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ANALYSIS

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Abstract

A large, but inconclusive, literature addresses how economic heterogeneity affects the use of local resources and local environmental quality. One line of thought, which derives from Nash equilibrium provision of public goods, suggests that in contexts in which individual actions degrade local environmental quality, wealthier people in a community will tend to do more to protect environmental quality. In this paper we report on experiments performed in rural Colombia that were designed to explore the role that economic inequality plays in the 'provision' of local environmental quality. Subjects were asked to decide how much time to devote to collecting firewood from a local forest, which degrades local water quality, and how much to unrelated pursuits. Economic heterogeneity was introduced by varying the private returns to these alternative pursuits. Consistent with the Nash equilibrium prediction, we found that the players with more valuable alternative options put less pressure on local water quality. However, the subjects with less valuable alternative options showed significantly more restraint relative to their pure Nash strategies. Furthermore, they were willing to bear significantly greater opportunity costs to move their groups to outcomes that yielded higher average payoffs and better water quality than the Nash equilibrium outcome.

Keywords: Local environmental quality; Burden-sharing; Economic inequality; Experiments

1. Introduction

Many rural communities in the developing world depend to a large degree on access to local natural resources and on local environmental quality. A large body of literature has emerged that addresses how economic heterogeneity—in-

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equality of wealth, income, or economic opportunity within a community—affects the use of local resources and environmental quality. Taken as a whole, this literature is inconclusive (Varughese and Ostrom, 2001; Bardhan and Dayton-Johnson, 2002). One line of thought, however, originates with Olson's (Olson, 1965) well-known hypothesis that wealthier people in a group will tend to take on a larger share of providing a public good than their poorer counterparts. Refining Olson's hypothesis, Bergstrom et al. (1986) suggested that this effect is enhanced by greater income inequality.[1] These results suggest the hypothesis that in contexts in which individual actions degrade local environmental quality, the wealthier members of the community will do more to protect local environmental resources than their poorer neighbors because they will limit their damaging actions to a greater extent. Greater inequality suggests a further shift of the burden of environmental protection to the wealthier members of a community.[2]

The theoretical predictions of how income inequality affects the provision of public goods are generated from models of Nash non-cooperative behavior; that is, using the standard assumption of purely self-interested strategic behavior. However, we know from a wealth of experimental literature that subjects in experiments involving public goods do not typically play purely self-interested strategies.[3] Rather, they make choices that seem to balance pure self-interests against group interests. Consequently, groups of individuals in public good environments tend to achieve more efficient outcomes than Nash equilibrium outcomes.

In this paper we report on experiments we designed to explore the role that economic inequality plays in the 'provision' of local environmental quality in the developing world. Rather than test Nash equilibrium predictions about how economic inequality affects local environmental quality, we explore burden sharing in achieving better-than-Nash equilibrium outcomes. Specifically, we ask the question of whether the richer members of a community do more than their poorer neighbors to help the community escape the adverse welfare and environmental effects of purely self-interested strategic behavior, or whether it is the other way around.

Our experiments were performed in three rural areas of Colombia. The areas were chosen because villagers in each region have significant interests in local natural resources and environmental quality. In fact, the experiments were designed to approximate an environmental quality problem that rural villagers in developing countries are likely to face. Subjects were asked to decide how much time to devote to collecting firewood from a local forest, and how much to devote to an alternative market pursuit such as wage labor or farming one's own land. Time spent collecting firewood has adverse environmental consequences because it leads to soil erosion and worsened local water quality due to increased sedimentation. The public goods aspect of the problem is that individual restraint in firewood collection improves water quality, which is a benefit shared by all in the community.[4]

[1] They also show that an income redistribution from poorer individuals to wealthier individuals will lead to increased provision of a public good if the redistribution leads more of the poorer members of a community to choose to freeride completely on the contributions of their richer neighbors. Experimental tests of this hypothesis by Chan et al. (1996) offer some support. On the other hand, Bergstrom, Blume and Varian predicted that a small redistribution of income—small enough so that the set of contributors to a public good is not changed—would not affect aggregate contributions. Chan et al. (1999) test and reject this hypothesis.

[2] Sandler (1992) notes that the link between income inequality and the provision of a public good proposed by Olson and Bergstrom, Blume and Varian is sensitive to assumptions about preferences for the public good, the technology that characterizes provision of the good, and the exact form of strategic interaction.

[3] For a review of this literature, see Ledyard (1995).

[4] While we chose to place our subjects in a public good environment, many local resource dilemmas in the developing world are better characterized as common pool resource problems. Since public good models are structurally different from common pool models, one should be cautious about using our results about burden-sharing in the provision of local environmental quality to draw conclusions about local use of a common pool resource. Further research that extends our approach to examine burden-sharing in the exploitation of common pool resources will likely yield valuable insights.

While subjects faced symmetric private returns from time spent collecting firewood and symmetric shared costs from water quality degradation, economic heterogeneity was introduced by varying the private returns to the alternative market pursuit.[5] Two treatments of the experiment were administered—one in which the subjects faced different returns in the market, and the other in which subjects faced symmetric returns to this alternative. The model that we used to generate the payoffs for the experiments was constructed so that average returns to the market alternative (per unit of effort) are the same in both the symmetric and asymmetric treatments. More importantly, the Nash equilibria of the two treatments yield the same aggregate amount of time spent collecting firewood, and hence, local water quality. However, individual Nash equilibrium choices differ in the two treatments. Consistent with the prediction of Olson and Bergstrom, Blume and Varian, individual equilibrium choices in the symmetric treatment are also symmetric, but in the equilibrium of the asymmetric game, the high-wage players—those with more valuable alternative market options—are predicted to show more restraint in exploiting the local forest, thereby doing more to protect local water quality than their less advantaged neighbors.[6]

Each group of subjects played a number of rounds of the game without being able to communicate with others in their group, and then continued to play additional rounds in which they were allowed to engage in non-binding and non-threatening communication between rounds. Allowing subjects to communicate with each other was motivated by the fact that many local environmental and natural resource dilemmas are addressed through cooperative efforts by local residents (Ostrom, 2000). Moreover, an overwhelming amount of experimental evidence suggests that face-to-face communication is effective in enhancing cooperation in experiments of this type (Hackett et al., 1994; Ostrom et al., 1994; Ledyard, 1995).

