, for $\rho = 10$, $\kappa = 1$, and $\gamma = 0.9$.

We see that when altruism is weak ($\alpha \leq 1/\rho = 0.1$), the siblings expect no transfers from each other and therefore choose the autarky effort $p^0 \simeq .61$.[14] As α increases beyond 0.1, each sibling expects to give (receive) a transfer, should he become rich (poor) and the other sibling poor (rich). The free-rider effect from an increase in the other's altruism reduces

[14] Recall that the effort made by a selfish individual living in autarky is positive iff $\gamma < \kappa \ln \rho$. For $\gamma = 0.5$ and $\kappa = 1$, this inequality is met for all $\rho > \sqrt{e} \approx 1.65$.

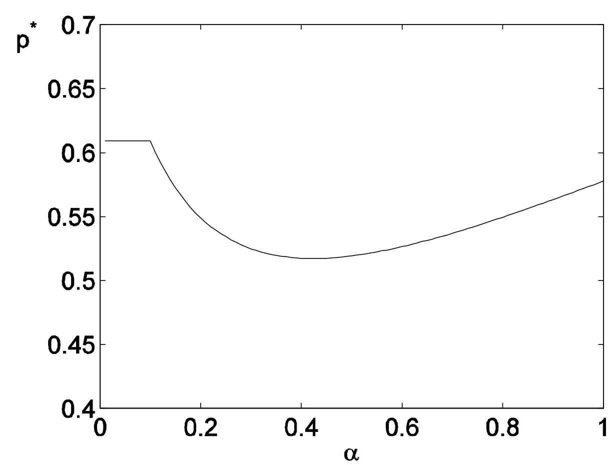

Figure 1: The success probability p^* as a function of altruism, α (for $\rho = 10$, $\kappa = 1$, and $\gamma = 0.9$).

the return from one's own effort, while the empathy effect from an increase in own altruism, beyond 0.1, increases the return from one's own effort. We see in Figure 1 that when altruism is moderate, the free-rider effect dominates — an increase in α then decreases the equilibrium effort—while when altruism is strong, the empathy effect dominates— an increase in α then increases the equilibrium effort.[15] This non-monotonicity holds generally:

Proposition 3 *Suppose that $\gamma < \kappa \ln \rho$ and that the siblings have the same degree α of altruism. If $\alpha = 1/\rho$, then $p^*(\alpha + \Delta\alpha) < p^*(\alpha)$ for $\Delta\alpha > 0$ sufficiently small. If $\alpha = 1$, then $p^*(\alpha - \Delta\alpha) < p^*(\alpha)$ for $\Delta\alpha > 0$ sufficiently small.*

In Figure 1, the equilibrium effort was the higher for selfish individuals, who make no transfers to each other, than for fully altruistic individuals, who always share total output equally among themselves: insurance leads to a lower effort. By contrast, Figure 2 shows an example ($\rho = 5$, $\kappa = 1$, and $\gamma = 0.9$) in which the equilibrium effort level is higher at full altruism than for selfish individuals: here a higher level of insurance does not lead to a lower effort. Instead, a high degree of altruism *adds* to the siblings' incentives to make effort. We note that the riskiness of the environment is lower in the second example, which

[15] In the figure the lowest equilibrium level of effort is positive. In the log-linear utility specification it can be shown generally that if the autarky equilibrium effort is positive, i.e., if $p^0 > 0$ for $\alpha < 1/\rho$, then the equilibrium effort is also positive for $\alpha \geq 1/\rho$.

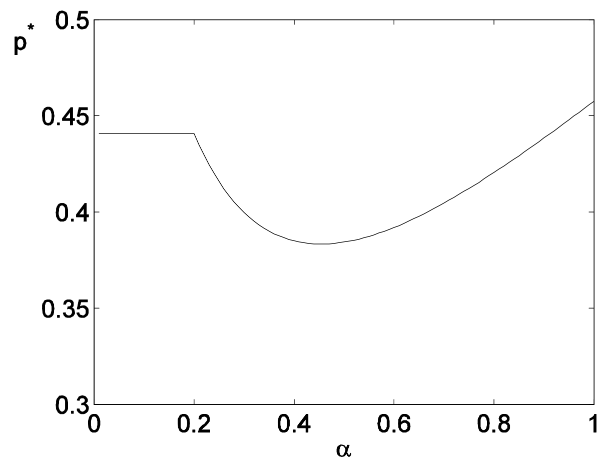

Figure 2: The success probability p^* as a function of altruism, α (for $\rho = 5$, $\kappa = 1$, and $\gamma = 0.9$).

suggests that this may happen more easily in less risky environments. Intuitively, in less risky environments the autarky effort is low and the marginal cost of extra effort is then also low. The free-rider effect is therefore weaker and the empathy effect stronger than in a more risky environment, where the marginal cost of effort is higher.

The numerical examples are valid for the highest possible institutional quality, $\kappa = 1$. Other numerical examples indicate that the empathy effect becomes stronger relative to the free-rider effect as institutional quality decreases. Figure 3 shows the equilibrium success probability p^* as a function of the common degree of altruism α, for $\rho = 10$ and $\gamma = 0.9$ (the same values as in Figure 1). The upper curve is drawn for $\kappa = 1$ while the lower curve is drawn for $\kappa = 0.7$. Whereas the equilibrium success probability is lower for $\alpha = 1$ than in autarky when $\kappa = 1$, the equilibrium success probability is higher for $\alpha = 1$ than in autarky when $\kappa = 0.7$. In this sense, the net effect of family ties changes sign as the institutional quality falls.

Is the high effort level induced by strong altruism "too high" for the material wellbeing of the siblings? The answer is no: the common degree of altruism, α, that leads to the highest *expected material utility* in equilibrium is full altruism, granted that some effort is worthwhile in autarky:

Proposition 4 *If $\gamma < \kappa \ln \rho$, the level of common altruism that maximizes the equilibrium expected material utility is full altruism, $\alpha = 1$.*

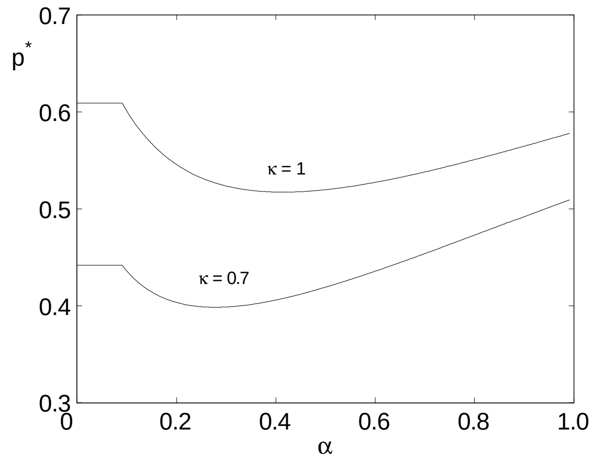

Figure 3: The success probability p^* as a function of altruism, α, for $\rho = 10$, and $\gamma = 0.9$: the upper curve is for $\kappa = 1$, and the lower for $\kappa = 0.7$.

When both individuals are fully altruistic, then each individual fully internalizes the external effect of his or her own behavior on the other's material utility. Hence, their incentives are perfectly aligned, with each individual acting like a utilitarian social planner. For lower degrees of altruism, however, their incentives are imperfectly aligned and there is room for some free-riding. It follows from this proposition that the (*ex ante* expected) equilibrium outcome of the interaction between two equally altruistic siblings is Pareto-efficient, in terms of the individuals' altruistic preferences, if and only if both siblings are fully altruistic:[16]

Corollary 5 *Assume that $\gamma < \kappa \ln \rho$. The unique perfect Bayesian equilibrium is Pareto efficient if and only if $\alpha = 1$.*

It may come as a surprise that the outcome is inefficient even in the absence of altruism, $\alpha = 0$. In the absence of this externality, why does not the independent strife of selfish individuals lead to a Pareto-efficient outcome? The explanation is that both individuals' utility would be increased if they exerted their common equilibrium effort x^0 but the rich would give a small transfer to the poor if they end up with distinct outputs. This follows from the concavity of the utility from consumption.

