

1 **Electronic Supplementary Material**

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## 1. Actual and marginal costs and benefits

In our model,  $B$  and  $C$  are the actual benefits and costs exchanged in an interaction. We suppose that the dependence of  $B$  on  $C$  exhibits diminishing returns; that is, for  $B$  both positive and negative, the  $|B/C|$  ratio decreases as  $C$  increases. In each case the actor chooses the desired  $(B, C)$  values based on the information it has about its partner. To check whether a current  $(B, C)$  choice for a particular actor-recipient pair is stable under the action of selection, we look at the fitness of a mutant strategy playing  $(B+b, C+c)$  for small increments  $b$  and  $c$  and these are what the inclusive-fitness increment employs. The ratio  $b/c$  can be approximated by the derivative  $dB/dC$  at the base point  $(B, C)$ . The mutant ratio  $b/c$  is the slope of the tangent line at the point and the actual ratio  $B/C$  is the slope of the secant line drawn from the origin (Fig. 1 of the main text). For any particular interaction, the evolutionary equilibrium is attained at a point at which  $W_{IF} = Rb - c = 0$ , that is, where the slope  $b/c$  is equal to  $1/R$ .

The geometry of the curve can be used to show that such a point must be convergence stable [1]. We make the argument using the upper branch of the curve ( $B > 0$ ). Starting at such a point, if we increase  $B$  and  $C$  (i.e. move up the curve), the  $b/c$  ratio decreases (i.e. diminishing returns) so that  $b/c < 1/R$  and that implies  $Rb < c$  which, in turn, implies  $W_{IF} < 0$ . Thus for a higher value of  $B$  and  $C$ , mutants with positive  $b$  and  $c$  are less fit than residents, and selection moves  $B$  and  $C$  to lower values. A similar argument shows that a decrease in  $B$  and  $C$  favours mutants with positive  $b$  and  $c$ , moving  $B$  and  $C$  to higher values. An analogous argument holds for the lower branch ( $B < 0$ ).

## 2. Generality of Assertions

Our purpose here is to establish (and make precise) the three principal assertions made in the paper: (1) that altruism evolves more easily among migrant than native actors; (2) that spite evolves more easily among native than migrant actors; and (3) that under some circumstances, natives will pay costs that surpass those they spitefully impose on others. We make the standard assumption on the  $B$ - $C$  trade-off curve that the level of both altruism and spite increases with cost but exhibits diminishing returns; in terms of Fig. S1, that the top half of the curve (altruism) is increasing and concave-down and the bottom half of the curve (spite) is decreasing and concave-up. We also assume, as seems reasonable, that buds are relatively small; that is, that  $q < 1/2$ .

For assertions (1) and (2), we compare the behaviour of a migrant and a native actor when they have the same coefficient of consanguinity (CC) with their partners. That is, we compare the behaviour of a migrant actor interacting with a signal  $s$  partner with that of a native actor with a signal  $s'$  partner, where  $G_N(s') = G_M(s)$ . Let  $\rho_I(s)$  be the evolutionarily stable marginal cost-benefit ( $c/b$ ) ratio for a native ( $I = N$ ) or migrant ( $I = M$ ) in an interaction with a partner with signal  $s$ . These are found by inverting eqs. (7) and (8) in the main text. We get:

$$\rho_N(s) = \frac{G_N(s) - (1 - q)}{q} \tag{S1}$$

$$\rho_M(s) = \frac{G_N(s) - q}{1 - q} \quad (\text{S2})$$

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61 Now let  $\tau(s)$  be the solution  $s'$  to the equation  $G_N(s') = G_M(s)$ . We will show that,  
 62 when  $q < 1/2$ ,

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$$\rho_N(\tau(s)) < \rho_M(s). \quad (\text{S3})$$

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65 From (S1)

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$$\begin{aligned} q\rho_N(\tau(s)) &= G_N(\tau(s)) - (1 - q) \\ &= G_M(s) - (1 - q) \\ &= [(1 - q)\rho_M(s) + q] - (1 - q) \\ &= (1 - q)\rho_M(s) - 1 + 2q, \end{aligned}$$