The results of our experiments yield intriguing insights about burden-sharing in the provision of local environmental quality. As predicted by the equilibrium of our asymmetric game, the high-wage players spent less time harvesting firewood than their poorer counterparts, thereby putting less pressure on local water quality. As expected, however, the subjects did not choose pure Nash strategies. Across the board the groups achieved outcomes with higher average payoffs and better water quality than the equilibrium predictions, thereby setting the stage for exploring burden-sharing in achieving these more efficient outcomes. Our results from this exploration are unequivocal. By calculating the differences between individuals' actual choices and their Nash best-responses, we found that although the high-wage players put less pressure on local environmental quality, their choices ultimately were quite close to their Nash best-responses. On the other hand, the low-wage players showed significantly more restraint relative to their Nash best-responses. Thus, the restraint necessary for these groups to achieve better-than-Nash equilibrium outcomes came largely from the low-wage subjects. Furthermore, by calculating individuals' foregone payoffs from *not* playing pure Nash strategies, we found that the low-wage players were, on average, willing to bear significantly greater opportunity costs than their richer counterparts to help their groups achieve better-than-Nash equilibrium outcomes.

Face-to-face communication only enhanced the willingness of the low-wage subjects to bear the costs of moving their groups to more efficient outcomes. In fact, this was the main effect of communication, since through these rounds of the

[5] In real settings, these returns may vary for a number of reasons, including unequal land ownership, access to credit, or differences in education levels. Of course, there are other dimensions of economic inequality. The typical public goods model would focus on differences in exogenous income (Bergstrom et al., 1986; Chan et al., 1996, 1999). Others have focused on asset inequality (Bardhan and Dayton-Johnson, 2002). For a set of common pool experiments, Hackett et al. (1994) vary the exogenous endowment of an input across individuals. Whether our results will hold along other dimensions of economic inequality is a question for future research.

[6] One should be clear that we are not proposing this result as a general statement about Nash equilibrium provision of environmental quality in the developing world, only that it is consistent with one line of thought in the literature.

experiment the high-wage subjects stuck close to their Nash best-responses. Not surprisingly, these groups fared much better when they were allowed to communicate between rounds than when they were not.

Not only do our results suggest that economic asymmetry plays an important role in the manner in which groups share the burden of achieving better-than-Nash equilibrium outcomes, they also suggest that heterogeneity may have an important role in determining aggregate outcomes that go unrecognized in models of purely self-interested provision of a public good. Even though aggregate levels of exploitation of the local forests were predicted to be the same for both treatments, the groups with unequal market wages put significantly less pressure on local environmental quality than the groups with symmetric market returns. While the subjects in our symmetric treatment also did not choose pure Nash strategies, and achieved better outcomes in doing so, on average they did not assume as large a burden of moving their groups to more efficient outcomes as the low-wage subjects in the asymmetric treatment did for their groups. Consequently, the heterogeneous groups consistently enjoyed higher levels of environmental quality than their homogeneous counterparts.

2. Experimental design

As noted in the introduction, we designed our experiments to confront our subjects with a local environmental quality problem that would closely mimic their actual experiences. Toward that end, our field experiments were undertaken in three rural areas in Colombia where villagers have significant interests in local natural resources and environmental quality. Payoffs for the games were generated from a model of individual efforts to collect firewood from local forests. Higher levels of effort devoted to firewood extraction leads to greater erosion and sedimentation of local water supplies; thus, restraint in harvesting firewood from local forests generates the pure public good of better water quality.

2.1. The payoffs

A simple model of a fixed number of individuals who exploit a local forest for firewood generated the payoffs for our experiments. In each round of the games, each individual was given an endowment of time e, of which all or part could be allocated to collecting firewood. Let x_i denote the amount of time individual i spends collecting firewood. This effort yields a private benefit, which we assume takes the quadratic form $g(x_i) = \gamma x_i - \phi(x_i)^2/2$, where γ and ϕ are strictly positive and are chosen in part to guarantee $g(x_i) > 0$, for $x_i \in [1, e]$. The strict concavity of $g(x_i)$ indicates diminishing marginal private returns to time spent collecting firewood.

Alternatively, the individual could allocate his or her labor to an alternative market pursuit such as wage labor or farming one's land. Let w_i denote the individual's return to time devoted to the market alternative. Henceforth, we refer to this return as the market wage. In one experimental treatment this wage will vary among individuals in a group, while in the other treatment all individuals in a group will face the same market wage. Note that i's decision to provide $(e - x_i)$ units of labor to the market alternative yields a payoff of $w_i \times (e - x_i)$.

Subjects were told explicitly that their decision to spend time extracting firewood would affect water quality in the area adversely. We assumed that water quality q is a quadratic function of the aggregate amount of time individuals in the community spend collecting firewood; specifically, $q(\Sigma x_j) = q^0 - (\Sigma x_j)^2/2$, where q^0 is interpreted to be water quality in the absence of firewood extraction. The value of q^0 was chosen, in part, to guarantee $q(\Sigma x_j) > 0$ for all feasible Σx_j.

Define $u_i(x_i, \Sigma x_j) = q(\Sigma x_j) + g(x_i) + w_i \times (e - x_i)$. Parameters were chosen, in part, to guarantee that $u_i(x_i, \Sigma x_j) > 0$ for all possible x_i and Σx_j. To facilitate scaling individual payoffs, we take an individual's payoff function to be a positive, monotonic transformation F of u. In particular, $F(u_i) = k \times (u_i)^\eta$, where k and η are positive constants. An individual's payoff function is then,

$$U_i(x_i, \sum x_j) = k \times [f(\sum x_j) + g(x_i) + w \times (e - x_i)]^\eta$$

$$= k \times \left[\left(q^0 - \frac{(\sum x_j)^2}{2} \right) + \left(\gamma x_i - \frac{\phi (x_i)^2}{2} \right) + w_i \times (e - x_i) \right]^\eta . \quad (1)$$

Each group consisted of $n = 8$ subjects, and each subject was allocated $e = 8$ units of time in each round. Pre-testing of the experimental designs at the University of Massachusetts-Amherst and the Humboldt Institute for Biodiversity in Villa de Leyva, Colombia, led us to denominate units of time as months per year. Scale concerns led us to choose the following remaining parameter values: $k = 4/16\,810$, $q^0 = 1372.8$, $\gamma = 97.2$; $\phi = 3.2$, and $\eta = 2$. Therefore:

$$U_i(x_i, \sum x_j) = \left(\frac{4}{16810} \right) \left[1372.8 - \frac{(\sum x_j)^2}{2} + 97.2 x_i - \frac{3.2 (x_i)^2}{2} + w_i \times (8 - x_i) \right]^2 . \quad (2)$$

By varying the market wage rate, we generated two treatments of the experiment. For the baseline case we assumed that $w_i = 30$ for each of the eight individuals in a symmetric-wage group. For the other treatment we assigned a lower market wage, $w_i = 20$, to six members of a asymmetric-wage group, and a higher wage, $w_i = 60$, for the other two members. Note that average market wages are the same for the symmetric-wage and asymmetric-wage groups.

