2015

Indirect Reciprocity, Resource Sharing, and Environmental Risk: Evidence from Field Experiments in Siberia

E. Lance Howe
University of Alaska - Anchorage

James J. Murphy
University of Alaska - Anchorage

Drew Gerkey
Oregon State University

Colin Thor West
University of North Carolina - Chapel Hill

Recommended Citation

Howe, E.L., Murphy, J., Gerkey, D., & West, C.T. (2015). Indirect reciprocity, resource sharing, and environmental risk: Evidence from field experiments in Siberia. ESI Working Paper 15-20. Retrieved from http://digitalcommons.chapman.edu/esi_working_papers/169

Indirect Reciprocity, Resource Sharing, and Environmental Risk: Evidence from Field Experiments in Siberia

Comments

Working Paper 15-20

UAA Department of Economics Working Paper

Title: Indirect Reciprocity, Resource Sharing, and Environmental Risk: Evidence from Field Experiments in Siberia

Short Title: Risk and Reciprocity: Field Experiments in Siberia

Authors: E. Lance Howe[1*], James J. Murphy[1,2,3], Drew Gerkey[4], Colin Thor West[5]
[1] Department of Economics and Public Policy, University of Alaska Anchorage, 3211 Providence Dr., Anchorage, AK 99508; [2] Institute of State Economy, Nankai University, 94 Weijin Road, Tianjin, China 300071; [3] Economic Science Institute, Chapman University, One University Drive, Orange, CA 92866; [4] Department of Anthropology, School of Language, Culture & Society, Oregon State University, 218 Waldo Hall, Corvallis, OR, 97330; [5] Department of Anthropology, University of North Carolina, 301 Alumni Building, Chapel Hill, NC, 27599

*** Corresponding author**

E-mail: elhowe@uaa.alaska.edu

Abstract

Integrating information from existing research, qualitative ethnographic interviews, and participant observation, we designed a field experiment that introduces idiosyncratic environmental risk and a voluntary sharing decision into a standard public goods game. Conducted with subsistence resource users in rural villages in remote Kamchatka Russia, we find evidence consistent with a model of indirect reciprocity and local social norms of helping the needy. When experiments allow participants to develop reputations, as is the case in most small-scale societies, we find that sharing is increasingly directed toward individuals experiencing hardship, good reputations increase aid, and risk-pooling becomes more effective. Our results highlight the importance of investigating social and ecological factors, beyond strategic risk, that affect the balance between independence and interdependence when developing and testing theories of cooperation.

Introduction

Research on cooperation and collective action often focuses on strategic risks—the costs and benefits of cooperating or defecting—and associated free-riding behavior in a single domain (1, 2). Expected payoffs are a function of individual and group choices, and interactions are typically limited to a production or investment domain. Previous studies have found that rewards can mitigate the costs of cooperation (3, 4), punishment can increase the costs of defection (5–8), reputations can facilitate positive assortment among cooperators (9), and cultural norms and institutions can structure incentives and expectations in ways that sustain cooperation (1, 10).

In small-scale resource dependent communities, cooperation can often occur in multiple domains, such as contributing to a public good, harvesting from a shared resource, punishing defectors, rewarding cooperators or sharing with those who experience a hardship (11–13). These domains usually interact which reflects the fact that benefits of cooperation can extend beyond a single period, domain, or state of nature. Cooperation may be preferred to non-cooperation precisely because future states of nature are uncertain in one or more linked domains. As such, environmental risk—defined as the spatial and temporal fluctuations in biotic and abiotic components of the environment that affect access to resources, health, and other measures of human well-being—could increase interdependence and, as a result, long-term success depends upon cooperation in multiple domains.

Idiosyncratic environmental risk creates uncertainty about future payoffs in a collective action problem. Individual harvesting success may be stochastic, harvested resources may spoil, animals may destroy stored food, or an injury may prevent the individual from participating in collective action. In subsistence communities, when an individual experiences a hardship, or a "shock," his or her survival depends upon the largesse of others. Thus, the decisions about sharing subsistence resources may depend upon the individual's reputation for cooperating in other domains. Although environmental risk can increase variation in the production domain, sharing among individuals and households can compensate for these short-term production deficits, linking strategic dynamics and cooperation across the two domains (14–17).

In this paper we present results from a framed public goods experiment, conducted in subsistence-dependent communities in Siberia, designed to test how idiosyncratic environmental risk interacts with strategic risk to affect cooperation within and between the production and sharing domains. Consistent with a model of indirect reciprocity, our results indicate that decisions in the sharing domain are conditioned on reputations for cooperation in the production domain. We also find evidence for risk-pooling, as individuals share more with those in need. Further, when reputations for cooperation extend across multiple rounds, the aid provided to cooperators increases substantially and risk-pooling becomes more effective—a result that highlights the importance of local social norms which emphasize resource sharing and helping the needy (18, 19). However, the rewards from sharing are insufficient to improve cooperation in the production domain. Similarly, we find cooperation in the production domain is unaffected by environmental risk that is unavoidable, consistent with theoretical predictions.

