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# Benefits, costs, and livelihood implications of a regional payment for ecosystem service program

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**Despite broad interest in using payment for ecosystem services to promote changes in the use of natural capital, there are few ex-post assessments of impacts of payment for ecosystem services programs on ecosystem service provision, program cost, and changes in livelihoods resulting from program participation. In this paper, we evaluate the Paddy Land-to-Dry Land (PLDL) program in Beijing, China, and associated changes in service providers' livelihood activities. The PLDL is a land use conversion program that aims to protect water quality and quantity for the only surface water reservoir that serves Beijing, China's capital city with nearly 20 million residents. Our analysis integrates hydrologic data with household survey data and shows that the PLDL generates benefits of improved water quantity and quality that exceed the costs of reduced agricultural output. The PLDL has an overall benefit–cost ratio of 1.5, and both downstream beneficiaries and upstream providers gain from the program. Household data show that changes in livelihood activities may offset some of the desired effects of the program through increased expenditures on agricultural fertilizers. Overall, however, reductions in fertilizer leaching from land use change dominate so that the program still has a positive net impact on water quality. This program is a successful example of water users paying upstream landholders to improve water quantity and quality through land use change. Program evaluation also highlights the importance of considering behavioral changes by program participants.**

social-ecological systems | sustainable household livelihoods | watershed management | sustainability | regional collaboration

Payment for ecosystem services (PES) can serve as an effective mechanism to translate external, nonmarket values of ecosystem services into financial incentives for local actors to provide such services (1), and has been highlighted as an innovative approach to integrate conservation and socioeconomic development (2–4). In principle, when the benefits derived from increased provision of ecosystem services exceed the cost of provision, PES mechanisms can make both ecosystem service beneficiaries and providers better off. Despite considerable promise and interest in the use of PES worldwide and increasing assessments of the benefits and costs of PES programs, there is little documentation of resulting changes in program participants' livelihoods. Livelihood changes can alter the total effect of a program through unintended changes in an area's economic structure or other natural capital assets (5–8). Taking stock of these socioeconomic impacts highlights the dynamic and distributional effects of PES programs, and is necessary for understanding the equity implications and overall efficiency of a program.

Beijing faces a water crisis requiring urgent solutions, and PES programs are one strategy being used to protect water resources. The Miyun Reservoir is the only surface water source for domestic water in Beijing. Its main purpose is to supply residents with drinking water, up to one-half of which comes from the reservoir (9). However, competition between Hebei Province (upstream) and Beijing City (downstream) for water resources originating in Hebei is intensifying. Upstream townships, where farmers' average income is about one-third of the downstream farmers, require water resources for local agricultural and industrial sectors and for improving local livelihoods. At the same time, Beijing's demand for water continues to increase with population growth, currently at around 20 million residents. One of the greatest challenges in the watershed is how to address the interests of both upstream and downstream stakeholders, to achieve shared and sustainable goals.

We use a PES program between the city of Beijing and the Miyun Reservoir watershed, the Paddy Land-to-Dry Land (PLDL) conversion program, as a case to explore the efficiency and livelihood implications of a PES program. We first analyze the costs and benefits for ecosystem service providers and beneficiaries to show how PLDL program impacts both parties. Second, we use household survey data from PLDL participants and nonparticipants to better understand changes in livelihood activities and their related environmental consequences. Finally, we provide recommendations for PES policy design for a more integrated approach to watershed management.

## Background

**Miyun Reservoir Watershed.** The Miyun Reservoir is located about 100 km north of Beijing, China. It is the biggest artificial lake in Asia, spanning 188 $km^2$ with a storage capacity of $43.17 \times 10^8$ $m^3$. About four-fifths of the watershed is located in Hebei Province with the remaining one-fifth in the greater municipality of Beijing (Fig. 1). The current total population in the catchment is about 878,000, of which roughly 92% are engaged in agricultural work (10). The average net income of farmers in the Beijing townships is about three times that in Hebei Province.