[16] Assuming that the siblings are fully altruistic is mathematically equivalent to assuming that they are selfish but make decisions collectively so as to maximize their joint expected material utility (as in Arnott and Stiglitz, 1991, in the case where they assume that the individuals may observe each other's effort).

Proposition 4 and Corollary 5 establish that both the expected material utility and the expected total utility is highest at $\alpha = 1$. Recall, however, that effort, and hence also the expected disposable output,

$$y^*(\alpha) = y^L + \left(y^H - y^L\right) p^*(\alpha)\,\kappa,$$

need not be the highest at full altruism. We see in Figures 1 and 2 that $y^*(1)$ is higher than $y^*(0) = y^0$ in the less risky environment ($\rho = 5$), whereas the reverse is true in the more risky environment ($\rho = 10$).

5 Evolutionarily robust family ties

There is evidence that family ties are stronger in some parts of the world than in others (see the following section). Some of this evidence, including conclusions drawn by Max Weber, suggests that family ties grew weak in northeastern Europe prior to the industrial revolution. May this have had something to do with the tough climate there? In preindustrial northeastern Europe most people were subsistence farmers. In order to survive the long and cold winters people had to produce and find secure storage for a large amount of food in a relatively short amount of time. Thus, in terms of our model it seems reasonable to assume that in preindustrial northeastern Europe the riskiness ρ was high, as was the marginal cost γ of increasing the success probability. Here we place our model in an evolutionary framework and ask whether lower altruism between siblings should be expected in harsher climates.

If altruism is a trait that is inherited from parent to child, is such a trait then robust against mutations towards higher and lower degrees of altruism? In order to determine the resulting fitness of an individual playing against a sibling, we follow and extend somewhat Bergstrom's (1995, 2003) approach. More specifically, suppose that a child inherits either its father's or its mother's degree of altruism, with equal probability for both events, and with statistical independence between siblings.[17] If both parents have the same degree of altruism α, then all siblings will also have altruism α. But if the father's degree of altruism

[17] If transmission is genetic, this corresponds to the *sexual haploid reproduction* case, where each parent carries one copy of the gene, and the child inherits either the father's or the mother's gene. The human species uses *sexual diploid reproduction*: then each individual has two sets of chromosomes; one set is inherited from the father, and the other from the mother. Whether a gene is expressed or not depends on whether it is recessive (two copies are needed for the gene to be expressed), or dominant (one copy is sufficient for the gene to be expressed). Bergstrom's (2003) analysis of games between relatives shows that the condition for a

is α_f whereas the mother's is $\alpha_m \neq \alpha_f$, then with probability 1/4 any two siblings will have altruism α_f, with probability 1/4 they will both have altruism α_m, and with probability 1/2 they will have different degrees of altruism.

Consider a homogeneous population where the initial degree of altruism is α. We can think of a sequence of generations in this population as follows. At the beginning of each time period, the individuals who survived to the age of reproduction mate randomly. Each matched pair has exactly two offspring, and each sibling pair plays the game in section 2.2 once. Suppose that a mutation occurs in this population, so that a small share of the individuals who are about to reproduce carry the mutant degree of altruism, $\alpha'' \neq \alpha$. Random mating takes place and reproduction occurs. We call the incumbent degree of altruism, α, *evolutionarily robust against* α'' if a child carrying the incumbent degree of altruism earns a higher expected material utility than a child carrying the mutant degree, for all sufficiently small population shares of the mutant degree of altruism, α''. As we will presently see, the condition for the incumbent degree of altruism α to be evolutionarily robust against a mutant degree $\alpha'' \neq \alpha$ boils down to the inequality

$$u^*(\alpha, \alpha) > \frac{1}{2}\left[u^*(\alpha'', \alpha) + u^*(\alpha'', \alpha'')\right], \tag{16}$$

where $u^*(\alpha_1, \alpha_2)$ is the expected equilibrium value of the material utility to an individual with altruism α_1 when his or her sibling's degree of altruism is α_2 and both siblings know their degrees of altruism (the equilibrium efforts and expected material utilities in the asymmetric case $\alpha_1 \neq \alpha_2$ are derived in the appendix).[18] A degree α is *evolutionarily robust* if it meets (16) for all $\alpha'' \neq \alpha$. Mathematically, a degree of altruism α is thus evolutionarily robust if and only if the right-hand side of (16), viewed as a function of $\alpha'' \in [0, 1]$, reaches its unique maximum value, $u^*(\alpha, \alpha)$, at $\alpha'' = \alpha$.

To see that (16) indeed is necessary and sufficient for evolutionary robustness as defined

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population carrying the same gene to resist the invasion by a mutant gene in the haploid case is the same as the condition for a population carrying the same recessive gene to resist the invasion by a dominant mutant gene in the diploid case.

[18]Bergstrom (1995, 2003) derives a condition similar to (16) in a slightly different model, in which each individual is programmed to play a strategy. Bergstrom shows that for a sexual haploid species, a sufficient condition for a population consisting of x-strategists to be stable against an invasion of y-strategists is

$$\Pi(x, x) > \frac{1}{2}\Pi(y, x) + \frac{1}{2}\Pi(y, y).$$

where $\Pi(s, s')$ denotes the payoff to strategy s against strategy s'.

above, note that the term on the left-hand side, $u^*(\alpha, \alpha)$, approximates the expected material utility to a child with the incumbent degree of altruism, α. For if the proportion of mutant carriers in the parent generation, $\varepsilon > 0$, is close to zero, then with near certainty both parents of this child are α-altruists, implying that the child's sibling almost surely also is an α-altruist. Likewise, the term on the right-hand side approximates the expected material utility to a child carrying the mutant degree of altruism α''. For ε close to zero, such a child almost certainly has exactly one parent carrying the mutant degree of altruism (the probability that both parents are mutants is an order of magnitude smaller, ε^2, and the probability that none is, is zero).[19] Therefore, with probability close to $1/2$ this child's sibling carries the incumbent degree of altruism α and with the complementary probability the sibling carries the mutant degree of altruism α''.

The process by which a mutation appears may affect the extent to which the mutant degree of altruism differs from the incumbent degree. In particular, cultural "drift" in values in a society may arguably lead to smaller differences between incumbents and mutants while migration from one community or society may lead to larger such differences. We will here report numerical simulations of both types. The relevant evolutionary robustness criterion against "cultural drift" thus is a local version of the above definition. We will call a degree of altruism $\alpha \in [0, 1]$ *locally evolutionarily robust* if there exists a $\delta > 0$ such that inequality (16) holds for all $\alpha'' \neq \alpha$ within distance δ from α.[20]

5.1 How climate affects family ties

In our model, where ρ represents the riskiness of the environment (the ratio of high to low output) and γ the marginal cost of increasing the probability for high output, we will call an environment, or climate, harsher (milder) if both ρ and γ are higher (lower). Following Weber, we should therefore expect higher degrees of altruism to be (at least locally) evolutionarily robust for lower values of ρ and γ, for a given level of institutional quality κ. Numerical simulations support this conjecture. Figure 4 shows two down-ward sloping bands in a diagram with ρ on the horizontal axis and γ on the vertical. The lower (upper)

[19] This presumes that "mutations" occur after siblings' interactions.