Subjects were given a table of payoffs generated by Eq. (2). Table 1 is a slightly shortened version of the payoff table given to each of the subjects in the symmetric market wage treatment (the bottom seven rows are deleted here to conserve space. The shaded cells indicate an individual's pure Nash strategy. The subjects received complete tables without the shading). Tables 2 and 3 are shortened versions of the payoff tables given to the high-wage and low-wage subjects, respectively, in the asymmetric-wage treatment.

2.2. Nash strategies and the balance between self-interested and group-oriented behavior

The treatments were designed to generate the same aggregate amount of time devoted to firewood harvesting in the two Nash equilibria, although individual equilibrium choices would be different. The Nash equilibrium of the symmetric market wage game is for each of the eight players to spend 6 months collecting firewood. In this equilibrium, each subject receives 155 points. In the equilibrium of the asymmetric market wage game, the high-wage subjects are predicted to spend no time collecting firewood, choosing instead to devote all of their time to the alternative market pursuit. On the other hand, the low-wage subjects are predicted to devote all of their endowment of 8 months to collecting firewood.[7] Consistent with the predictions of Olson (1965) and Bergstrom et al. (1986), in the asymmetric-

[7] One may verify that these choices constitute Nash equilibria from the payoff tables. Recall that in a Nash equilibrium each player's choice has to be a best-response to all the other players' choices. Consider first the symmetric market wage treatment in which each player is predicted to spend 6 months collecting firewood. From Table 1, if each of seven of the eight players chooses 6 months for a total of 42, then the best-response of the eighth player is to choose 6 months. Now consider the equilibrium of the asymmetric-wage treatment in which the high wage players choose to spend no time collecting firewood, while each of the low-wage players devote all of their 8 months to collecting firewood. Using Table 2—the payoffs for a high-wage player in this treatment—note that in the proposed equilibrium the choices of all low-wage players and the other high-wage player sum to 48 months. A high-wage player's best-response is, therefore, to spend no time collecting firewood. For a low-wage player, the sum of the other players' choices in the proposed equilibrium is 40 months. From Table 3, a low-wage player's best-response is to spend 8 months collecting firewood.

Table 1
Individual payoffs and Nash responses for symmetric-wage subjects

MY MONTHS IN THE FOREST

THEIR MONTHS IN THE FOREST	0	1	2	3	4	5	6	7	8	
0	619	670	719	767	813	856	896	933	967	**0**
1	619	669	717	764	809	851	890	926	959	**1**
2	617	667	714	760	804	845	883	918	950	**2**
3	615	664	711	756	798	838	875	909	940	**3**
4	613	660	706	750	792	831	867	900	929	**4**
5	609	656	701	744	784	822	857	889	917	**5**
6	605	651	695	737	776	813	847	877	905	**6**
7	600	645	688	729	767	803	836	865	891	**7**
8	595	638	680	720	757	792	824	852	877	**8**
9	588	631	672	711	747	780	811	838	862	**9**
10	581	623	663	700	735	768	797	823	846	**10**
11	573	614	653	689	723	755	783	808	830	**11**
12	565	605	642	678	711	741	768	792	813	**12**
13	556	594	631	665	697	726	752	775	795	**13**
14	546	583	619	652	683	711	736	758	776	**14**
15	536	572	606	638	668	695	719	739	757	**15**
16	525	560	593	624	653	678	701	721	737	**16**
17	513	547	579	609	636	661	683	701	717	**17**
18	501	534	565	594	620	643	664	681	696	**18**
19	488	520	550	578	603	625	645	661	674	**19**
20	475	506	535	561	585	606	625	640	653	**20**
21	461	491	519	544	567	587	605	619	630	**21**
22	447	476	502	527	548	567	584	597	608	**22**
23	433	460	485	509	529	547	563	575	585	**23**
24	418	444	468	490	510	527	541	553	561	**24**
25	402	428	451	472	490	506	520	530	538	**25**
26	387	411	433	453	470	485	498	507	514	**26**
27	371	394	415	434	450	464	476	484	490	**27**
28	355	377	396	414	430	443	453	461	466	**28**
29	338	359	378	395	409	421	431	438	442	**29**
30	322	341	359	375	389	400	409	415	418	**30**
31	305	324	341	355	368	378	386	392	394	**31**
32	288	306	322	336	347	357	364	368	371	**32**
33	272	288	303	316	327	335	341	345	347	**33**
34	255	270	284	296	306	314	319	323	324	**34**
35	238	253	266	277	286	293	297	300	300	**35**
36	221	235	247	257	265	272	276	278	278	**36**
37	205	218	229	238	245	251	254	256	255	**37**
38	189	200	211	219	226	231	233	234	233	**38**
39	173	184	193	201	206	211	213	213	212	**39**
40	157	167	175	182	188	191	193	193	191	**40**
41	142	151	159	165	169	172	174	173	171	**41**
42	127	135	142	148	152	154	155	154	152	**42**
43	113	120	126	131	134	136	137	136	133	**43**
44	99	106	111	115	118	119	119	118	115	**44**
45	86	92	96	100	102	103	103	101	99	**45**
46	73	78	82	86	87	88	88	86	83	**46**
47	61	66	69	72	73	74	73	71	68	**47**
48	51	54	57	59	60	61	60	58	55	**48**
49	40	44	46	48	49	48	47	45	43	**49**

Table 2
Individual payoffs and Nash responses for high-wage subjects in asymmetric-wage treatment