Environmental Risk and Cooperation

Because environmental risk introduces variability in resource acquisition, it can be difficult or impossible for a solitary individual to consistently acquire sufficient resources to survive. Thus, environmental risks can affect the relative viability of independent versus cooperative behavior. Previous research shows that environmental risk affects cooperation over rivalrous goods in small-scale, resource-dependent communities. In theoretical studies, environmental risk or uncertainty can increase or decrease cooperation in social dilemmas (20, 21). Experimental studies generally find that increasing the variability of returns to either the group or private account reduces cooperation in the riskier domain (22–24); in contrast the idiosyncratic shock in our design is unavoidable, it affects both the group and private accounts equally.

Although environmental risks have received relatively less attention in research on cooperation and collective action, theoretical and empirical studies of risk-pooling in anthropology (25, 26) and economics (27, 28) have explored interactions between strategic and environmental risks. Smith (29) suggests risk-pooling is likely to occur when an individual's success in resource acquisition exhibits stochastic variation that is asynchronous among individuals, creating opportunities for individuals to reduce environmental risk by sharing resources. Related economic studies have identified the use of non-market mechanisms—including informal loans, remittances, and social networks—to pool risk and minimize the negative effects of consumption variability (16, 30, 31).

Smoothing consumption by pooling resources can enhance odds of survival, but this form of cooperation entails strategic risk in both the production and sharing domains. As such, the insurance provided by pooling resources presents another social dilemma since free-riders may benefit without contributing, undermining the long-term stability of risk-pooling. Related theoretical models have shown a strong commitment device is needed to facilitate effective risk-pooling, insuring the long-term benefits of participation exceed the short-term gains of leaving a network (32).

Experimental research echoes the results of these models. Studies have explored commitment in the context of endogenous group formation (33, 34). For example, Barr and Genicot (33) found individuals were most likely to form risk-pooling groups in the presence of a strong, exogenously enforced, commitment device. Charness and Genicot (35) find strong evidence for risk-pooling with a limited commitment device; however, direct reciprocity is a central feature of their incentive structure. In contrast, direct reciprocity is not an explicit feature of our design, which allows us to test for risk sharing in the absence of commitment devices.

Our study complements existing research by integrating insights on risk-pooling with more general theoretical and empirical research on cooperation. Specifically, we combine factors that increase interdependence and encourage risk-pooling—stochastic resource acquisition and voluntary resource sharing—with factors that amplify strategic risks of defection—rewards and reputations. We utilize methodological tools from anthropology and economics to design a series of field experiments involving 136 participants from 3 villages located on the Kamchatka Peninsula in Northeast Siberia. People living in Kamchatka's remote villages must continually cope with strategic and environmental risks, with limited support from formal institutions (36). Prior to the experiments, we conducted qualitative ethnographic interviews and participant observation to identify the particular strategic and environmental risks that people in Kamchatka face. These insights informed the design of our experiments.

Research Design

Our field experiments were conducted in three small communities in the Karaginskii region of Kamchatka over a four day period in each community during Spring 2011. This is a large, remote region (40,600 km^2) with a small population (4,824 people) that is dependent upon harvesting local resources for subsistence. Approximately 85% of experiment participants were indigenous and had lived in the area for most of their lives.

Subjects were recruited through bulletin board announcements, door-to-door visits, and by a local community coordinator. Experiments were conducted in Russian and all supporting materials were presented in Russian. Participants read a consent form prior to the start of the experiment and provided verbal affirmation of informed consent prior to participation. Signatures were not collected since our study was determined to be of minimal risk, subjects experienced risk similar to that encountered in everyday life, and signatures would have unnecessarily linked subjects to the study. Investigator contact information was provided to subjects and left with village mayors and community coordinators. Researchers returned to communities two years later to report related research findings to participants and community members. Our study and consent procedures were approved by the UAA Institutional Review Board (project id #216266). The protocol was pre-tested with native Russian-speaking students at the University of Alaska Anchorage. Instructions were read aloud and accompanied by PowerPoint slides projected onto a screen. Instructions in English and Russian, field protocol, and an image of information displayed to subjects, can be found at the data review url included in our submission.

Each session lasted approximately three hours, during which subjects played a modified version of a linear public goods game. Experiments were hand-run, with the aid of a single laptop computer and a projector. For each round, decisions were written on slips of paper, collected by one of the experimenters, and entered into a spreadsheet. Results were projected onto the screen, and subjects wrote the outcomes on a record sheet. Once this process was completed, another round followed.

Subjects were randomly assigned to one of two five-person groups. In 4 of the sessions there was one 5 person group and one 4 person group. In the remaining 10 sessions there were 2 five person groups. In all treatments, individuals were identified by a letter known only by the individual and the experimenter. Thus, although participants knew the composition of each group, there was no way for other group members to link an individual to his or her decisions. Moreover, with one exception (described later), each individual's letter randomly varied every round. This method eliminated the possibility of using information about a particular group member's actions in prior rounds and prevented individuals from developing reputations.

Subjects were paid in cash, with average earnings of 610 rubles (about $22 US dollars at the time), equivalent to a typical daily wage. In addition, all participants received a 200 ruble show-up payment.

The modified public goods game was framed as team subsistence production (37, 38), and consisted of two stages. Stage 1 was identical for all groups and consisted of a standard linear public goods game for five rounds. This serves as our Baseline Treatment. Each round, every individual started with an initial endowment of 50 "hours" which had to be allocated between an individual and a group activity. The activity was framed as "fishing, hunting, or collecting mushrooms and berries…" where "sometimes you do these activities on your own" (the individual production activity) but "sometimes you do them with other people" (the group production activity). Each hour allocated to the individual activity yielded a private return of 10 rubles. Time allocated to the group activity yielded 20 rubles per hour, because "people often get more done when working together." Returns from the group activity were divided equally among all group members, regardless of the time allocated. At the end of each round, the allocation decision of each group member was publicly revealed (identified only by a letter).