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then

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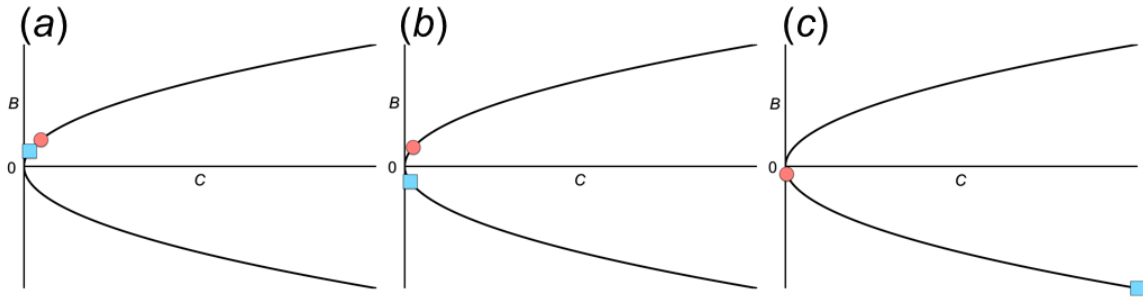
$$\begin{aligned} q[\rho_N(\tau(s)) - \rho_M(s)] &= (1 - q)\rho_M(s) - 1 + 2q - q\rho_M(s) \\ &= (1 - 2q)\rho_M(s) - (1 - 2q) \\ &= (1 - 2q)(\rho_M(s) - 1) \end{aligned}$$

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73 and this is negative for  $q < 1/2$  since  $\rho_M(s)$  is clearly less than 1 from eq. (S2). That  
 74 establishes (S3).

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76 The  $\rho_I(s)$  are the evolutionarily stable  $c/b$  ratios so that their reciprocals are the  $b/c$   
 77 ratios, which interpret as slopes in figure 2a of the main text. For the case of native and  
 78 migrant altruism ( $B > 0$ ,  $C > 0$ ; upper branch of the curve in figure S1a), condition (S3)  
 79 tells us that the slope of the trade-off curve at the native evolutionarily stable strategy  
 80 (ESS) is greater than the slope at the migrant ESS and, since the curve is concave-down,  
 81 this tells us the migrant has the higher ( $B, C$ ) value and thus pays more to give a higher  
 benefit. This supports assertion (1).

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**Figure S1.** Three scenarios for interactions when  $K = 5$ ,  $q = 1/K$  (no budding) and  $G_N(s) = G_M(s)$  along the benefit-cost trade-off curve  $C = B^2$ . Values represent evolutionarily stable  $(B, C)$  pairs for native (blue squares) and migrant actors (red circles) for (a)  $G = 0.9$ , (b)  $G = 0.5$ , and (c)  $G = 0.1$ . The upper branch of each curve represents altruistic behaviour ( $B > 0, C > 0$ ) and the lower branch represents spiteful behaviour ( $B < 0, C > 0$ ). Both types of actor can be altruistic (a), migrants can be altruistic whereas natives can be spiteful (b), or both types can be spiteful (c).

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A second possibility for (S3) would have migrant altruism ( $B > 0, C > 0$ ; upper branch of the curve in figure S1b) and native spite ( $B < 0, C > 0$ ; lower branch in figure S1b), so that the first slope is positive and the second is negative. Observe that we cannot reverse these and have migrant spite and native altruism. This gives support to both assertions (1) and (2).