THEIR MONTHS IN THE FOREST	MY MONTHS IN THE FOREST: 0	1	2	3	4	5	6	7	8	H
0	817	848	876	901	922	939	952	962	**967**	0
1	816	847	874	897	917	934	946	954	**959**	1
2	815	845	871	893	912	928	939	946	**950**	2
3	813	841	867	888	906	920	931	937	**940**	3
4	810	837	862	882	899	913	922	928	**929**	4
5	806	832	856	875	891	904	912	**917**	**917**	5
6	801	827	849	868	883	894	901	**905**	**905**	6
7	795	820	841	859	873	883	890	**893**	891	7
8	789	813	833	850	863	872	878	**879**	877	8
9	782	804	823	839	851	860	864	**865**	862	9
10	773	795	813	828	839	847	**850**	**850**	846	10
11	764	785	802	816	826	833	**836**	835	830	11
12	755	774	791	803	813	818	**820**	818	813	12
13	744	763	778	790	798	803	**804**	801	795	13
14	733	750	765	776	783	**787**	**787**	783	776	14
15	721	737	751	761	767	**770**	769	765	757	15
16	708	724	736	745	751	**752**	751	746	737	16
17	694	709	721	729	733	**734**	732	726	717	17
18	680	694	705	712	715	**716**	713	706	696	18
19	665	678	688	694	**697**	696	692	685	674	19
20	650	662	671	676	**678**	677	672	664	653	20
21	634	645	653	657	**658**	656	651	642	630	21
22	617	627	634	**638**	**638**	636	629	620	608	22
23	600	609	615	**618**	**618**	614	608	598	585	23
24	583	591	596	**598**	597	593	585	575	561	24
25	565	572	576	**578**	576	571	563	552	538	25
26	546	553	556	**557**	554	549	540	528	514	26
27	527	533	**536**	535	532	526	517	505	490	27
28	508	513	**515**	514	510	503	494	481	466	28
29	488	492	**494**	492	488	480	470	458	442	29
30	468	**472**	**472**	470	465	457	447	434	418	30
31	448	**451**	**451**	448	442	434	423	410	394	31
32	428	**430**	429	426	420	411	400	386	371	32
33	407	**409**	407	403	397	388	377	363	347	33
34	**387**	**387**	385	381	374	365	353	339	324	34
35	**366**	**366**	364	359	352	342	330	316	300	35
36	**345**	**345**	342	337	329	319	307	293	278	36
37	**325**	324	320	315	307	297	285	271	255	37
38	**304**	303	299	293	285	275	263	249	233	38
39	**284**	282	278	271	263	253	241	227	212	39
40	**264**	261	257	250	242	231	219	206	191	40
41	**244**	241	236	229	221	211	199	185	171	41
42	**224**	221	216	209	201	190	179	166	152	42
43	**205**	202	196	189	181	171	159	147	133	43
44	**186**	183	177	170	162	152	140	128	115	44
45	**168**	164	159	152	143	133	123	111	99	45
46	**150**	146	141	134	125	116	106	95	83	46
47	**133**	129	123	117	109	100	90	79	68	47
48	**117**	113	107	100	93	84	75	65	55	48
49	**101**	97	92	85	78	70	61	52	43	49

Table 3
Individual payoffs and Nash responses for low-wage subjects in asymmetric-wage treatment

MY MONTHS IN THE FOREST

THEIR MONTHS IN THE FOREST	0	1	2	3	4	5	6	7	8	L
0	559	615	671	725	778	829	878	924	967	**0**
1	559	614	669	722	774	824	872	917	959	**1**
2	558	612	666	718	769	818	865	909	950	**2**
3	556	609	662	714	764	812	857	900	940	**3**
4	553	606	658	708	757	804	849	890	929	**4**
5	550	602	653	702	750	796	839	880	917	**5**
6	546	597	647	695	742	787	829	868	905	**6**
7	541	591	640	688	733	777	818	856	891	**7**
8	536	585	633	679	724	766	806	843	877	**8**
9	530	578	625	670	713	755	793	829	862	**9**
10	523	570	616	660	702	742	780	815	846	**10**
11	516	562	606	649	691	729	766	799	830	**11**
12	508	553	596	638	678	716	751	783	813	**12**
13	499	543	585	626	665	701	735	767	795	**13**
14	490	532	574	613	651	686	719	749	776	**14**
15	480	521	562	600	636	671	702	731	757	**15**
16	470	510	549	586	621	654	685	712	737	**16**
17	459	498	536	572	606	638	667	693	717	**17**
18	447	485	522	557	590	620	648	673	696	**18**
19	435	472	507	541	573	602	629	653	674	**19**
20	423	458	493	525	556	584	609	632	653	**20**
21	410	444	477	509	538	565	589	611	630	**21**
22	396	430	462	492	520	546	569	590	608	**22**
23	383	415	446	474	501	526	548	568	585	**23**
24	369	400	429	457	483	506	527	546	561	**24**
25	354	384	412	439	463	486	506	523	538	**25**
26	340	368	395	421	444	465	484	501	514	**26**
27	325	352	378	402	424	445	462	478	490	**27**
28	310	336	360	383	405	424	440	455	466	**28**
29	294	319	343	365	385	403	418	432	442	**29**
30	279	303	325	346	365	382	396	409	418	**30**
31	263	286	307	327	345	360	374	385	394	**31**
32	248	269	289	308	325	339	352	363	371	**32**
33	232	253	272	289	305	318	330	340	347	**33**
34	217	236	254	270	285	298	308	317	324	**34**
35	202	219	236	251	265	277	287	295	300	**35**
36	186	203	219	233	246	257	266	273	278	**36**
37	171	187	202	215	226	236	245	251	255	**37**
38	156	171	185	197	208	217	224	230	233	**38**
39	142	156	168	179	189	197	204	209	212	**39**
40	128	140	152	162	171	179	184	189	191	**40**
41	114	126	136	146	154	160	165	169	171	**41**
42	101	111	121	129	137	143	147	150	152	**42**
43	88	98	106	114	120	126	130	132	133	**43**
44	76	84	92	99	105	109	113	115	115	**44**
45	64	72	79	85	90	94	97	98	99	**45**
46	54	60	67	72	76	80	82	83	83	**46**
47	44	50	55	59	63	66	68	69	68	**47**
48	35	40	44	48	51	54	55	55	54	**48**
49	26	31	34	38	40	42	43	43	42	**49**

wage treatment the high-wage subjects are expected to take on a disproportionate burden of protecting local water quality. In this asymmetric equilibrium, low-wage subjects receive 191 points, while the high-wage subjects receive only 117 points. In both the symmetric and asymmetric-wage treatments, aggregate equilibrium time spent collecting firewood is 48 months.[8]

Although Nash equilibrium choices are a standard benchmark for games of this type, we are more interested in analyzing off-equilibrium choices and comparing these to individuals' pure Nash strategies; that is, their payoff-maximizing choices, given the choices of others in their group. In fact, we take the difference between an individual's Nash best-response to the choices of the other subjects in his or her group and his or her actual choices to be an indicator of how that person balances self-interests against the interests of the entire group.