Stage 2 consisted of eight additional rounds under one of four sharing treatments. Treatments varied in terms of the presence of environmental risk and incentives to cooperate as determined by the information available to subjects when making decisions. In all treatments, subjects first made the same time allocation decision as in Stage 1. After the decisions were made, some information was revealed, then subjects were given the opportunity to share rubles with other group members. The instructions emphasized the voluntary nature of sharing and used the Russian verb *podelit'sya* ("to share"). There was no restriction on the number of fellow group members with whom an individual could share. To avoid sharing commitments in excess of an individual's earnings, the total amount shared by an individual was limited to 250 rubles. Table 1. summarizes key information for each treatment.

Table 1. Experimental Design

		Risk and Sharing Treatment		Information Revealed Prior to Sharing Decision		
Treatment	N	Idiosyncratic Risk	Voluntary Sharing	Player Shocked	Allocation decisions in current round	All decisions in prior rounds
Baseline	136	no	no	--	--	--
Reward	40	no	yes	--	yes	no
Shock	29	yes	yes	yes	no	no
No Reputation	38	yes	yes	yes	yes	no
With Reputation	29	yes	yes	yes	yes	yes

Reward Treatment. The first treatment was identical to the Baseline except that after time allocation decisions were completed and publicly revealed, subjects made a sharing decision. Because individual time allocation decisions were common knowledge, subjects could use sharing as a mechanism to reward others for contributing to the group activity in the current period or to indirectly punish non-cooperators by withholding sharing, increasing the cost of defection relative to the Baseline Treatment. Because sharing was a zero-sum transfer, it had no impact on group earnings. After sharing decisions were collected, the amounts shared and received were revealed to the group. Note that in all Stage 2 treatments, only aggregate sharing outcomes were revealed; the amount transferred between two particular players was not disclosed. This treatment is similar to the Reward Treatment in Sefton, Shupp and Walker (39).

Risk Treatment. The second treatment introduced idiosyncratic environmental risk. After the time allocation decisions were made, but before they were revealed, one individual from each group was randomly selected by the roll of a die to incur a "shock" which was described as "not catching any fish, getting sick, or having all the food you've gathered spoil." The individual who incurred the shock lost all earnings from both the group and individual activities. Only the amount received from voluntary sharing by others determined the individual's earnings for that round. The letter of the individual incurring the shock was announced to the group prior to the sharing decision. After the sharing decisions were collected, both the time allocation and sharing decisions of all group members were revealed.

Risk/Reward Treatment. The third treatment was identical to the Risk Treatment, except that prior to the sharing decision, both the letter of the individual shocked and the allocation decisions of all group members were revealed. This allowed sharing to be based on whether an individual was shocked and/or the individual's time allocation in the current period. After the sharing decisions were collected, the individual sharing and time allocation decisions were revealed to the group.

Risk/Reward/Reputation Treatment. In the final treatment (which we will refer to as the Reputation Treatment), individual player letters were constant across rounds, but otherwise followed the same rules as the Risk/Reward Treatment. Holding player letters constant created an opportunity for individuals to develop a reputation for cooperative behavior not only in the production domain, but also the sharing domain. This allowed other group members to condition sharing on these reputations. The Reputation Treatment brings the experiment closer to naturally occurring contexts of cooperation in small-scale societies, where individuals have access to and utilize reputations.

Individual cash earnings were determined by a single round that was randomly selected by a die roll at the end of the experiment (13, 35). Selecting a single round eliminated the possibility for subjects to pool earnings over time, which would have been analogous to individually insuring against shocks. Our design choice parallels field conditions in northern Kamchatka where there is substantial seasonal variation in weather and resource availability and it is difficult to self-insure against shocks to subsistence harvests.

Related Studies and Hypotheses

The design of our experiment is most similar to a computerized laboratory experiment by Cherry, Howe, and Murphy (13) but differs in terms of the framing, the source of the shock, the nature of sharing, and the amount of information revealed. They find strong evidence for risk-pooling without a commitment device. In contrast, our design introduces unavoidable idiosyncratic risk and allows us to test the effect of reputations on sharing and cooperation decisions.

In each of our treatments, the static Nash equilibrium allocations to the group activity and to sharing are both zero. Further, because direct reciprocity was not possible in our game environment given actual decisions, sharing arrangements are not self-enforcing; that is, the expected future individual gain from cooperating by sharing does not exceed the current benefit of defecting. Essential features of this decision environment have been modeled by Nowak and Sigmund (9) who explore cooperation via indirect reciprocity. In our decision environment, indirect reciprocity is defined as the sharing given to an individual that is conditioned on the observed cooperation of that individual with other group members in both the production and sharing domains when possible (9, 40).

A growing number of experimental studies provide support for the importance of reputation and the role of indirect reciprocity in cooperation and collective action (4, 9, 40–42). In the context of two linked cooperative domains, Panchanathan & Boyd (43) suggest indirect reciprocity depends on two conditions: 1) reputations formed by actions in the first domain increase benefits received in the second domain and 2) the benefits of a good reputation in the second domain exceed the costs of cooperation in the first domain. We investigate how environmental risk affects these strategic dynamics of reputation and indirect reciprocity.