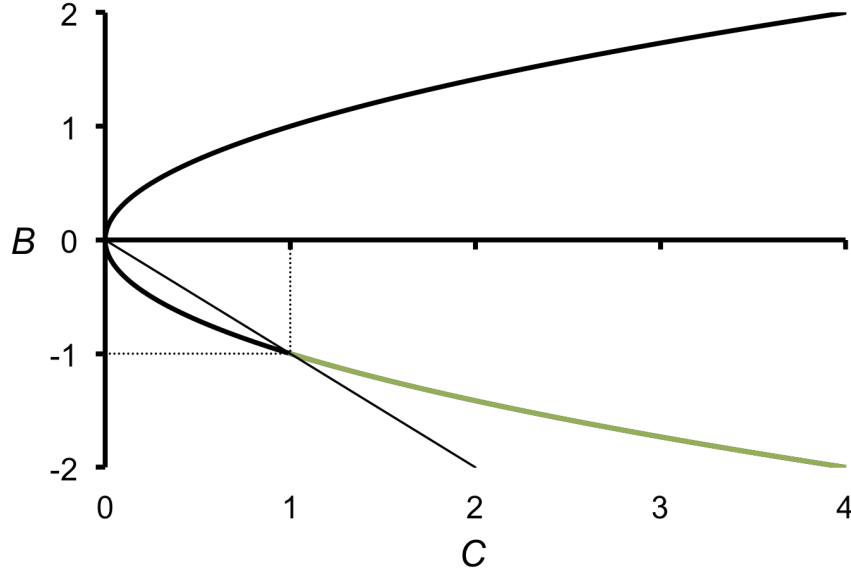
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Third, for the case of native and migrant spite ( $B < 0, C > 0$ ; lower branch of the curve in figure S1c), the  $c/b$  ratios represented by  $\rho_I(s)$  are negative so that the native slope  $b/c$  in (S3) is greater than the migrant slope. For negative slopes, that means that the native slope is less steep than the migrant slope and hence (since the lower branch of the curve is concave-up) the native ESS is the farther from the origin. Thus, the native actor pays a greater cost to exact a greater harm than does the migrant, giving support to assertion (2).

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Finally we look at assertion (3). We need to get hold of the set of signals  $s$  for which a native actor will pay a greater cost  $C$  than the inflicted harm  $-B$ . These are the signals for which  $C > -B$ , which we dub ‘extreme’ spite, and a standard geometric argument will show that since the lower branch of the trade-off curve is concave up, it must eventually cross and lie above the diagonal line  $-B = C$ . The question is whether, for large enough  $s$ , the native  $(B, C)$  point will actually cross that line and enter the section (coloured in green in figure S2) where  $C > -B$ . Well, as  $s$  gets large,  $G_N(s)$  will certainly approach zero, and from eq. (S1), the slope of the curve,  $1/\rho_N(s)$  will approach  $-q/(1-q)$ . In most cases, for reasonably small  $q$ , we can expect this to send the point into the extreme spite zone of the curve, but examples of trade-off curves can be constructed where this will not be the case.

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119 **Figure S2.** The case of ‘extreme’ spite for the benefit-cost trade-off curve  $C = B^2$ . The  
120 diagonal line  $C = -B$  is drawn in black. Beyond this line, along the green portion of the  
121 benefit-cost trade-off curve, actors pay costs that exceed those they impose on recipients  
122 ( $C > -B$ ).  
123

124 However, for the curve  $C = B^2$  we can certainly calculate the  $s$  value at which this will  
125 happen. For this equation:  
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$$127 \quad \rho_N(s) = \frac{c}{b} = \frac{dC}{dB} = 2B \quad (S4)$$

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129 and the condition  $C > -B$  becomes