[20] A sufficient condition for local robustness of a degree α of altruism is that (i) the first-order derivative of the right-hand side in (16), with respect to α'' and evaluated at $\alpha'' = \alpha$, be zero, and (ii) that the corresponding second-order derivative, also evaluated at $\alpha'' = \alpha$, is negative. The first-order derivative equals $\frac{1}{2}u_1^*(\alpha, \alpha) + \frac{1}{2}u_2^*(\alpha, \alpha)$ (with subscripts for partial derivatives).

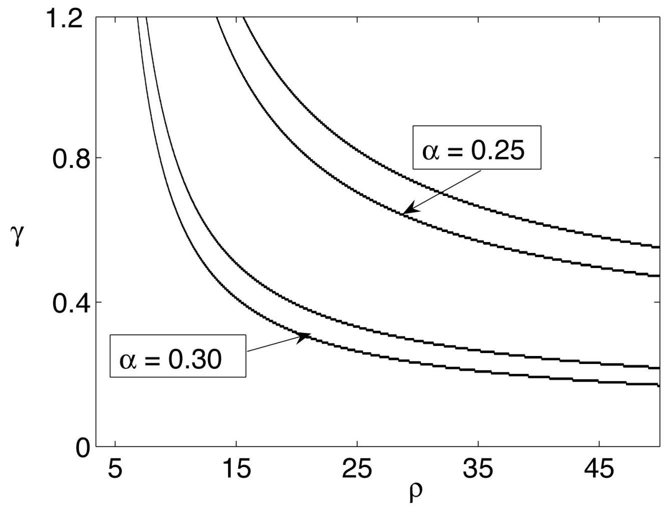

Figure 4: Climates (ρ, γ) in which altruism of degrees $\alpha = 0.30$ and $\alpha = 0.25$, respectively, are robust against mutations $\hat{\alpha} = \alpha \pm 0.01$, given an institutional quality $\kappa = 1$.

band is the region of climates (ρ, γ) in which altruism of degree $\alpha = 0.30$ ($\alpha = 0.25$) is robust against mutations $\alpha'' = \alpha \pm \delta$ for $\delta = 0.01$ (using logarithmic consumption utility and exponential success probability), given that $\kappa = 1$.

Other computer simulations, for different degrees α of altruism and step size δ, result in qualitatively similar diagrams. These simulations suggest a few regularities. First, that robustness against smaller perturbations δ seems to imply robustness against larger δ. Hence, it may well be that local robustness in this model specification implies global robustness. Secondly, our simulations suggest that neither high nor low degrees of altruism, roughly those below 0.2 and above 0.4, are locally evolutionarily robust in any climate. Thirdly, for values of ρ between 5 and 50, and values of α between 0 and 1, both the highest and the lowest parameter value γ for which α is robust to perturbations of size $\delta = 0.01$ are decreasing in α. In sum: numerical simulations suggest that moderate degrees of family altruism will prevail in most climates, with higher degrees of family altruism in milder than in harsher climates. In this sense, Darwin lends theoretical support to Weber (in so far as Protestantism is more prevalent in harsher climates and Catholicism in milder climates): evolutionary forces seem to select stronger family ties in milder climates, such as in southern Europe, than in harsher climates, such as in northern Europe.

Based on these simulations we further calculated equilibrium effort and income as functions of the climate (ρ, γ), for the associated evolutionarily robust altruism value. Figure

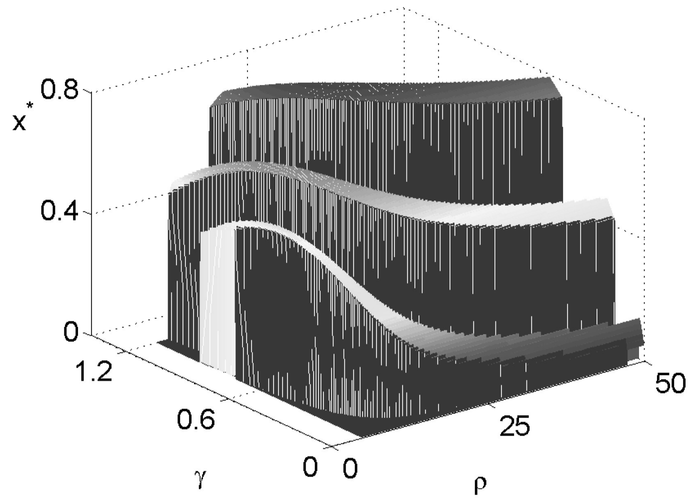

Figure 5: Equilibrium effort x^* as a function of climate (ρ, γ), for $\theta = 1/\gamma$, and for robust altruism levels.

5 shows effort x^* as a function of the climate (ρ, γ), in three distinct "climate zones" in the (ρ, γ)-plane, namely the mildest zone (nearest the origin) in which the evolutionarily robust degree of altruism is $\alpha = 0.35$, the intermediate zone where it is $\alpha = 0.30$, and the harshest climate zone (furthest from the origin) where it is $\alpha = 0.25$.[21] Siblings — with the corresponding evolutionarily robust degree of family altruism — exert more work effort in harsher climates. In sum, their family ties are weaker and they work harder. For an outside observer, it is thus as if those who live in milder climates are lazier than those who live in harsher climates, while in all these simulations all individuals actually have identical preferences concerning effort ($\beta = 1$). Max Weber (1904-1905) argued that the "Protestant work ethic" was a key element behind the development of capitalism in northwestern Europe and the United States. Our results suggest that such a work ethic may actually just be a social codification of attitudes that "nature" has already selected for individuals living in harsher climates. (We leave it to future research to investigate evolutionarily robustness of parameter values β, the disutility of effort.)

It turns out that the higher effort exerted in harsher climate is not sufficient to yield higher expected incomes. Indeed, income may well decrease as the environment becomes harsher, see figure 6 (note that the γ-axis is reversed compared to figure 5).In the three

[21] The taste parameter β was set equal to 1 in all these simulations.

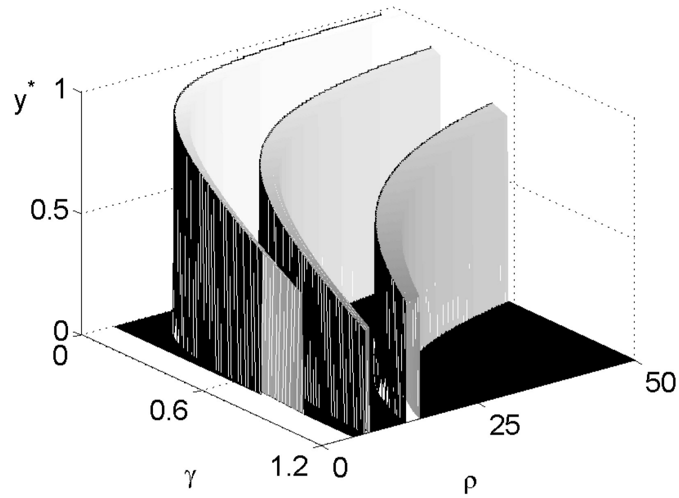

Figure 6: Equilibrium income y^* as a function of climate (ρ, γ) for robust altruism levels.