By comparing decisions across the four treatments in Stage 2, we can test the extent to which time allocation and sharing decisions are interlinked and how they respond to risk. Based on the Panchanathan & Boyd (43) model of indirect reciprocity, we hypothesize that sharing decisions will be conditioned on observable behavior, and people who exhibit more cooperation in these domains will receive more support. This implies that in the Reward Treatment, subjects will use sharing to reward cooperation and will punish non-cooperators by withholding sharing (H1). In the Risk Treatment, those experiencing a hardship will receive additional support, but it will be independent of allocation and sharing decisions because these are unobservable (H2). In the Risk/Reward Treatment, sharing will be directed towards the individual who was shocked and sharing will increase with the shocked individual's group allocation decision in the current round (H3). In the Reputation Treatment, the amount shared with a shocked individual should increase with both his or her allocation decision in the current period and his or her sharing decision in the previous period (H4). Finally, if we observe sharing that is conditioned on allocations to the group activity in the final two treatments, then we expect the amount of time allocated to the group activity will be greater than in the Risk treatment, which does not facilitate conditional sharing (H5).

Results

Sharing. In the Reward Treatment, the average amount received from sharing was 96 rubles. In the three treatments with idiosyncratic risk, the average amount received was not substantially different; however, sharing was overwhelmingly directed toward those experiencing a hardship. Moreover, the more a shocked individual cooperated in the production domain, the more he or she received from sharing. We explore this result with four random effects regression models in Table 2, one regression for each of the four Stage 2 treatments. The models all use the same basic structure: $Y_{it} = \beta_0 + \beta_1 \cdot \theta_{it} + \beta_2 \cdot t + \omega_i + \varepsilon_{it}$, where in Table 2. Y_{it} is the total amount received in sharing by subject i in round $t \in [6,13]$, θ_{it} is a set of independent variables that control for whether each individual was shocked, the amount shared in the previous period, the amount allocated to the group activity in the current period, and interactions of these variables, ω_i captures unobserved individual subject characteristics and ε_{it} represents the contemporaneous error term. Because subjects participated in multiple rounds of a single treatment, subject-specific heterogeneity is modeled as a random effect. We use a Huber (44) and White (45) robust estimate of variance.

Table 2. Individual Amount Received from Sharing (Stage 2)

	Reward	Risk	Risk /Reward	Reputation
Amount Shared$_{t-1}$	0.09 (0.06)	0.14 (0.12)	0.07 (0.06)	0.03 (0.07)
Group Activity$_t$	1.15*** (0.39)	-0.31 (0.25)	-0.25 (0.36)	-0.22 (0.52)
Shocked$_t$		108.24*** (24.53)	82.18** (32.99)	-40.70 (42.69)
Shocked$_t$ X Amount Shared$_{t-1}$		-0.14 (0.19)	-0.19 (0.13)	1.16** (0.55)
Shocked$_t$ X Group Activity$_t$		2.48 (1.51)	2.28** (1.14)	5.66*** (1.73)
Period$_t$	-0.92 (1.43)	-1.18 (1.76)	-2.78** (1.16)	-2.30 (1.87)
Constant	72.71*** (22.64)	45.60** (22.27)	72.87*** (16.62)	73.13** (33.38)
N	280	161	210	161

Robust standard errors in parentheses are clustered at the group-level. Dependent variable is the amount received in sharing. Statistical significance: ***: $p<0.01$; **: $p<0.05$

The first model shows results for the Reward Treatment, which does not include a shock and therefore related variables are not included. Consistent with H1, the *Group_Activity*$_t$ coefficient is positive and statistically significant. Conversely, whether the individual shared resources in the previous round is unknown and, as expected, the *Amount_Shared*$_{t-1}$ variable is not significant. Thus, consistent with Sefton, Shupp, and Walker (39), individuals used the sharing mechanism to reward cooperative behavior in the group activity decision. However, the magnitude of the effect is relatively modest. Each hour allocated to the group activity yielded a return of 5.15 rubles—1.15 received from sharing plus 4 rubles from the group activity—which is only about half of the 10 ruble return from an hour allocated to the individual activity. Recall that every hour allocated to the group activity yields 4 rubles for the individual, as well as each of the other group members (20 rubles per hour which is evenly divided among all five group members).

The next three models include interactions of whether the individual was shocked, the allocation to the group activity in the current round, and the amount shared in the previous round.

In all treatments, individuals conditioned sharing decisions on the available information, and unavailable information is not significant, as expected. In the Risk Treatment, participants received an average of 108.24 rubles just for incurring a shock, supporting the hypothesis (H2) that people use sharing to assist those in need. With more information about other group members' behavior in the Risk/Reward and Reputation Treatments, sharing was still directed toward those in need, and the amount received increased for those individuals with higher levels of cooperation in the group activity (Figure 1.). In the Risk/Reward treatment, those who experienced a shock continued to receive some support that was independent of their actions (82.18 rubles), but subjects receiving a shock also received an additional 2.28 rubles per hour allocated to the group activity (consistent with H3). In the Reputation treatment, behavior in both the current and previous rounds was common knowledge. In support of H4, sharing was conditioned on both the shocked individual's most recent sharing decision (period t–1) and the most recent group activity decision (period t). For each ruble shared, shocked players received 1.16 rubles in sharing. For each hour allocated to the group activity, shocked players received 5.66 rubles in sharing. In both the Risk/Reward and Reputation Treatments, sharing was not used to reward cooperation independent of the shock. Instead, sharing was directed only toward those in need and was conditioned on their cooperation.