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$$131 \quad B < -1$$

$$132 \quad \rho_N(s) = 2B < -2 \quad \text{from (S4)}$$

$$133 \quad G_N(s) - (1 - q) < -2q \quad \text{from (S1)}$$

$$134 \quad P_N(s) = G_N(s) < 1 - 3q \quad \text{from eq. (4)}$$

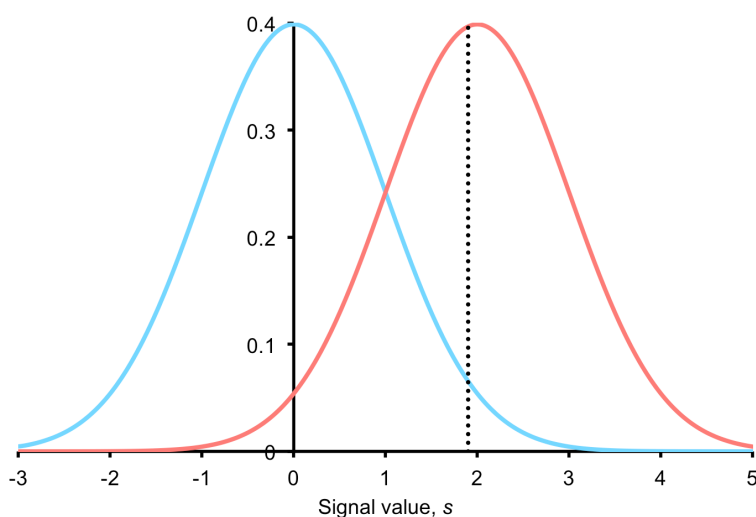
$$135 \quad \frac{P_N(s)}{P_M(s)} = \frac{P_N(s)}{1 - P_N(s)} < \frac{1 - 3q}{1 - (1 - 3q)} = \frac{1 - 3q}{3q} \quad \text{since } P_M(s) = 1 - P_N(s)$$

$$136 \quad \frac{D_N(s)(1 - q)}{D_M(s)q} < \frac{1 - 3q}{3q} \quad \text{from eq. (6)}$$

$$137 \quad \frac{D_N(s)}{D_M(s)} < \frac{1 - 3q}{3(1 - q)} \quad (S5)$$

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Condition (S5) gives us the critical  $s$ -value for what we have called extreme spite, that being the score value  $s^*$  at which the ratio of the density functions  $D_I(s)$  is  $(1-3q)/(3-3q)$ . When a native encounters a partner with a signal  $s > s^*$ , we can expect it to act with extreme spite. Since the critical ratio  $(1-3q)/(3-3q)$  decreases with  $q$ , the critical score  $s^*$  increases with  $q$ , and thus small  $q$  (small relative bud size  $q$  or large deme size  $K$ ) promotes extreme spite. For example, for deme size  $K = 5$  and no budding ( $q = 1/5$ ), the critical ratio is  $2/12 = 1/6$  such that the signal is at least 6 times as likely to belong to a migrant than to a native. This gives a critical score of  $s^* = 1.90$ , as illustrated in the signal distribution drawn in figure S3. This critical  $s$ -value is less than the migrant mean ( $s = 2$ ); that tells us that in more than half of all native-migrant encounters, the native will pay a cost that exceeds the inflicted harm. This supports assertion (3).



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**Figure S3.** Example probability density distribution distributions of native (blue curve) and migrant (red curve) signals. The dashed line marks  $s = 1.90$ ; more than half of all migrants bear a signal above this value.

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Figure 1 of the main text has equation  $C = B^2$  and we use this to provide a numerical example. For this equation,  $dB/dC = 1/2B$  and from this we deduce that  $b/c = B/2C$  so that the secant has twice the slope of the tangent. Suppose the deme has  $K = 10$  breeders and there is no budding ( $q = 1/10$ ) and consider a native actor that knows her partner is a migrant. According to table 1 (‘marginal ESS’) of the main text, she would (as a ‘mutant’) be willing to pay a higher cost if that could increase the harm done to the migrant by as much as one ninth of the cost increase. Thus at equilibrium, the harm done by a native actor to a known migrant should be two ninths of the cost she bears (‘actual ESS’). Conversely the harm done by a migrant actor to a known native would have to be eighteen times the cost sustained by the actor. A native is thus much more likely to inflict harm on a known migrant than a migrant is to inflict harm on a known native.

In figure S4 we use a simulation to compare the behaviour of a native and a migrant actor interacting with partners with signals  $s_N$  and  $s_M$ , respectively, of comparable consanguinity (i.e.  $G_N(s_N) = G_M(s_M)$ ). When faced with partners of the same

171 consanguinity, native actors in this simulation are less altruistic or more spiteful than  
 172 migrant actors and, at high signal values, they evolve to pay costs that surpass those they  
 173 spitefully impose on their partners ( $-B < C$ ,  $B < 0$ ). Conversely, when migrant actors are  
 174 spiteful (at small  $s_M$ ) they always pay smaller costs than those that they impose ( $-B > C$ ,  
 175  $B < 0$ ).