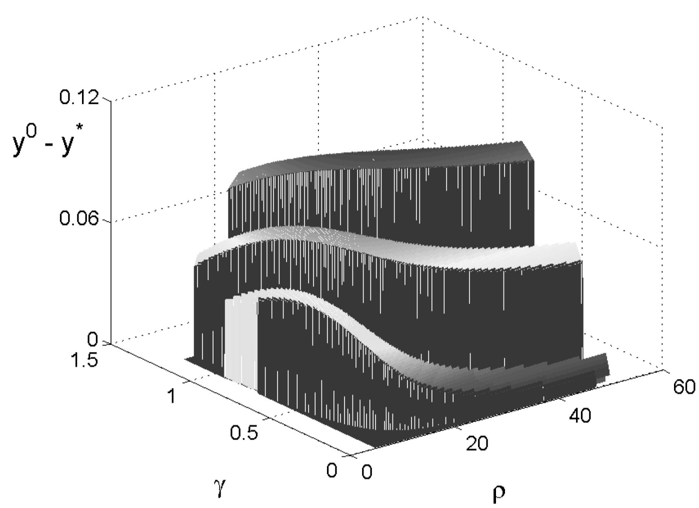

Figure 7: The difference $y^0 - y^*$ in income without and with family ties, as a function of climate (ρ, γ), for robust altruism levels.

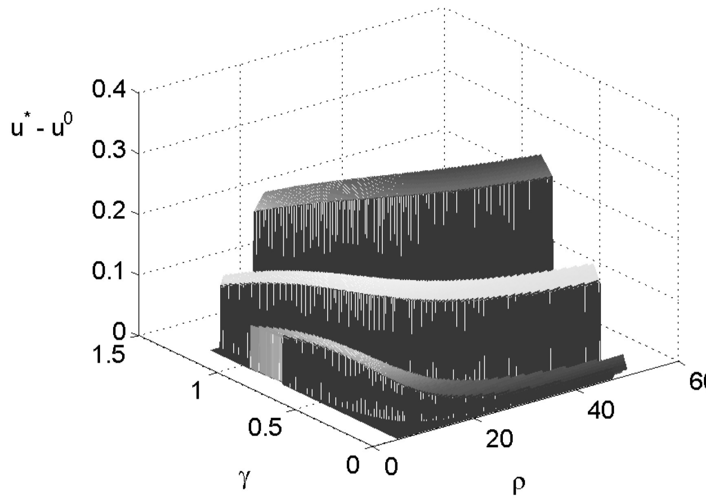

Figure 8: The difference $u^* - u^0$ in material utility with and without family ties, as a function of climate (ρ, γ), for robust altruism levels.

climate zones represented in figures 5 and 6 individuals are sufficiently altruistic for transfers to occur. The above analysis, which shows that such altruism has both a positive and a negative incentive effect on effort, thus prompts us to ask whether effort (or, equivalently, expected income) is higher or lower than if the individuals instead were selfish. Figure 7 shows that in all the considered environments, the moral hazard effect dominates: there is a positive difference between y^0, the expected income in autarky, and y^*, the expected income with the evolutionarily robust altruism. Furthermore, the absolute income reduction is higher in harsher climates, despite the lower level of altruism there. However, although altruism decreases the expected income, it increases the expected material utility: the difference between u^*, the expected material utility with the evolutionarily robust altruism, and u^0, the expected material utility in autarky is positive, as shown in figure 8. Moreover, the absolute gain in material utility is larger in harsher climates, despite the lower level of altruism.

5.2 Institutional quality and climate

How does institutional quality interact with climate in determining evolutionarily robust altruism levels? Numerical simulations suggest that lower institutional quality leads to a higher degree of altruism, irrespective of climate (ρ, γ). Similarly to Figure 4, and for the

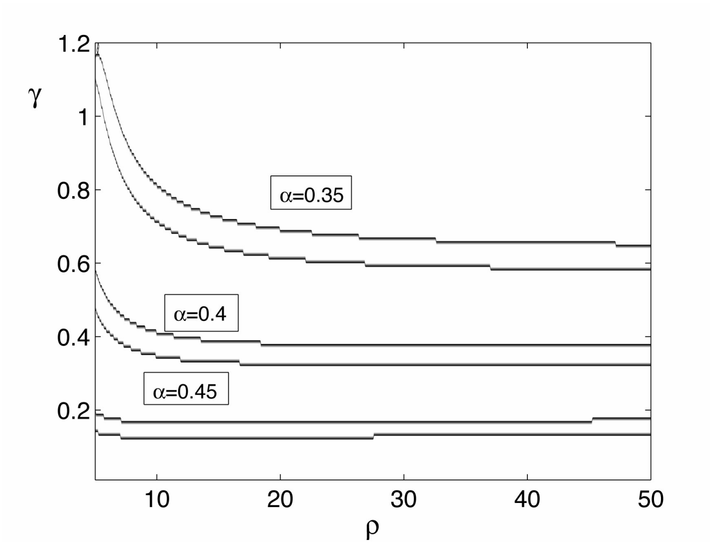

Figure 9: Climates (ρ, γ) in which altruism of degrees $\alpha = 0.45$, $\alpha = 0.4$, and $\alpha = 0.35$, respectively, are robust against mutations $\hat{\alpha} = \alpha \pm 0.01$, given an institutional quality $\kappa = 0.7$.

same ranges of ρ and γ values, Figure 9 shows bands of climates (ρ, γ) in which different degrees of altruism are robust, but now for institutional quality $\kappa = 0.7$ instead of $\kappa = 1$. The upper band is the climate zone in which altruism of degree $\alpha = 0.35$ is robust (against mutations of size ± 0.01 and using logarithmic consumption utility and exponential success probability), while the middle and lower bands are the climate zones in which degrees of altruism $\alpha = 0.4$ and $\alpha = 0.45$, respectively, are robust.

5.3 Robust sibling altruism under exogenous risk

The biological kinship factor (the amount of shared genes) between siblings is $1/2$. Hence, one might expect that we should find $\alpha = 1/2$ to be the robust degree of altruism, irrespective of climate (see Hamilton, 1964, and Bergstrom, 1995). Instead, we found lower robust degrees of altruism, degrees that also depended on climate. This difference is due to the endogeneity of risk in our model—the fact that siblings optimally adjust their risk-reducing efforts to climate. To see this, suppose instead that both siblings' success probabilities were fixed at some exogenously given level. What levels of kinship altruism α would then be evolutionarily robust?

In order to answer this question, a minor modification of the above analysis is sufficient: we apply the condition for evolutionary robustness (16) to a situation in which the effort of both siblings is exogenously fixed, independent of the level of altruism. Let the function $H : [0,1] \times \mathbb{R} \to \mathbb{R}$ be defined by

$$H(\alpha) = \ln(1 - t^*(\alpha)) + \frac{1}{2}\ln\left(\frac{1}{\rho} + t^*(\alpha)\right),$$

where the factor $\frac{1}{2}$ is the biological kinship factor, and $t^*(\alpha)$ is the equilibrium transfer from a rich sibling with altruism α to a poor sibling, defined as before—see equation (14). We show in the appendix that then the condition for evolutionary robustness boils down to the inequality $H(\alpha) > H(\alpha'')$, and that the function H has a unique maximum at $\alpha = 1/2$, for all $\rho > 2$ (in which cases the transfer is positive). Hence, the unique evolutionarily robust degree of altruism is independent of climate and equals the biological kinship factor:

Proposition 6 *Suppose that $\rho > 2$. If efforts are fixed and equal, then the unique evolutionarily robust level of altruism between siblings is $\alpha = 1/2$.*

6 Evidence on family ties

Our theoretical analysis relies on the two key assumptions that the family may be a source of mutual insurance, and that the level of effort chosen by an individual depends on the degree of mutual help within the family. In this section we summarize the empirical evidence that justifies these assumptions. We also discuss empirical studies by economists, anthropologists, sociologists and historians, studies suggesting that family ties are weaker in some societies than in others, and that such differences may have predated the industrial revolution. The evidence is in line the qualitative predictions of our evolutionary analysis, namely, that family ties are stronger in countries with milder climates.