Both water quality and quantity are important concerns in the reservoir's watershed. Inflows into the Miyun Reservoir have decreased due to upstream water withdrawals for agriculture and reduced precipitation (11, 12). The mean annual inflow runoff was 1.3 billion $m^3$ (BCM) in the 1960s, but fell to less than 0.4 BCM in the 2000s (13). Non–point-source pollutants, mainly from agricultural land, also affect the reservoir. The total nitrogen (TN) concentration, which averaged 0.76 $mg \cdot L^{-1}$ in 1987–1988, was up to 3.28 $mg \cdot L^{-1}$ in the period 2003–2005. Total

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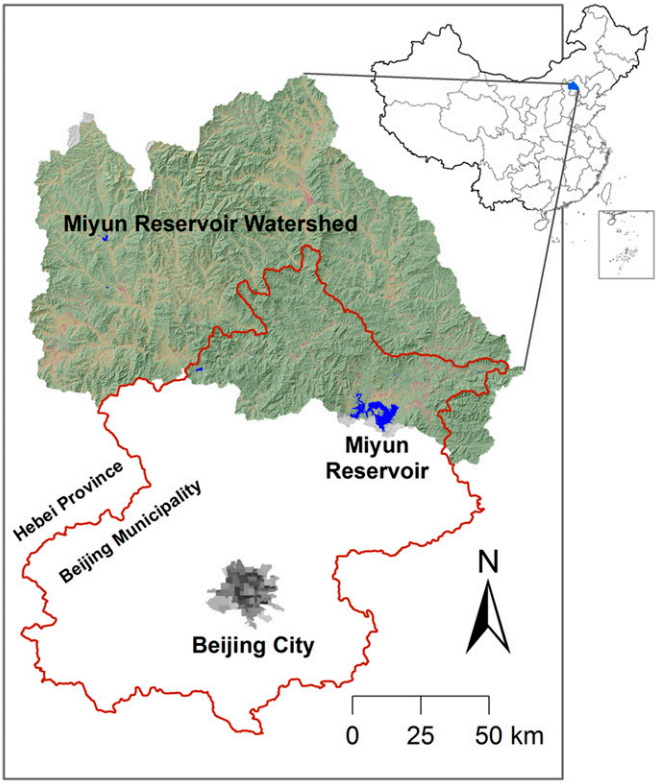


**Fig. 1.** Miyun Reservoir watershed. Beijing Municipality is the area within the red demarcation; the areas of the watershed outside this line are part of Hebei Province.

phosphorus (TP) currently ranges from 0.017 to 0.076 mg·L$^{-1}$ in Miyun Reservoir (14). The decrease in river discharge and increased nutrient concentration are a great concern for water resource managers in Beijing, who fear Miyun Reservoir could face a fate similar to Guangting Reservoir. Guangting was Beijing's second largest reservoir, but closed in 1997 due to the heavy concentrations of wastewater discharge, fertilizers, and pesticides (15).

**The PLDL Project.** Diminishing water quantity and quality in Miyun Reservoir has intensified competition and sparked interprovincial conflicts between Hebei Province and Beijing municipality. Since 2001, Beijing and Hebei Provinces jointly initiated a series of regional collaboration activities, one of which is the PLDL program. The goals of the program focus on increasing water yield and reducing nutrient pollution. Rice cultivation through flood-irrigated paddies is thought to be one of the primary causes of both decreased water yield and high nutrient loads in the Miyun Reservoir. In 2006, Beijing signed a "rice-to-dryland conversion" agreement with Chengde and Zhangjiakou, two municipalities in Hebei with land in the Miyun Reservoir watershed, to pay an average of 450 yuan per mu [~$844 USD per ha in 2006 (15 mu = 1 ha; 8 yuan ~ 1 USD in 2006)] per y for land that was converted from rice to dryland cultivation, with payments adjusted to reflect market land use values. In 2008, the Beijing government increased compensation to 550 yuan per mu per y to ensure that participation in the PLDL would not reduce household income. Instead of grown rice, the vast majority switched to growing corn. By 2010, households upstream of Miyun Reservoir had converted all 103,000 mu of rice fields to dryland crops.

**Integrated Framework for PES Program Assessment.** The PLDL PES program is an approach to watershed management that provides incentives for upstream communities to protect critical water sources and has the potential to reconcile competing stakeholder interests over watershed management. Under this program, upstream communities are compensated for providing ecosystem services valuable to downstream areas. Downstream communities pay for these services by providing compensation to offset upstream participants' opportunity cost of providing the service. By establishing a financial relationship between the providers of ecosystem services and their beneficiaries, the PES system harnesses gains from trade between downstream beneficiaries and upstream service providers to improve the efficiency of watershed management.