To illustrate our approach, consider the payoffs for an individual in our symmetric-wage treatment provided in Table 1. Recall that each experiment involved eight participants. Suppose that each of seven players chooses to spend 2 months collecting firewood from local forests. Since these subjects are choosing to spend 14 months in total collecting firewood, Table 1 indicates that the eighth player's Nash best-response is to spend 8 months collecting firewood. This choice is made purely out of self-interest without regard for the welfare of the others in the group. Note that player eight's payoff in this outcome is 776 points, while each of the other seven receive 535 points (each player chooses 2 months, while the sum of the others' choices is 20 months).

Now imagine that the eighth player chooses 3 months instead of 8, while the other seven subjects continue to choose 2 months. This is a significantly more group-oriented choice—it is costly because the eighth player's payoff is now 652 points instead of 776; however, each of the other players' payoffs increase from 535 points to 606 (each continues to choose 2 months, but the sum of the others' choices is now 15 months). With a choice of 3 months instead of 8, the eighth player bears a personal opportunity cost of 124 points to increase the payoffs to the others in the group by 497 points! Much of our analysis of the experimental data in the next section is based upon the differences between the subjects' actual choices and their Nash best-responses: choices that are close to Nash responses indicate relatively self-interested behavior, while those that are further away indicate stronger group-regarding behavior.

2.3. The subjects and experiments

As noted before, we intended our experiments to confront subjects with an environmental problem that closely mimicked their actual experiences. Our field experiments were undertaken in three rural areas in Colombia. In the village of Encino, located in the eastern Andean region, residents extract firewood and log timber on a small scale in local tropical cloud forests. Water for consumption and irrigation comes nearly untreated from local rivers. Of the three areas that we visited, the relationship between forest cover and water quality is most critical in Encino, and the residents of this village are acutely aware of the problem. Water quality degradation caused by forest cover losses is less severe in the villages of Circasia and Filandia in the Quindio coffee region in the mid-Andes, but nevertheless is a significant problem. In Quindio, subjects for our experiments were drawn specifically from a group of families whose livelihood is related to the extraction and processing of natural fibers from local forests. As in Encino, water is drawn from local rivers, and residents are aware that extracting forest products

[8] The other common benchmark for games of this type is the welfare maximizing outcomes. Although this benchmark is not very useful for our purposes, it is interesting to note how poorly the subjects fare in the Nash equilibria, relative to what is possible. It is easy to show that in the efficient outcome of the symmetric-wage game, each player would choose to spend only 1 month harvesting firewood and would receive a payoff of 645 points. This is more than four times greater than the Nash equilibrium payoffs. Efficiency in the asymmetric-wage treatment would require the high-wage players to forego spending time collecting firewood, and the low-wage players to spend only 1 month collecting firewood. In this outcome the high-wage players would receive 801 points, about 6.8 time greater than their Nash equilibrium payoffs, and the low-wage players would receive 602 points, or just over three times their Nash payoffs.

can lead to lower water quality. In Nuqui, located on the Pacific coast, villagers harvest coastal mangroves for firewood and other wood products, but their water comes from further inland; hence, they do not experience a direct link between their exploitation of local sources of wood and water quality. However, they face a similar dilemma because their exploitation of the mangroves for wood adversely affects coastal fish populations upon which also they depend.

In total, 120 subjects participated in the experiments. The subjects were distributed into 15 groups, 10 of which played the symmetric-wage treatment, and five the asymmetric-wage treatment. In the case of the asymmetric-wage treatment, the assignment of high-wage and low-wage payoff tables was done randomly. In each of the three settings, the participants generally knew each other well, having lived in the same village for most of their lives (we avoided having close relatives in the same group). Schooling, age and income levels varied significantly within each group. Most participants had fewer than 6 years of schooling, roughly half were between 30 and 50 years old, and all were 16 or older.

Each session of the experiment involved eight subjects and two monitors. The subjects sat at individual desks that were distributed in a circle with enough separation between the desks so they could not look at another's work. Except in periods when communication was allowed, the desks faced away from the center of the circle. In each round, each subject would choose how many units of time, between zero and eight, to spend collecting firewood. Subjects were given a payoff table and large posters of these tables were placed on a wall of the 'field lab'. In the symmetric-wage treatment, individuals knew that the other participants consulted the same table. In the asymmetric-wage treatment, individuals knew how many high-wage and low-wage players there were, but not which individuals, other than themselves, were low-wage and high-wage players. Although individuals could not know in advance the decisions of others, they knew the payoffs upon which their decisions were based. Once a subject made a decision for a particular round, this decision was written on a slip of paper in private. When all subjects had made their decisions, a monitor collected each slip of paper and gave them to another monitor who recorded the decisions and calculated the total for the group. This total was announced to the subjects, who then determined their own payoffs from their payoff tables. Subjects kept a record of their own payoffs as a check on the monitor's record.

Each session began with welcoming remarks within which the subjects were told that the session would last approximately 2 hours. A monitor then read the instructions to the participants (the instructions are available from the authors). Results from pre-tests of the experiment led us to decide not to give the subjects written instructions because of the wide variation in levels of literacy. The instructions explained the basic setting of the game, how points were earned, how these points were converted to cash at the end of the session, and the procedures of the game. The instructions included three different examples to familiarize the subjects with the payoffs and the procedures. Two practice rounds were conducted. The monitor asked for questions at several points, and when there were no further questions the game began with round 1. In addition to posters of the payoff tables, large posters of the forms the subjects used during the game and the examples from the instructions were placed on one wall of the 'field lab'.

Each of the 15 groups played 8–11 initial rounds of the game without being allowed to communicate with the others in their group or with the monitors. The subjects were not told how many rounds would be played in the initial stage, or that the rules for communication would be changed at some point. After the initial rounds the monitors stopped the game and announced a new set of rules for the forthcoming rounds. A monitor read from a new poster, which was subsequently placed on the wall, announcing that from now on the individuals in a group would be allowed 5 minutes of discussion between rounds. Their discussions could be about anything, but they could not threaten each other or agree to transfers of cash or points after the session. Between rounds the subjects turned their desks to face each other. Once 5 minutes elapsed, the subjects were required to turn their desks back around to make their decisions in private. The groups played in this way for another 9–12 rounds, again without knowing when the final round would be.