First, there is evidence that transfers within the extended family are a source of insurance in countries where formal insurance is not well-developed, essentially in developing countries.[22] In their survey on private transfers between households, Cox and Jimenez (1990) conclude that in developing countries 20-90% of households receive (private) transfers, which can represent up to 20% of the average household income. In the U.S. the corresponding figures are 15% and 1%, respectively. Since the average income of donor households exceeds that of recipient households (Cox, Galasso and Jimenez, 2006), these transfers appear to

[22] In 2003 the total value of insurance premia (life and non-life) as a percent of GDP was 12.48 in the US, 9.85 in France, 1.42 in Turkey, and 1.74 in Mexico (Insurance Statistics Yearbook: 1994-2003, OECD, 2005).

provide some insurance; see also Cox and Fafchamps (2006). Several other studies, such as Udry (1990), Towsend (1994), Miller and Paulson (2000), and Kurosaki and Fafchamps (2002), confirm the hypothesis that insurance occurs within the extended family.

Second, what is the empirical support for the assumption that the degree of intra-family insurance affects effort? Despite the previous strong emphasis in the literature on the possible moral hazard effect of intrafamily altruism, there seems to be a limited number of empirical studies on this topic. Two of those studies suggest that mutual insurance within the extended family induces moral hazard. Using data on farmer output in Mali, Azam and Gubert (2005) establish that recipients of remittances from emigrated relatives in Mali decrease their effort in response to an increase in remittances. Similarly, the analysis of Thai data by Miller and Paulson (1999) reveals that better insurance in the form of remittances leads to more gambling, both among those who are potential remitters, and among those who are likely to receive remittances. By contrast, the findings by Kohler and Hammel (2001) indicate that mutual insurance within the family may have a positive effect on individuals' risk-reducing effort. Using census data for Slavonia from 1698, Kohler and Hammel find that the number of different crops grown by a family tended to increase as the nearby extended family increased. The authors were expecting the opposite effect, namely that as a result of expected intra-family insurance a family would invest less in risk-reducing planting strategies. However, our results suggest that there exists an intuitive explanation for this pattern: when a family expects to help another family out, the expected benefit of the risk-reducing planting strategy is increased. The situation investigated by Azam and Gubert is perhaps closer to a model with one-sided altruism: with remittances, essentially only the emigrant family member is in a position to help out the family that stayed in the home country. Hence, the only effect of family altruism on the latter is the free-riding effect, inducing lower effort. By contrast, Kohler and Hammel studied households living in the same area, suggesting that any household could end up as a donor or a recipient of transfers.

Finally, we summarize studies showing geographic variations in the strength of family ties. U.S. data collected by Keefe et al (1979) indicates that second and third generation Mexican-American families have stronger kin ties than white Anglo families, even after controlling for variables such as education, occupation and the number of years of residence in the same city. Keefe (1984) further finds that Mexican-Americans (people of Mexican descent but born in the U.S.) attach a larger value than Anglos to the physical presence of family members. Using another data set, Gonzales (1998) shows that Mexican-Americans tend to live closer to and have more contact with kin than Anglos, even after several generations in the U.S.

Her analysis further suggests that both Mexican-Americans and Mexican immigrants are significantly more sympathetic to the idea that parents (adult children) should let their adult children (parents) live with them if in need. This evidence is consistent with our predictions, since on average the climate in Mexico is arguably milder than in the U.S. It also indicates that the strength of family ties perdures for several generations, and that current data may be interpreted as a reflection of the past. Thus, to the extent that the prevailing strength of family ties in the U.S. may be the result of immigration from all over Europe, and that we may expect the climate of the representative immigrant's country of origin to be harsher than in Mexico, these findings indicate that family ties are stronger in milder climates.

Reher (1998) argues that one can measure the strength of a society's family ties by studying the age at which a child leaves his/her parents' home. In 1995, the average age of children living with their parents was 15 in Spain, 18 in Italy, 9 in the UK, 11 in the US, and 13 in Germany (Bentolila and Ichino, 2000). Although these differences may be affected by differences in economic opportunities, availability and cost of housing, and the extent of publicly provided insurance, there is evidence that preferences for cohabitation between parents are children vary among countries. Using U.S. data Rosenzweig and Wolpin (1993) analyzed how the rate of cohabitation between parents and their adult children responded to an exogenous increase in the parents' income: they found that the rate of cohabitation decreased as a result of the increase in the parents' income. Thus, cohabitation between parents and adult children is may be viewed as an inferior good in the U.S. But in other countries it is a normal good: using Italian data Manacorda and Moretti (2006) found that the rate of cohabitation between parents and their adult children *increased* as a result of an exogenous increase in the parents' income. Again, this is consistent with our predictions that family ties are stronger in milder climates.

A study conducted by Bentolila and Ichino (2000) provides further support for our hypothesis that family ties are stronger in milder climates. They find that the drop in consumption due to a prolongation of unemployment is significantly smaller in Italy and Spain, than in the UK and Germany, despite the fact that the unemployment insurance was more generous in the latter two countries than in the former during the studied period. They also argue that the smaller consumption drop in Italy and Spain is largely due to additional intra-family help. Thus, in Spain and Italy, where the climate historically has been milder than in the UK and Germany, intra-family help *more* than outweigh the relative lack of formal insurance. Together with the evidence on the perdurance of family ties, this indicates that family ties are weaker in northern than in southern Europe, and that this has been so also prior to the advent of the welfare state.

Apart from Weber's suggestion that Protestantism has shattered the "fetters of the sib," the direct evidence from pre-industrial Europe is scarce. However, such evidence again reveals a pattern that is consistent with our theoretical evolutionary predictions. Hajnal (1982) reports data on servants in northwestern Europe during the 17th-19th centuries; approximately half of all youngsters served outside the parental home at some point, some leaving the parental home at the age of 10. Thus, in 17th century England, "the unit of production was the husband and the wife and hired labor, not children" (Macfarlane, 1978). By contrast, in southern and eastern Europe hired labor was in the same period scarce, and children would typically work on the parental farm; several related couples and their children would constitute the more widespread type of household. Finally, differences in the legal systems may provide further insights into the strength of family ties. In England, parents had the right to bequeath or sell their assets to anyone. According to Macfarlane (1992), this right may be traced back to the thirteenth century. By contrast, in France the heirs must be given the opportunity to purchase the assets (Macfarlane, 1992).

7 Conclusion

Family ties are stronger in some parts of the world than in others, and this may have been so for a very long time. In particular, it seems that family ties grew weaker in northwestern Europe prior to the industrial revolution, as suggested by Weber (1951). This observation prompted us to ask first, how family ties affect economic outcomes, and second, whether evolutionary forces may have shaped family ties differently in different climates. With a preindustrial world in mind, we focused on the family's potentially important role as an insurance provider for its members. We modelled a family as a pair of siblings who interact in a two-stage game. In the first stage, each sibling exerts effort, thereby enhancing the probability of a high output, and in the second stage each sibling decides how much output, if any, to transfer to the other sibling. We analyzed how altruistic family ties affect the productive effort, the expected income and welfare of each sibling. We also studied how these effects depend on climate, defined by two parameters: the riskiness, ρ, and return to effort, θ. Second, we used the equilibrium predictions to explore the possibility that (biological or social) evolutionary forces have led to family ties of different strength in different climates.

In our model with mutual altruistic family ties, family members have an additional motive to exert effort, namely, to increase the probability to be in a position to help other family members. We call this the *empathy effect* (of one's own altruism) and study its conflict with the opposing effect, the *free-riding effect* (of other family members' altruism), the motive to reduce one's effort in the hope of being helped by other family members. We found that, at the margin, the free-riding effect outweighs the empathy effect at low levels of altruism, while the opposite holds at high altruism levels. When riskiness ρ is low, the empathy effect induce individuals to exert more effort than if they were living in autarky. These findings call for more empirical studies on the effects of family ties on effort, of which there currently exists only a small number (see Section 6).