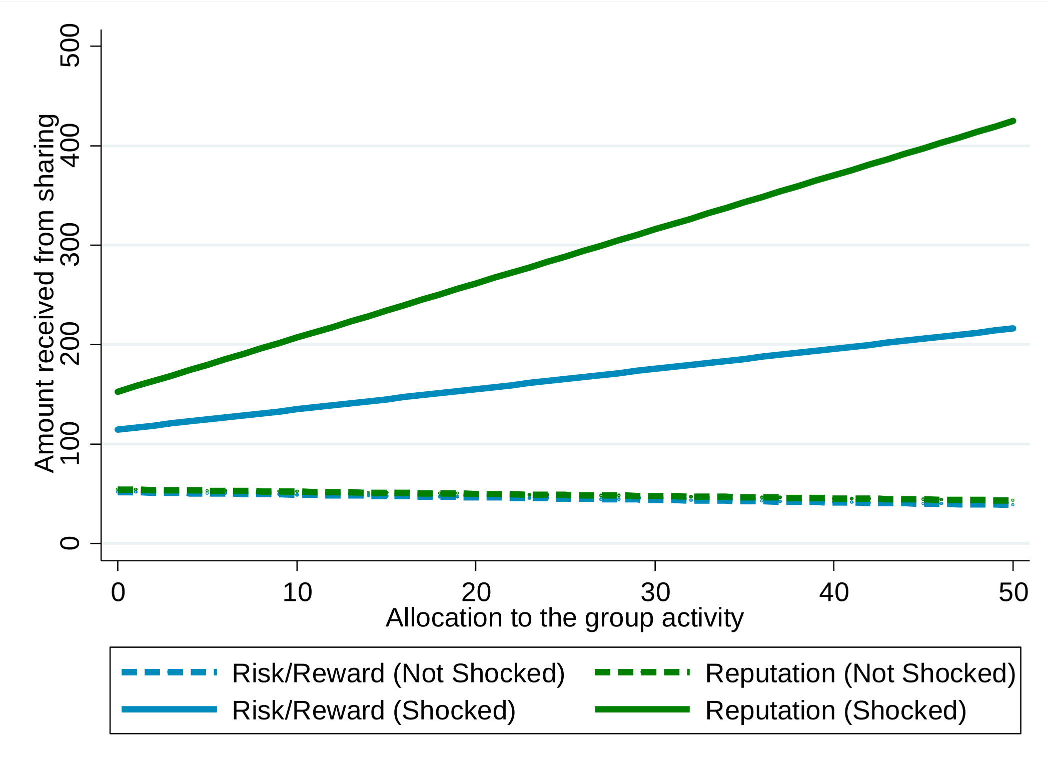

Figure 1. Predicted individual amount received in sharing, conditioned on whether the individual received a shock, using coefficients in Table 2.

Group Activity. In the first five rounds (Stage 1), all groups participated in the Baseline Treatment. In Stage 1, average allocations to the group activity (about 40% of the initial endowment) were consistent with results from other linear public goods games (2, 46). Table 3 presents the results of two random effects models for the group activity decision in Stage 2 (rounds 6-13 only). In these regressions the dependent variable Y_{it} is the individual allocation to the group activity of subject *i* in round *t*. Model 2 adds individual characteristics and fixed effects for the communities. To protect subject confidentiality and to make data publically available for replication we have not identified specific communities, gender, or race in the regression results. We exploit the within-subject design by using the individual's average group allocation over all five rounds of Stage 1 Baseline as an independent variable (*Baseline Group Activity*). Since the idiosyncratic environmental risk was unavoidable, cooperation in the Risk Treatment should be unaffected by risk, which is precisely what the results in Table 3 suggest. However, contrary to H5, the ability to share failed to increase cooperation in both the Risk/Reward and Reputation treatments. Although results indicate sharing with those experiencing the shock is conditioned on the individual's allocation to the group activity (Table 2), the levels of sharing are insufficient to induce an increase in cooperation. If a person receives a shock in the Reputation Treatment, the return from an hour allocated to the group activity was 9.66 rubles (5.66 as reward for an allocation via sharing plus 4 from the group activity), which is still lower than the per hour return of 10 rubles from the individual activity.