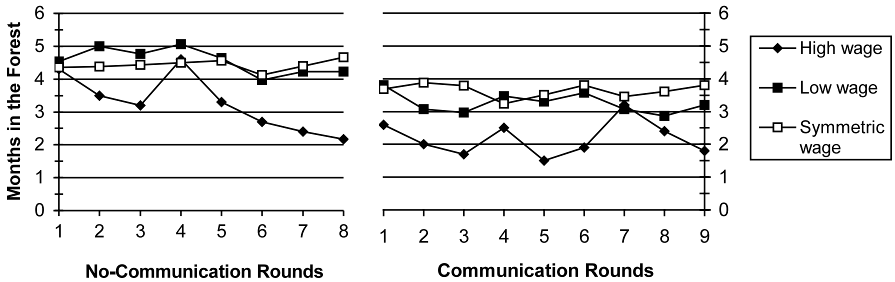

Fig. 1. Average months harvesting firewood.

At the end of each session, total points for each individual were calculated, and they were paid that number in pesos for their participation. Each individual also received a gift (a common household item such as a lamp, table set, machete, etc.) for participation, which was not related to their play during the experiments. For the villages in which the experiments were conducted, a daily minimum wage centered around 7000 pesos (about US $5.40 at the time). The average payoff (including payoffs for practice rounds) was, as planned, about 1.5 days of work at the local minimum wage.

3. Results

We begin the analysis of the experimental data by considering average choices of time spent harvesting firewood. Fig. 1 and the first block of rows in Table 4 summarize these decisions. As indicated earlier, we ended the first and second stages at different points so that the subjects could not anticipate the terminal rounds. All groups played 8–11 rounds in the first stage, within which they were not able to communicate with each other. We, therefore, consider only the first eight rounds of first-stage decisions for each group. All groups played nine rounds in the second stage in which they were allowed to communicate with each other between rounds, and some a few more; therefore, we consider only the first nine rounds of second-stage decisions for each group.

Let us focus first on the high-wage and low-wage players' choices in the asymmetric payoff treatment. After the initial round in which average choices for both types of players were between 4 and 5 months harvesting firewood, there is a large separation of average time spent harvesting firewood. As predicted, the high-wage players spent less time harvesting firewood than the low-wage players. In the first three rounds of the no-communication stage the average choice of the high-wage players was 3.667, while for the low-wage players the average was 4.767. This difference is statistically significant (P-value = 0.040 from the Wilcoxon–Mann–Whitney rank sum test—this test is used for comparing means throughout the analysis). Both types of subjects reduced their amounts of time collecting firewood as the experiment proceeded through the no-communication stage. The high-wage subjects reduced their average time collecting firewood from 3.667 in the first three rounds of the no-communication stage to 2.462 in the last three rounds (P-value = 0.084), while the low-wage subjects reduced their average time in the forest from 4.767 in the first three rounds to 4.128 in the last three rounds (P-value = 0.035). Notice that high-wage players continued to exploit the local forest to a lesser degree than low-wage players in the last three rounds of the first stage. The difference between their average choices, 2.462 for the high-wage subjects as compared with 4.767 for the low-wage subjects, remained statistically significant (P-value = 0.004).

As expected, the players put significantly less pressure on local environmental quality when they were allowed to communicate between rounds in the second stage. However, the main effect of communication was to induce the low-wage players to reduce their harvesting of firewood. From

Table 4
Summary data

	No-communication rounds		Communication rounds	
	Rounds 1–3	Rounds 6–8	Rounds 1–3	Rounds 7–9
Months in the forest				
Asymmetric payoffs				
High wage	3.667	2.462	2.100	2.467
Low wage	4.767	4.128	3.278	3.044
Combined	4.492	3.712	2.983	2.900
Symmetric payoffs	4.388	4.388	3.783	3.616
Earnings				
Asymmetric payoffs				
High wage	$406.63	$522.08	$618.80	$634.37
Low wage	$347.71	$447.86	$503.44	$498.39
Combined	$362.44	$466.41	$532.28	$532.38
Symmetric Payoffs	$368.17	$371.41	$444.47	$460.14
Deviations from best-responses				
Asymmetric payoffs				
High wage	−2.300	−0.192	1.467	1.400
Low wage	3.233	3.872	4.722	4.956
Symmetric payoffs	3.146	3.224	3.975	4.223
Opportunity costs of non-Nash choices				
Asymmetric payoffs				
High wage	$18.57	$6.85	$16.30	$18.10
Low wage	$44.68	$74.42	$125.76	$138.99
Symmetric payoffs	$35.61	$33.49	$58.00	$65.50

the last three rounds of the no-communication stage into the first three rounds of the communication stage, the low-wage players reduced their average time spent harvesting firewood from 4.128 to 3.278 (P-value = 0.035) and a bit further to 3.044 for the last three rounds of the communication stage. On the other hand, the high-wage players reduced their time spent harvesting firewood only slightly from 2.462 in the last three rounds of the no-communication stage to 2.100 in the first three rounds of the communication stage. This difference is both small and statistically insignificant (P-value = 0.492). In the last three rounds of the communication stage, the high-wage players' average choices edged back up to the same level as their average choices in the last three rounds in the no-communication stage.

As the asymmetric-wage subjects reduced their time spent harvesting firewood, their average earnings improved. The second block of rows of Table 4 indicates that in the no-communication stage the average earnings of the high-wage subjects rose from about $407 in the first three rounds to about $522 in the last three rounds (P-value = 0.005), while the earnings of the low-wage subjects rose from about $348 to about $448 ($P$-value = 0.000). This continued into the communication stage. Average earnings for the high-wage players rose from $522 in the last three rounds of the no-communication stage to nearly $619 in the first three rounds of the communication stage (P-value = 0.010), and to over $634 in the last three rounds of this stage. The same thing occurred for the low-wage players, but at lower levels. Note that the subjects' earnings were much higher than the Nash equilibrium earnings of $117 per round for each high-wage player and $191 per round for each low-wage player.