Our numerical simulations in the evolutionary analysis suggest that neither very weak nor very strong family ties are robust to population drift in the strength of family ties. It may not come as a surprise that full altruism (giving equal weight to one's siblings welfare as to one's own) is not robust. If a few individuals would become slightly less altruistic toward their kin, then these would do better in terms of material utility from consumption and effort. More surprising, perhaps, is our finding that pure selfishness is not robust either; if a few individuals in such a society would become slightly altruistic towards their own sibling, then these individuals would do better in terms of material utility. Instead, our numerical simulations show that intermediate degrees of family altruism are robust in certain climates. Moreover, the harsher the climate — higher riskiness ρ and lower return θ to effort — the weaker are the family ties that are evolutionarily robust. If, in our model, family members' risk-reducing efforts had been exogeneous, then the evolutionarily robust degree of altruism would in all climates have been one half, the degree of genetic relatedness between siblings, in agreement with Hamilton's rule (Hamilton, 1964). However, in our model we allow for the siblings to choose their levels of risk-reducing effort in anticipation of helping out or being helped out. The effect of this endogeneity is to reduce the evolutionarily robust degree of altruism to a level below one half, a level that, moreover, depends on climate.

In a companion sequel paper, Alger and Weibull (2007), we extend the analysis to *coerced altruism*, whereby we mean socially coerced intra-family transfers. In that model, individuals may be more or less altruistic to their siblings, but there is a social norm that requires them to act as if they were even more altruistic. In that study, we also compare the performance of coerced intra-family transfers as a form of insurance with that of insurance in perfectly competitive markets and under compulsory insurance programs. In our evolutionary analysis we focus on the case where preferences are transmitted from parents to children, and where each family has exactly two children. It would be interesting to extend the analysis to allow for a richer menu of family sizes, relatedness and transmission mechanisms, between and among different generations (see Hauk and Saez-Marti (2002), and Lindbeck and Nyberg (2006) for models of intergenerational transmission mechanisms). It might also be fruitful to extend the analysis to other settings, in particular to credit markets. In many developing countries, as well as in some developed ones, microfinance systems thrive, such as the Grameen Bank in Bangladesh (for a survey, see Armendáriz and Morduch, 2005). In many of these programs, poor individuals take bank loans backed by their relatives and neighbors. If a loan-taker defaults, a whole group of closely related individuals are liable. Allowing for altruistic motives among related individuals may provide additional insights regarding the performance of microfinance programs. Another extension could be migration. When one or more family members migrate from a developing country with strong family ties to a developed country with weak family ties, what are the net incentive effects of family altruism on effort and income, and what are the likely long-run effects on such ties in such situations?

8 Appendix

We here give mathematical proofs of propositions in Sections 3-5, along with some background calculations for the numerical simulations in Section 5.

8.1 Proposition 2

Let

$$\begin{aligned} F^*(p) &= \kappa(1-\kappa p-\kappa\alpha p)\ln(1-t^*)+\kappa(\alpha-\kappa p-\kappa\alpha p)\ln(1+\rho t^*)+\kappa\ln\rho-\frac{\gamma}{1-p} \\ &\equiv \left.\frac{\partial U_i(p_i,p_{i'})}{\partial p_i}\right|_{p_i=p_{i'}=p} \end{aligned}$$

where

$$t^* = \max\left\{0, \frac{\rho\alpha-1}{\rho\alpha+\rho}\right\}.$$

A common strictly positive equilibrium effort p necessarily satisfies $F^{*}(p) = 0$. For $1/\rho < \alpha \leq 1$ this yields the following polynomial equation in p after some algebraic manipulation:

$$\kappa^2 \left[\ln(\alpha/\rho) + 2\ln\left(\frac{1+\rho}{1+\alpha}\right)\right] \cdot p^2 - \kappa \left[\kappa \ln(\alpha/\rho) + (1+2\kappa)\ln\left(\frac{1+\rho}{1+\alpha}\right) + \frac{\alpha}{1+\alpha}\ln\alpha\right] \cdot p$$
$$+\kappa \ln\left(\frac{1+\rho}{1+\alpha}\right) + \kappa\frac{\alpha}{1+\alpha}\ln\alpha - \frac{\gamma}{1+\alpha} = 0. \tag{17}$$

Let A, B, and C be the coefficients in equation (17), when written in the form $Ap^2 - Bp + C = 0$. Note that $A > 0$ iff $\kappa > 0$ and $(\alpha - 1/\rho)(\rho - \alpha) > 0$. It follows that $B^2 - 4AC \geq 0$ for all $\gamma \geq 0$, $\alpha \in [0,1]$, and $\rho > 1$ and such that $\alpha\rho > 1$, because $B^2 - 4AC > (2A - B)^2 \geq 0$ iff $A(B - A - C) > 0$ iff $B - A - C > 0$ iff $\gamma/(1+\alpha) \geq 0$. Hence the two roots are

$$q_1 = \frac{B - \sqrt{B^2 - 4AC}}{2A} \quad \text{and} \quad q_2 = \frac{B + \sqrt{B^2 - 4AC}}{2A},$$

and $A > 0$ implies $q_2 \geq q_1$.

The previous observation that, for all $\gamma \geq 0$, $\alpha \in [0,1]$, and $\rho > 1$ and such that $\alpha\rho > 1$, we have $B^2 - 4AC > (2A - B)^2$ if and only if $\gamma/(1+\alpha) \geq 0$ implies that $q_2 > 1$.

It remains to show that the smaller root q_1 is less than 1. This follows from the fact that F^* is continuous, $\lim_{p\to 1} F^*(p) = -\infty$, and $\lim_{p\to -\infty} F^*(p) = +\infty$. To see the last property note that $\gamma/(1-p)$ tends to zero as p tends to $-\infty$, and that the coefficient for p in F^* is negative when $\alpha\rho > 1$, since:

$$\begin{aligned}
\kappa^2(1+\alpha)\ln\left[(1-t^*)(1+\rho t^*)\right] &> 0 \\
&\Leftrightarrow (1-t^*)(1+\rho t^*) > 1 \\
&\Leftrightarrow (1+1/\rho)(\alpha+\alpha\rho) > (1+\alpha)^2 \\
&\Leftrightarrow 2\alpha + \alpha/\rho + \alpha\rho > 1 + 2\alpha + \alpha^2 \\
&\Leftrightarrow (\alpha - 1/\rho)(\rho - \alpha) > 0.
\end{aligned}$$

Finally, we note that the smaller root is strictly positive if and only if $F^*(0) > 0 \Leftrightarrow$

$$\gamma - \kappa\ln\rho < \kappa\left[\ln\left(\frac{1+\rho}{1+\alpha}\right) + \alpha\ln\left(\frac{\alpha(1+\rho)}{1+\alpha}\right) - \ln\rho\right].$$