Table 3. Individual Allocation to Group Activity (Stage 2 only, rounds 6-13)

	Model 1	**Model 2**
Reward Treatment	omitted	omitted
Risk Treatment	-1.642 (1.76)	-1.849 (1.60)
Risk/Reward Treatment	-0.961 (1.74)	-0.947 (1.77)
Reputation Treatment	0.380 (2.86)	0.642 (2.54)
Round	-0.095 (0.16)	-0.095 (0.16)
Baseline Group Activity	0.775^{***} (0.10)	0.754^{***} (0.11)
Gender 1		-1.525 (1.52)
Age		0.099^{**} (0.04)
Race 1		-0.206 (2.07)
Community 1		-3.427^{**} (1.42)
Community 2		-1.595 (1.73)
Community 3		omitted
Constant	3.616 (2.70)	2.375 (2.93)
N	1088	1072

Robust standard errors are clustered at the group-level. Baseline Group Activity is the mean of the individual's decisions in the Stage 1 Baseline treatment (rounds 1-5). Dependent variable is the individual allocation to the group activity. Statistical significance: ***: $p<0.01$; **: $p<0.05$

Thus, we find some support for Panchanathan & Boyd's (43) model of indirect reciprocity. Individuals in need do receive substantial support, and, when possible, this support is conditioned on their reputations for cooperation. However, the benefits from a positive reputation did not exceed the costs of participating in the group activity, and as a result, the ability to share did not increase cooperation.

Discussion

We systematically examined the interactions of strategic and environmental risks among people in Kamchatka who face these challenges repeatedly in the post-Soviet era (47). Introducing idiosyncratic environmental risk in the social dilemma increased interdependence, and people responded by channeling resources to those in need, rewarding individuals for cooperation, and punishing individuals who did not cooperate. The ability to share as a tool to mitigate environmental risk increased the interdependence among group members. As a result, high levels of sharing were achieved without direct reciprocity or a strong commitment device. Observed sharing is, however, consistent with local sharing norms. We find strong evidence for sharing, even without reputations, which is consistent with a model of pro-social behavior (and related experimental results) in which preferences for keeping social rules are the driving force behind pro-social behavior (48).

When current or past behavior was observable, sharing was conditioned on observed cooperative behavior. In the Reward Treatment, individuals who participated more in the group activity received more from sharing, consistent with previous studies that emphasize the importance of rewards, punishments, and reputations for the emergence of cooperation (42, 49). The positive relationship identified between sharing and allocations to the public good in the Risk/Reward and Reputation Treatments suggests that when both strategic and environmental risks are present in a social dilemma, the effects of strategic risks depend on environmental risks. These results have important implications for research on risk-pooling, the role of reputations, rewards, and punishments in theories of cooperation, and more generally, the role of environmental variability in human adaptation and resilience.

Ethnographic research on risk-pooling emphasizes the importance of supporting those in need and mechanisms of reputation to maintain cooperation (25, 50). Lab experiments inspired by this research have demonstrated that high-variance resources and reputations can play a key role in the emergence of risk-pooling, dramatically increasing reciprocal exchanges among individuals relative to low-variance resources (51) and that risk-pooling strategies can increase individual and pair-wise survival in environments with high degrees of risk (52). Similarly, agent-based simulations have shown increased environmental harshness—which can be mitigated via cooperation—can amplify cooperation (53). Each of these studies emphasizes the impact of interdependence on the emergence of cooperation. We contribute to this work by demonstrating how asymmetries of need caused by stochastic environmental risks or "shocks" interact with the strategic risks tied to rewards, punishments, and reputations to increase interdependence and enhance risk-pooling. In both the Risk/Reward and Reputation Treatments, individuals who contribute more to the public good receive more via sharing, but only when they suffer a shock. These interactions between strategic and environmental risks suggest strategic risks remain important for precisely those individuals who benefit most from risk-pooling, discouraging defectors and free-riders. Indeed, we found the effectiveness of risk-pooling increased when people had the ability to monitor and act upon reputations across multiple rounds. While previous research has emphasized the importance of exogenous commitment devices, formal institutions, endogenous group-formation, and direct reciprocity for effective risk-pooling, our experiments show that risk-pooling can emerge from endogenous reputation dynamics and indirect reciprocity.

Although the interaction of strategic and environmental risk enhanced the effectiveness of risk-pooling, we did not observe systematic increases in the group activity reported by previous studies where rewards are offered in the context of a social dilemma (5, 39, 42). One explanation is that the benefits of good reputations for cooperators never exceed the costs of contributing to the public good. Previous studies with a similar two-dilemma design amplify the impact of reputations by increasing the relative costs and benefits (i.e. efficiency) of rewards and/or punishments, often with ratios as high as 1:3 (4–7, 54). Thus, increasing levels of cooperation observed in previous experiments may not be due to the presence or absence of rewards and punishments *per se*, but the presence of *highly efficient* rewards and punishments (55–57). While highly efficient reward/punishment mechanisms have been shown to increase levels of cooperation in experiments, it is less clear how often such mechanisms are available in naturally occurring contexts of cooperation (58). Indeed, the way participants condition aid to needy players based on cooperation reflects local norms of indirect punishment, which are more commonly observed in our study region than norms of direct, individual costly punishment.

In addition to addressing individual strategic behavior, our study highlights the important role of factors that increase interdependence among individuals. We investigated one factor—stochastic resource acquisition—that increases interdependence by creating consumption deficits that can be overcome by pooling resources through sharing. Such deficits might also arise from differences in individual/household productive capacity and consumptive needs (59) or stochastic differences in harvests due to poor health or other misfortunes (60, 61). Our experiments incorporate consumption deficits via stochastic shocks, providing a specific factor for amplifying the impact of reputations relative to the highly efficient reward and punishment mechanisms utilized in previous studies.