Now let us compare the performance of the asymmetric-wage groups to that of the symmetric-wage groups. Even though the payoffs were constructed so that the Nash equilibria of the

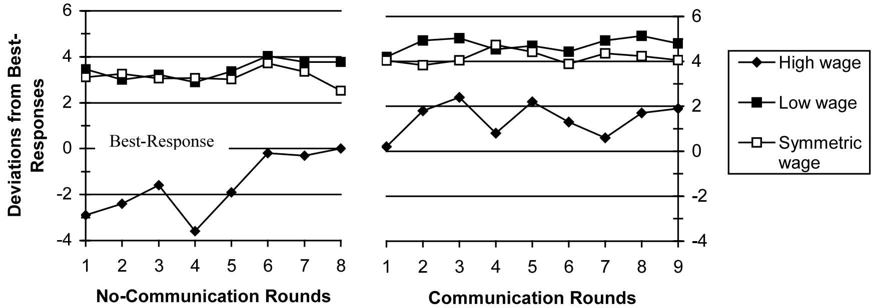

Fig. 2. Average deviations from Nash best-responses.

asymmetric and symmetric-wage treatments yields the same level of aggregate time harvesting firewood, and hence local water quality, on average the asymmetric-wage groups put less pressure on the local forest. The first block of rows of Table 4 and Fig. 1 indicate that after starting out at about the same levels, by the last three rounds of the no-communication stage the combined average choices of the asymmetric-wage groups fell below those of the symmetric-wage groups. In the last three rounds of the no-communication stage the asymmetric-wage subjects were averaging 3.712 units of time harvesting firewood, while the symmetric-wage subjects were averaging 4.388 months harvesting firewood (P-value $= 0.018$).

Like the subjects in the asymmetric-wage treatment, the symmetric-wage subjects reduced their exploitation of the forest when they were allowed to communicate with each other. Their average choices fell from 4.388 for the last three rounds of the no-communication stage to 3.616 for the last three rounds of the communication stage (P-value $= 0.001$). However, they continued to exploit the forest to a greater degree, and hence, experience lower water quality, than their asymmetric-wage counterparts. By the last rounds of the communication stage, the average choices of the asymmetric-wage subjects were 2.900 as compared with 3.616 for the symmetric-wage subjects (P-value $= 0.0173$). Clearly, economic heterogeneity played a role here in producing better environmental outcomes, even though the two treatments were constructed to produce the same Nash equilibrium levels of water quality.

Although the snapshot provided by analyzing average choices is illuminating, it does not give us a complete picture of how economic inequality affects burden-sharing in achieving the outcomes that are consistently better than Nash equilibrium outcomes. For this we analyze the average deviations of the participants' decisions from their individual Nash best-responses in each round. An individual's Nash best-response in a particular round is his or her payoff-maximizing choice given the actual aggregate choices of the rest of the group in that round. We then calculated the difference between each individual's best-response and their actual choice. These deviations from Nash best-responses are summarized in Fig. 2 and in the third block of rows in Table 4. Note that values close to zero indicate that players made choices that were, on average, close to pure Nash strategies, while positive values indicate average choices of time spent harvesting firewood that were less than individual best-responses. These positive deviations indicate more group-oriented choices than purely self-interested Nash strategies, and hence, a greater willingness to accept part of the burden of achieving more efficient outcomes than the Nash equilibrium outcomes.[9]

Focusing first on the high-wage and low-wage players' choices in the asymmetric payoff treatment, note the large separation between the average deviations from Nash best-responses of the two types of players throughout the sessions (these differences are always statistically signifi-

[9] One could argue that individual deviations from pure Nash strategies could be explained, at least in part, by subjects having a difficult time locating their best-responses. If this was the sole reason for these deviations, we would expect that average deviations would consistently be statistically indistinguishable from zero, which is not what we observe.

cant). In the first five rounds or so of the first stage, the high-wage players' average deviations from their best-responses are negative, indicating that they actually spent more time harvesting firewood than suggested by their Nash strategies. These choices are very inefficient—they are not individually optimal, and they are more environmentally damaging than their Nash strategies. As the high-wage players realized the inefficiency of their choices, they moved to their purely self-interested Nash best-responses in the last three rounds of the first stage. The low-wage players, on the other hand, made choices throughout the first stage that were consistently well below their Nash best-responses. By the last three rounds of the no-communication stage, the low-wage players were making choices, on average, that were nearly 4 units of time lower than their self-interested Nash strategies would indicate.

Both types of players made significant moves toward achieving better-than-Nash equilibrium outcomes when they were allowed to communicate with each other. The high-wage players' deviations from their Nash best-responses increased from about zero (− 0.192) in the last three rounds of the no-communication stage to 1.467 in the first three rounds of the communication stage (P-value = 0.057). Their average deviations from best-responses decreased slightly to 1.400 in the last three rounds of the communication stage, but the difference between the first three rounds and the last three rounds of this stage is not statistically significant. Similarly, the low-wage players' deviations from their best-responses rose from 3.872 in the last three rounds of the no-communication stage to 4.772 in the first three rounds when communication was allowed (P-value = 0.035), and remained at about that level through the rest of that stage.

Our comparison of the subjects' actual choices to their purely self-interested Nash strategies yields a very clear message. Even though the richer players put less pressure on the environment than the poorer players, the poorer players made choices that were significantly more group-oriented, thus taking on the primary responsibility for achieving outcomes that were consistently more efficient than the Nash equilibrium outcome.

The symmetric-wage subjects also made choices that were, on average, more group-oriented than their pure Nash strategies. Their choices averaged about 3.224 units of time lower than their Nash best-responses in the last three rounds of the no-communication stage, and fell to 4.223 units lower by rounds 7–9 of the communication stage (P-value = 0.000). Though the symmetric-wage players made choices that were significantly more group-oriented than their pure Nash strategies, they did not do so to the same extent as the low-wage subjects in the asymmetric-wage treatment, particularly in the communication rounds. Average deviations from best-responses for the symmetric-wage subjects in the first three rounds of the communication stage were about 3.98, while for the low-wage subjects in asymmetric-wage treatment they were about 4.722 (P-value = 0.021). This separation continued for rounds 7–9 in the communication stage—4.223 for the symmetric-wage subjects and 4.956 for the low-wage subjects in the asymmetric-wage treatment (P-value = 0.033). While these differences are not very large, the fact that the low-wage subjects in the asymmetric-wage groups were willing to take on more responsibility for moving their groups to more efficient outcomes than their symmetric-wage counterparts is the primary reason the asymmetric-wage groups were able to attain higher levels of environmental quality.

Another way of looking at the distribution of the burden of achieving better-than-Nash equilibrium outcomes is to examine what it costs individuals to show restraint in harvesting firewood relative to their Nash best-responses. Toward this end, for each individual in each round we calculated the difference between the individual's actual payoff and what they would have earned had they played their Nash best-responses instead. This calculation indicates an individual's personal opportunity costs of not making a purely self-interested choice, and hence, the costs they are willing to bear to help their group achieve more efficient outcomes. These opportunity costs are summarized in Fig. 3 and the last block of rows in Table 4.