This inequality is implied by our assumption that $\gamma < \kappa\ln\rho$, since the right-hand side of the inequality can be shown to be positive:

$$
\begin{aligned}
\ln\left(\frac{1+\rho}{1+\alpha}\right)+\alpha\ln\left(\frac{\alpha(1+\rho)}{1+\alpha}\right) &> \ln\rho \\
&\Leftrightarrow \ln\left(\frac{1+1/\rho}{1+\alpha}\right)+\alpha\ln\left(\frac{\alpha(1+1/\rho)}{1+\alpha}\right)+\alpha\ln\rho>0 \\
&\Leftrightarrow \ln\left(1-t^{*}\right)+\alpha\ln\left(1/\rho+t^{*}\right)>\ln 1-\alpha\ln\rho,
\end{aligned}
$$

which is true since for $\alpha\rho>1$, $t^{*}>0$ and

$$
t^{*}\in\arg\max_{t\in[0,1]}\quad \ln(1-t)+\alpha\ln(1/\rho+t)\,.
$$

8.2 Proposition 3

Given some ρ and γ, the unique equilibrium effort-*cum*-probability p^{*} and the transfer fraction t^{*} may be written as functions of α. Assuming that $\alpha\rho>1$, p^{*} is differentiable with respect to α, and straightforward calculations show that

$$
\frac{dp^{*}(\alpha)}{d\alpha}=\frac{1}{K}\left[\kappa\left[1-\kappa p^{*}(\alpha)\right]\ln\left[1+\rho t^{*}(\alpha)\right]-\kappa^{2}p^{*}(\alpha)\ln\left[1-t^{*}(\alpha)\right]-p^{*}(\alpha)\,\kappa^{2}\frac{1-\alpha^{2}}{1/\rho+t^{*}(\alpha)}\cdot\frac{dt^{*}(\alpha)}{d\alpha}\right],
$$

where, by (14), $\frac{d}{d\alpha}t^{*}(\alpha)>0$ when t^{*} is positive, and

$$
K=\frac{\gamma}{\left[1-p^{*}(\alpha)\right]^{2}}+\kappa^{2}(1+\alpha)\ln[\left(1-t^{*}(\alpha)\right)\left(1+\rho t^{*}(\alpha)\right)]>0.
$$

As $\alpha\downarrow 1/\rho$ (at which point p^{*} is not differentiable), the first two terms within the square brackets in the expression for $\frac{dp^{*}(\alpha)}{d\alpha}$ tend to zero, so that the last term determines the sign, whereas the opposite is true when $\alpha\uparrow 1$.

8.3 Proposition 4

We proceed in two steps. First, we characterize the socially optimal probability p and transfer t, to be given by the rich to the poor, under a Benthamite social welfare function. Secondly, we verify that these coincide with the equilibrium probability p^{*} and transfer t^{*} if and only if $\alpha=1$.

Consider a hypothetical social planner who chooses a probability p and transfer t so as to maximize the sum of the expected material utilities to each individual,

$$
W(p,t)=2\left[\ln y^{H}-(1-\kappa p)^{2}\ln\rho+\kappa p(1-\kappa p)\left[\ln(1-t)+\ln(1/\rho+t)\right]+\gamma\ln(1-p)\right]. \tag{18}
$$

The necessary first-order condition for an interior solution for p is

$$\kappa(1-2\kappa p)\ln(1-t)+\kappa(1-2\kappa p)\ln(1+\rho t)+\kappa\ln\rho-\frac{\gamma}{1-p}=0. \tag{19}$$

Moreover, for any value of p, the value of t that maximizes $W(p,t)$ is such that both individuals end up with the same consumption in all states: $1-t=1/\rho+t$, or, equivalently, $t=(1-1/\rho)/2$.

For $\gamma<\kappa\ln\rho$ the equilibrium transfer fraction t^* in the symmetric game G satisfies:

$$t^*(\alpha)=\frac{\alpha\rho-1}{\alpha\rho+\rho}.$$

Hence $\alpha=1$ is necessary for the equilibrium outcome in game G to coincide with the socially optimal outcome. It is also a sufficient condition, since the equation which defines the equilibrium success probability p^*,

$$\kappa\left(1-\kappa p^*-\kappa\alpha p^*\right)\ln\left(1-t^*(\alpha)\right)+\kappa\left(\alpha-\kappa p^*-\kappa\alpha p^*\right)\ln\left(1+\rho t^*(\alpha)\right)+\kappa\ln\rho-\frac{\gamma}{1-p^*}=0, \tag{20}$$

with $t^*(\alpha)=(1-1/\rho)/2$, coincides with (19), the necessary first-order condition for an interior solution for p, if and only if $\alpha=1$.

8.4 Corollary 5

Given the symmetry of the unique equilibrium outcome, this is Pareto efficient if and only if it maximizes the sum of both individuals' expected welfare levels, as defined in equation (9). If each individual chooses the effort-*cum*-probability p and gives the transfer t when rich and the other is poor, the mentioned sum is $S(p,t)=(1+\alpha)W(p,t)$, where $W(p,t)$ is the sum of the expected material utilities (see the definition in the proof of proposition 4). For any value of α, this is strictly increasing in $W(p,t)$. But, by proposition 4, in an equilibrium of game G the expected material utility u^* coincides with the maximum value of $W(p,t)$ if and only if $\alpha=1$.

8.5 Evolutionary robustness calculations

Here we study game G, which was introduced in section 2.2, allowing for the siblings' altruism levels to be different. We have already established (see section 3) that in equilibrium a rich individual i would give the following share of the high income y^H that to a poor sibling i':

$$t_i^* = \max\left\{0, \frac{\rho\alpha_i - 1}{\rho\alpha_i + \rho}\right\}.$$

From (13), which shows the *(ex ante) expected total utility* for individual i as a function of the two success probabilities p_i and $p_{i'}$, we derive an individual' best response p_i^* to his or her sibling's success probability $p_{i'}$:

$$\begin{aligned} p_i &= \max\{0, 1 - \\ & \frac{\gamma}{\kappa \ln \rho + \kappa\left[\ln\left(1-t_i^*\right) + \alpha_i \ln\left(1+\rho t_i^*\right)\right] - \kappa^2 p_{i'}\left[\ln\left[\left(1-t_i^*\right)\left(1+\rho t_{i'}^*\right)\right] + \alpha_i \ln\left[\left(1-t_{i'}^*\right)\left(1+\rho t_i^*\right)\right]\right]}\}. \end{aligned}$$

In the case where both equilibrium success probabilities, $p_{ii'}^*$ and $p_{i'i}^*$, are strictly positive the system of equations thus defined yields the following polynomial equation in $p_{ii'}^*$ after some algebraic manipulation:

$$\begin{aligned} 0 &= \kappa^2\left[\ln\left[\left(\rho - \rho t_{i'}^*\right)\left(\frac{1}{\rho} + t_i^*\right)\right] + \alpha_{i'} \ln\left[\left(1+\rho t_{i'}^*\right)\left(1-t_i^*\right)\right]\right] \cdot \left(p_{ii'}^*\right)^2 \\ & -\kappa\left[\left(1+\kappa\right)\left[\ln\left(\rho - \rho t_{i'}^*\right) + \alpha_{i'} \ln\left(1+\rho t_{i'}^*\right)\right] + \kappa\left[\ln\left(\frac{1}{\rho} + t_i^*\right) + \alpha_{i'} \ln\left(1-t_i^*\right)\right]\right] \cdot p_{ii'}^* \\ & -\frac{\kappa\gamma\left[\left(1-\alpha_i\right)\ln\left[\left(\frac{1-t_i^*}{1-t_{i'}^*}\right)\left(\frac{1+\rho t_{i'}^*}{1+\rho t_i^*}\right)\right] + \left(\alpha_i - \alpha_{i'}\right)\ln\left[\left(1+\rho t_{i'}^*\right)\left(1-t_i^*\right)\right]\right]}{\left(1-\kappa\right)\left[\ln\left(\rho - \rho t_i^*\right) + \alpha_i \ln\left(1+\rho t_i^*\right)\right] - \kappa\left[\ln\left(\frac{1}{\rho} + t_{i'}^*\right) + \alpha_i \ln\left(1-t_{i'}^*\right)\right]} \cdot p_{ii'}^* \\ & +\kappa \ln \rho - \gamma + \kappa \ln\left(1-t_{i'}^*\right) + \alpha_{i'}\kappa \ln\left(1+\rho t_{i'}^*\right) \\ & +\frac{\gamma\left[\ln\left(\frac{1-t_i^*}{1-t_{i'}^*}\right) + \alpha_i \ln\left(\frac{1+\rho t_i^*}{1+\rho t_{i'}^*}\right) + \left(\alpha_i - \alpha_{i'}\right)\ln\left(1+\rho t_{i'}^*\right)\right]}{\left(1-\kappa\right)\left[\ln\left(\rho - \rho t_i^*\right) + \alpha_i \ln\left(1+\rho t_i^*\right)\right] - \kappa\left[\ln\left(\frac{1}{\rho} + t_{i'}^*\right) + \alpha_i \ln\left(1-t_{i'}^*\right)\right]}. \end{aligned}$$