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### 177 3. Ethnicity and Hate Crime

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179 ‘Ethnicity’ can mean many things, but here we use it to mean a phenotypic marker for  
 180 (broad) consanguinity. Thus, we conceive as ‘ethnic’ any cues to recent ancestry,  
 181 language, religion, cultural heritage, or national origin [2]. We searched for literature on  
 182 ethnically motivated ‘hate’ crimes in which both offender and victim ethnicity were  
 183 reported. We found reports published by five sources from which we could glean such  
 184 information: the Los Angeles County Human Relations Commission (for the years 1999  
 185 to 2012, though offender ethnicity data are available only until 2006); the Chicago Police  
 186 Department (for the years 1995, 1997, 2000, 2002, 2004, 2006, 2008, and 2010); the US  
 187 Federal Bureau of Investigation (for the years 1996 to 2012); the Scottish Government  
 188 (for the years 2003 to 2013); and the UK Home Office, Ministry of Justice, and the  
 189 Office of National Statistics (for the year 2012 only; it covers England and Wales and  
 190 provides information on offender but not victim ethnicity) (3). For consistency within and  
 191 across sources, we use victim and offender ‘race’ as our marker of ethnicity.

192 For these five populations, we averaged over the available years the proportion of  
 193 ethnically motivated hate crimes with ethnic minority victims and the proportion of such  
 194 crimes with ethnic majority offenders. These proportions are presented in Table S1,  
 195 alongside the local majority ethnic group (categorized by ‘race’) and the proportion of the  
 196 local population represented by this group (4).

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198 **Table S1.** Ethnic composition by population and by victim-offender status.

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| Region          | Demography         |                         | Ethnically motivated hate crimes |                       |
|-----------------|--------------------|-------------------------|----------------------------------|-----------------------|
|                 | Majority ethnicity | Majority population (%) | Minority victim (%)              | Majority offender (%) |
| Los Angeles     | Latino             | 46.31                   | 79.6                             | 38                    |
| Chicago         | White              | 44                      | 72.83                            | 40.68                 |
| United States   | White              | 80.3                    | 80.75                            | 62.08                 |
| Scotland        | White Scottish     | 86                      | 81.8                             | 82.51                 |
| England & Wales | White British      | 85.5                    | --                               | 80.07                 |

200

201 Table S1 shows that members of the ethnic majority tend more often to be the  
 202 offenders than the victims of ethnically motivated hate crimes whereas the opposite is  
 203 true of members of ethnic minority groups. Indeed, there is a strong correlation between  
 204 the proportion of ethnically motivated hate crimes committed by members of the majority  
 205 ethnic group and the prevalence of this group in the population ( $r = 0.91$ ,  $p = .032$ ). This  
 206 supports the hypotheses that (1) individuals bearing common phenotypes will tend to  
 207 impose more harm on partners of rare phenotypes than the converse and (2) that this  
 208 pattern is magnified by the frequency of individuals bearing the majority phenotype.

209 Of course, members of the majority group will, *a priori*, more likely be involved  
210 in any crime than will members of minority groups, simply because they are more  
211 populous. However, an argument from base rates does not predict that members of the  
212 majority ethnic group would be the *perpetrators* any more than the *victims* of ethnically  
213 motivated hate crimes. On this logic, we should expect that members of both majority  
214 and minority groups are evenly distributed as perpetrators and victims of hate crimes. But  
215 this is clearly not the case: offenders seem to be disproportionately drawn from the  
216 majority ethnic group and their victims from minority groups.

217 Nevertheless, the data from these sources are limited. They rely on different  
218 definitions of hate crime, different pieces of evidence to track victim ethnicity and, with  
219 the exception of Los Angeles, they pertain to European-descent ethnic majority  
220 populations. Thus, a more appropriate test of our predictions awaits better data.

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