This exercise simply reinforces our finding that the asymmetric-wage groups were able to reach and sustain better-than-Nash equilibrium outcomes largely because the low-wage subjects were

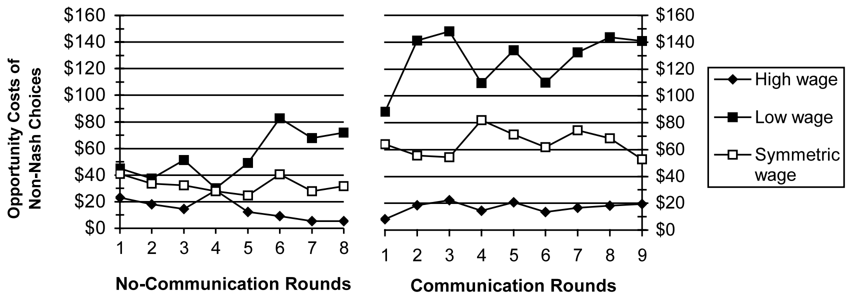

Fig. 3. Average opportunity costs of non-Nash choices.

willing to take on the burden of doing so. In the last three rounds of the no-communication stage, the low-wage subjects were bearing opportunity costs of not making purely self-interested choices that averaged $74.42 per subject per round, while the opportunity costs borne by the high-wage players were merely $6.85 ($P$-value = 0.0001). In the communication stage the difference is more dramatic—$125.76 for the low-wage players in the first three rounds of this stage as compared with $16.30 for the high-wage subjects (P-value = 0.0001), and about $140 versus $18 for rounds 7–9 of this stage (P-value = 0.0001).

Recall that from the perspective of the deviations from Nash best-responses, the willingness of the low-wage players in the asymmetric-wage groups to make more group-oriented choices than their symmetric-wage counterparts does not appear to be that great. However, from the perspective of the opportunity costs borne to make more group-oriented choices, the low-wage players in the asymmetric-groups showed significantly greater willingness to bear the costs of moving their groups to better-than-Nash equilibrium outcomes than the symmetric-wage subjects. Beginning in the last three rounds of the no-communication stage and on to the end of the sessions, the opportunity costs of making non-Nash choices borne by the low-wage players in the asymmetric-groups were consistently more than twice the opportunity costs borne by the symmetric-wage subjects (these differences in the costs of non-Nash choices are always statistically significant: the P-values are always around 0.0001). Again, not only were the low-wage players willing to accept the greater burden of achieving better outcomes than the high-wage subjects in their own groups, but they also did so to a greater extent than the subjects in the symmetric-wage treatment.

4. Concluding remarks

This study strongly suggests that any examination of the effects of economic inequality on the provision of shared environmental quality in rural communities of the developing world should recognize two modes of burden-sharing. The first, which derives from hypotheses of Olson (1965) and Bergstrom et al. (1986), focuses on the question of whether it is the more- or less-advantaged members of a community who are likely to put less pressure on the local environment. Our modification of this approach yielded the Nash equilibrium prediction that the richer members of a community—those with more valuable alternative options in our construct—would put less pressure on the local environment than their less-advantaged neighbors. Our experimental data lend strong support to this hypothesis.

However, a single-minded focus on this mode of burden-sharing misses an important point—subjects in public goods environments rarely choose pure Nash strategies, and typically achieve more efficient outcomes in doing so. Thus, the more important contribution of this study is to recognize and analyze another mode of burden-sharing; that is, the question of which individuals are likely to bear the burden of moving their group to these more efficient outcomes. Our results concerning this mode of burden-sharing are unequivocal. Even though the members of our groups with the more valuable alternative pursuits put less pressure on the local environment, those with less valuable options took on significantly more of the responsibility of moving their groups to outcomes with higher payoffs and better environmental quality.

These results may have important policy implications for whether and how governments should intervene in these contexts. A restriction on the use of a resource in order to improve local environmental quality may not produce the intended outcome if the policy is designed without regard for the way a community attacks the problem on its own. For example, a policy that focuses on restraining the behavior of the less-advantaged in a community because they tend to put more pressure on local environmental quality might be counterproductive if doing so weakens their willingness to accept most of the burden of moving their community to more efficient outcomes. From the perspective of our findings, at the very least, such a policy appears to be unfair. Even a policy that is construed to be more fair, like a uniform quota, may turn out to be ineffective if it causes the less advantaged to make more self-interested choices.

Our results may also have implications for the effects on local environmental quality of poverty alleviation programs. Many have argued that confronting rural poverty by enhancing the private market opportunities of poorer individuals (with more or better land, better access to credit, or more education) could lessen the pressure they place on local natural resources and environmental quality (Durning, 1989; Leonard, 1985, 1989). However, our results suggest that those without good private alternatives seek more cooperative solutions for the use of shared natural resources and environmental quality. Thus, government provision of better private opportunities to the rural poor may not have the desired impact on local environmental quality if these programs reduce the motivation of these individuals to make more efficient choices concerning their local environments. Further research is necessary to explore this hypothesis more rigorously.

Since our analysis focused on out-of-equilibrium outcomes, we had no a priori expectation of how our heterogeneous groups of subjects would share the burden of achieving better-than-Nash equilibrium outcomes. But our results simply invite the questions: What motivated the less-advantaged members of the heterogeneous groups to take on a disproportionate share of the burden of moving their groups to more efficient outcomes? From the other perspective, why did not the richer members of these groups respond as the poorer members did and make more group-oriented choices? Perhaps the answers lie in the establishment of behavioral norms, or notions of equity in sharing the burden. It is possible that the high-wage members of the groups, by making choices that put less pressure on the environment, signaled a standard of restraint that the low-wage subjects felt compelled to emulate. It is also possible that the high-wage members, because they made less damaging choices, felt that they were doing their ‘fair share’ to protect the environment, and hence, were not motivated to do more than what was indicated by their purely self-interested Nash strategies. As plausible as these conjectures are, they probably do more to suggest further research than to explain how economic inequality affects burden-sharing in these contexts.

And further analyses are needed to check the robustness of our results in other contexts. As we noted in the introduction, further research is necessary to check our results across different natural resource and environmental dilemmas, as well as different dimensions of economic inequality. Even if contrary patterns emerge, we stand to gain valuable lessons about how communities in the developing world distribute the burden of confronting local environmental and natural resource dilemmas, and about how public polices can help them do so more effectively.

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