Letting $p^*\left(\alpha_i, \alpha_{i'}\right)$ denote the equilibrium success probability of an individual with altruism level α_i playing game G against a sibling with altruism $\alpha_{i'}$ the equilibrium expected material utility of individual i is:

$$\begin{aligned} u^*(\alpha_i, \alpha_{i'}) = \ln y^H &- \left[1 - \kappa p^*\left(\alpha_i, \alpha_{i'}\right)\right]\left[1 - \kappa p^*\left(\alpha_{i'}, \alpha_i\right)\right] \ln \rho \\ &+ \kappa p^*\left(\alpha_i, \alpha_{i'}\right)\left[1 - \kappa p^*\left(\alpha_{i'}, \alpha_i\right)\right] \ln(1 - t^*\left(\alpha_i\right)) \\ &+ \kappa p^*\left(\alpha_{i'}, \alpha_i\right)\left[1 - \kappa p^*\left(\alpha_i, \alpha_{i'}\right)\right] \ln(1/\rho + t^*\left(\alpha_{i'}\right)) \\ &+ \gamma \ln\left[1 - p^*\left(\alpha_i, \alpha_{i'}\right)\right], \end{aligned}$$

where

$$t^*(\alpha) = \max\left\{0, \frac{\rho\alpha - 1}{\rho\alpha + \rho}\right\}.$$

Our computer simulations were carried out in Matlab, using increments of 0.01 for ρ and 0.005 for γ when generating figures 4 - 8.

8.6 Proposition 6

Formally, we consider a game $\tilde{G}$, which is very similar to game G: the only difference is that individuals do not choose the success probability. Letting $p \in [0,1)$ denote the common, exogenously given success probability for both siblings, we can use the above analysis to see that the equilibrium expected material utility of individual with altruism level α_i playing $\tilde{G}$ against a sibling with altruism $\alpha_{i'}$ is:

$$\begin{aligned}\tilde{u}(\alpha_i, \alpha_{i'}) &= \ln y^H - (1-\kappa p)^2 \ln \rho \\ &+ \kappa p (1-\kappa p)\left[\ln(1 - t^*(\alpha_i)) + \ln(1/\rho + t^*(\alpha_{i'}))\right] \\ &+ \gamma \ln(1-p),\end{aligned} \tag{21}$$

where

$$t^*(\alpha) = \max\left\{0, \frac{\rho\alpha - 1}{\rho\alpha + \rho}\right\}.$$

For the evolutionary robustness analysis, we again let α denote the incumbent degree of altruism, and α'' the mutant degree of altruism. Assuming that $p \in [0,1)$ is the common, exogenously given success probability for incumbents and mutants alike, and following arguments similar to those above, we obtain the following condition for the incumbent degree of altruism α to be evolutionarily robust against a mutant degree $\alpha'' \neq \alpha$:

$$\tilde{u}(\alpha, \alpha) > \frac{1}{2}\left[\tilde{u}(\alpha'', \alpha) + \tilde{u}(\alpha'', \alpha'')\right], \tag{22}$$

Using (21) inequality (22) may be written

$$\begin{aligned}&\ln y^H - (1-\kappa p)^2 \ln \rho + \gamma \ln(1-p) \\ &+ \kappa p(1-\kappa p)\left[\ln(1 - t^*(\alpha)) + \ln(1/\rho + t^*(\alpha))\right] \\ &> \ln y^H - (1-\kappa p)^2 \ln \rho + \gamma \ln(1-p) \\ &+ \frac{1}{2}\kappa p(1-\kappa p)\left[\ln(1 - t^*(\alpha'')) + \ln(1/\rho + t^*(\alpha))\right] \\ &+ \frac{1}{2}\kappa p(1-\kappa p)\left[\ln(1 - t^*(\alpha'')) + \ln(1/\rho + t^*(\alpha''))\right]\end{aligned}$$

which simplifies to

$$\ln(1-t^*(\alpha))+\ln(1/\rho+t^*(\alpha))>\ln(1-t^*(\alpha''))+\frac{1}{2}\ln(1/\rho+t^*(\alpha))+\frac{1}{2}\ln(1/\rho+t^*(\alpha''))$$

or

$$\ln(1-t^*(\alpha))+\frac{1}{2}\ln(1/\rho+t^*(\alpha))>\ln(1-t^*(\alpha''))+\frac{1}{2}\ln(1/\rho+t^*(\alpha'')) \qquad (23)$$

Letting the function $H:[0,1]\times\mathbb{R}\to\mathbb{R}$ be defined by

$$H(\alpha)=\ln(1-t^*(\alpha))+\frac{1}{2}\ln\left(\frac{1}{\rho}+t^*(\alpha)\right),$$

clearly the condition for evolutionary robustness (23) boils down to the inequality $H(\alpha)>H(\alpha'')$. The function H is differentiable, and we now show that it reaches its maximum at $\alpha=1/2$. The necessary first-order condition for an interior maximum is:

$$\frac{dH(\alpha)}{d\alpha}=\left[-\frac{1}{(1-t^*(\alpha))}+\frac{1}{2}\frac{1}{\left(\frac{1}{\rho}+t^*(\alpha)\right)}\right]\frac{dt^*(\alpha)}{d\alpha}=0$$

which, conditionally on $t^*(\alpha)$ being positive (and therefore strictly increasing in α) is equivalent to

$$\begin{aligned}1-t^*(\alpha) &= 2\left(\frac{1}{\rho}+t^*(\alpha)\right)\\ &\Leftrightarrow\ 1-\frac{\rho\alpha-1}{\rho(1+\alpha)}=2\left(\frac{1}{\rho}+\frac{\rho\alpha-1}{\rho(1+\alpha)}\right)\\ &\Leftrightarrow\ 1+\rho=2\alpha(1+\rho)\\ &\Leftrightarrow\ \alpha=\frac{1}{2}.\end{aligned}$$

The second-order derivative is

$$\begin{aligned}\frac{dH^2(\alpha)}{d\alpha^2} &= \left[-\frac{1}{(1-t^*(\alpha))^2}-\frac{1}{2}\frac{1}{\left(\frac{1}{\rho}+t^*(\alpha)\right)^2}\right]\left(\frac{dt^*(\alpha)}{d\alpha}\right)^2\\ &\quad+\left[-\frac{1}{(1-t^*(\alpha))}+\frac{1}{2}\frac{1}{\left(\frac{1}{\rho}+t^*(\alpha)\right)}\right]\frac{dt^{*2}(\alpha)}{d\alpha^2}.\end{aligned}$$

This is strictly negative at $\alpha=1/2$, since the term in the first square brackets is strictly negative, and the term in the second square brackets is equal to zero by virtue of the first-order condition.

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