Scholars studying processes of contemporary human adaptation to unprecedented forces of global climatic, economic, political, and cultural change have emphasized the crucial role of strategies that mitigate environmental risks (62). Many components of contemporary adaptation—including the role of traditional ecological knowledge, social networks, institutions, and other forms of social capital—depend on cooperation among individuals to maintain resilience in the face of shocks and perturbations (63). Therefore, understanding how environmental risks interact with strategic risks to affect the emergence and stability of cooperation can improve our attempts to adapt to the challenges we face in contemporary environments. Our research suggests theories of cooperation can contribute to this goal by investigating a broader range of factors that increase interdependence.

Acknowledgements

This research was supported by the National Science Foundation (#0729063 and #1019303). DG was supported by a post-doctoral fellowship from the National Socio-Environmental Synthesis Center (SESYNC) under funding from the National Science Foundation (DBI-1052875). We wish to thank all the people in Kamchatka who participated in our research, as well as Dr. Viktoria Petrasheva, Tatiana Degai, and Daniel Allen for research assistance. We especially thank Cristina Gaina Blanton who assisted in translations, transcriptions, and conducting field experiments. We thank Martha Madsen at Explore Kamchatka for outstanding logistics support.

References

1. Ostrom E, Gardner RJ, Walker JM (1994) *Rules, Games, & Common-Pool Resources* (University of Michigan Press, Ann Arbor).

2. Chaudhuri A (2010) Sustaining cooperation in laboratory public goods experiments: a selective survey of the literature. *Exp Econ* 14:47–83.

3. Dreber A, Rand DG, Fudenberg D, Nowak MA (2008) Winners don't punish. *Nature* 452:348–51.

4. Rand DG, Dreber A, Ellingsen T, Fudenberg D, Nowak MA (2009) Positive interactions promote public cooperation. *Science* 325:1272–5.

5. Fehr E, Gächter S (2000) Cooperation and punishment in public goods experiments. *Am Econ Rev* 90:980–994.

6. Fehr E, Gächter S (2002) Altruistic punishment in humans. *Nature* 415:137–140.

7. Henrich J et al. (2006) Costly punishment across human societies. *Science* 312:1767–70.

8. Gurerk O, Irlenbusch B, Rockenbach B (2006) The competitive advantage of sanctioning institutions. *Science* 312:108–111.

9. Nowak MA, Sigmund K (2005) Evolution of indirect reciprocity. *Nature* 437:1291–8.

10. Ostrom E (2005) *Understanding Institutional Diversity* (Princeton University Press, Princeton).

11. Janssen MA, Anderies JM, Cardenas J-C (2011) Head-enders as stationary bandits in asymmetric commons: Comparing irrigation experiments in the laboratory and the field. *Ecol Econ* 70:1590–1598.

12. Schott S, Buckley NJ, Mestelman S, Muller RA (2007) Output sharing in partnerships as a common pool resource management instrument. *Environ Resour Econ* 37:697–711.

13. Cherry TL, Howe EL, Murphy JJ (2015) Sharing as Risk Pooling in a Social Dilemma Experiment. *Ecol Soc* 20:68.

14. Fienup-Riordan A (1986) *When Our Bad Season Comes: A Cultural Account of Subsistence Harvesting & Harvest Disruption on the Yukon Delta* (Alaska Anthropological Assn, Anchorage, AK).

15. Alvard MS, Nolin DA (2002) Rousseau ' s whale hunt ? *Curr Anthropol* 43:533–559.

16. Fafchamps M, Lund S (2003) Risk-sharing networks in rural Philippines. *J Dev Econ* 71:261–287.

17. Fafchamps M, Gubert F (2007) The formation of risk sharing networks. *J Dev Econ* 83:326–350.

18. Fehr E, Fischbacher U (2004) Social norms and human cooperation. *Trends Cogn Sci* 8:185–90.

19. Biel A, Thøgersen J (2007) Activation of social norms in social dilemmas: A review of the evidence and reflections on the implications for environmental behaviour. *J Econ Psychol* 28:93–112.

20. Boucher V, Bramoullé Y (2010) Providing global public goods under uncertainty. *J Public Econ* 94:591–603.

21. Bramoulle Y, Treich N (2009) Can uncertainty alleviate the commons problem? *J Eur Econ Assoc* 7:1042–1067.

22. Rapoport A, Suleiman R (1992) Equilibrium solutions for resource dilemmas. *Gr Decis Negot* 1:264–294.

23. Wit A, Wilke H (1998) Public good provision under environmental and social uncertainty. *Eur J Soc Psychol* 28:249–256.

24. Gangadharan L, Nemes V (2009) Experimental analysis of risk and uncertainty in provisioning private and public goods. *Econ Inq* 47:146–164.

25. Cashdan E ed. (1990) *Risk and Uncertainty in Tribal and Peasant Economies* (Westview Press, Boulder).

26. Wiessner P (1982) in *Politics and History in Band Societies*, eds Leacock E, Lee R (Cambridge University Press, Cambridge, UK), pp 61–84.

27. Fafchamps M (2003) *Rural Poverty, Risk and Development* (Edward Elgar Publishing Limited).

28. Townsend RM (1994) Risk and Insurance in Village India. *Econometrica* 62:539.

29. Smith EA (1988) in *Hunters and Gatherers: History, Evolution, and Social Change*, eds Ingold T, Riches D, Woodburn J (Berg, Oxford), pp 222–252.

30. Udry C (1994) Risk and insurance in a rural credit market: an empirical investigation in Northern Nigeria. *Rev Econ Stud* 61:495–526.

31. De Weerdt J, Dercon S (2006) Risk-sharing networks and insurance against illness. *J Dev Econ* 81:337–356.

32. Genicot G, Ray D (2003) Group formation in risk-sharing arrangements. *Rev Econ Stud* 70:87–113.

33. Barr A, Genicot G (2008) Risk sharing, commitment, and information: an experimental analysis. *J Eur Econ Assoc* 6:1151–1185.

34. Barr A, Dekker M, Fafchamps M (2012) Bridging the gender divide: an experimental analysis of group formation in African villages. *World Dev* 40:2063–2077.

35. Charness G, Genicot G (2009) Informal risk sharing in an infinite-horizon experiment. *Econ J* 119:796–825.

36. Gerkey D (2011) Abandoning fish: The vulnerability of salmon as a cultural resource in a post-Soviet commons. *Anthropol Work Rev* 32:77–89.

37. Croson RTA (2001) Feedback in voluntary contribution mechanisms: An experiment in team production. *Res Exp Econ* 8:85–97.

38. Eckel CC, Grossman PJ (2005) Managing diversity by creating team identity. *J Econ Behav Organ* 58:371–392.

39. Sefton M, Shupp R, Walker JM (2007) The effect of rewards and sanctions in provision of public goods. *Econ Inq* 45:671–690.

40. Bolton GE, Katok E, Ockenfels A (2005) Cooperation among strangers with limited information about reputation. *J Public Econ* 89:1457–1468.

41. Engelmann D, Fischbacher U (2009) Indirect reciprocity and strategic reputation building in an experimental helping game. *Games Econ Behav* 67:399–407.

42. Milinski M, Rockenbach B (2012) On the interaction of the stick and the carrot in social dilemmas. *J Theor Biol* 299:139–43.

43. Panchanathan K, Boyd R (2004) Indirect reciprocity can stabilize cooperation without the second-order free rider problem. *Nature* 432:499–502.

44. Huber PJ (1967) The behavior of maximum likelihood estimates under nonstandard conditions. *Proc Fifth Berkeley Symp Math Stat Probab* 1:221–233.

45. White H (1980) A heteroskedasticity-consistent covariance matrix estimator and a direct test for heteroskedasticity. *Econometrica* 48:817–838.

46. Henrich J et al. (2004) *Foundations of human sociality: economic experiments and ethnographic evidence from fifteen small-scale societies* (Oxford University Press, Oxford).

47. Gerkey D (2013) Cooperation in context: public goods games and post-Soviet collectives in Kamchatka, Russia. *Curr Anthropol* 54:144–176.

48. Kimbrough EO, Vostroknutov A Norms make preferences social. *J Eur Econ Assoc*.

49. Balafoutas L, Nikiforakis N, Rockenbach B (2014) Direct and indirect punishment among strangers in the field. *Proc Natl Acad Sci U S A* 111:15924–15927.

50. Winterhalder B, Lu F, Tucker B (1999) Risk-senstive adaptive tactics: Models and evidence from subsistence studies in biology and anthropology. *J Archaeol Res* 7:301–348.

51. Kaplan HS, Schniter E, Smith VL, Wilson BJ (2012) Risk and the evolution of human exchange. *Proc Biol Sci* 279:2930–5.

52. Aktipis CA, Cronk L, Aguiar R (2011) Risk-pooling and herd survival: an agent-based model of a Maasai gift-giving system. *Hum Ecol* 39:131–140.

53. Smaldino PE, Schank JC, McElreath R (2013) Increased costs of cooperation help cooperators in the long run. *Am Nat* 181:451–63.

54. Herrmann B, Thöni C, Gächter S (2008) Antisocial punishment across societies. *Science* 319:1362–1367.

55. Ambrus A, Greiner B (2012) Imperfect public monitoring with costly punishment: an experimental study. *Am Econ Rev* 102:3317–3332.

56. Egas M, Riedl A (2008) The economics of altruistic punishment and the maintenance of cooperation. *Proc Biol Sci* 275:871–8.

57. Roberts G (2013) When punishment pays. *PLoS One* 8:e57378.

58. Guala F (2012) Reciprocity: Weak or strong? What punishment experiments do (and do not) demonstrate. *Behav Brain Sci* 35:1–15.

59. Hooper PL, Gurven M, Winking J, Kaplan HS (2015) Inclusive fitness and differential productivity across the life course determine intergenerational transfers in a small-scale human society. *Proc Biol Sci* 282:20142808.

60. Gurven M, Allen-Arave W, Hill K, Hurtado M (2000) "It's a Wonderful Life" signaling generosity among the Ache of Paraguay. *Evol Hum Behav* 21:263–282.

61. Sugiyama LS (2004) Illness, injury, and disability among Shiwiar forager-horticulturalists: implications of health-risk buffering for the evolution of human life history. *Am J Phys Anthropol* 123:371–89.

62. Tucker B, Tsimitamby, Humber F, Benbow S, Iida T (2010) Foraging for development: a comparison of food insecurity, production, and risk among farmers, forest foragers, and marine foragers in Southwestern Madagascar. *Hum Organ* 69:375–386.

63. Berkes F, Folke C, Colding J (1998) *Linking social and ecological systems management practices and social mechanisms building resilience* (Cambridge University Press, Cambridge).