The PLDL PES program also has the potential to promote economic development in upstream communities by providing additional financial resources to households and changing land use and production activities. By increasing households' flexible cash income, households may, for example, choose to increase education or migrate out of the watershed for better income-earning opportunities. Doing so can lead to long-term shifts in livelihood activities that depend less on critical or fragile ecosystems and reduce pressure on the watershed's natural capital. This idealized social-ecological system is illustrated in Fig. 2.

We take PLDL program as a case study to show how (*i*) regional cooperation reconciles the interests of ecosystem service providers and the beneficiaries, and (*ii*) it can drive shifts in livelihood activities, which can also have an impact on overall sustainability and cost effectiveness (Fig. 2).

## Results

**Environmental Goals of PLDL Program.** The PLDL program has been successful in achieving improvements in water quantity and water quality. We estimate the program increased water yield by $1.82*10^7$ m$^3$ per y and reduced TN and TP by 10.36 and 4.34 tons per y, respectively (Fig. 3). The increase in water yield is 5% of the average runoff in Miyun Reservoir between 2000 and 2009.

**Cost–Benefit Analysis of Ecosystem Service Providers and Beneficiaries.** Farmers who convert paddy land to dry land are ecosystem service providers. We estimate the net income for planting rice and corn are around 8,602 yuan per ha and 1,501 yuan per ha, respectively. The opportunity cost for ecosystem service providers (the farmers) includes the difference of net income between rice planting and corn planting, which is 7,101 yuan per ha (Table S1). The payment from the Beijing government is 8,250 yuan per ha (550 yuan per mu), about 1.2 times the estimated opportunity cost (Fig. 4).

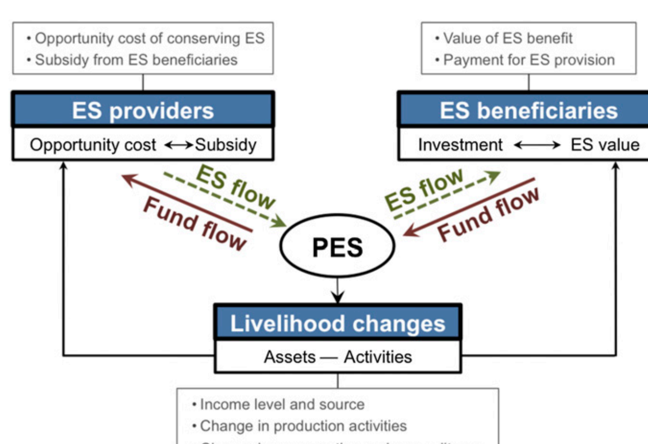


**Fig. 2.** Assessment framework of the PLDL program.



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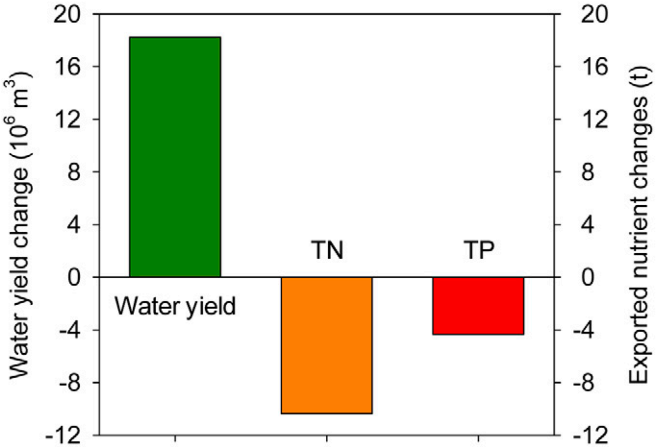


**Fig. 3.** Estimated water yield and nutrient changes due to the PLDL program.

For downstream beneficiaries, costs include the direct payment of 8,250 yuan per ha plus the transaction and programmatic costs of running the program of 1,053 yuan per ha (16), totaling 9,303 yuan per ha. The benefits of the program include the value of increased water resources and the reduced cost for TN and TP treatment due to PLDL program implementation (see *Methods* for details). We estimate the benefits of water quantity to be about 12,341 yuan per ha and the reduced cost for TN and TP treatment to be 46 yuan per ha due to PLDL program implementation. In aggregate, these benefits are about 1.3 times the cost of the PLDL program (Fig. 4) to the beneficiaries.

Our analysis suggests that overall benefits of the PLDL program exceed the costs of program implementation. The program's benefits (the value of increased water yield and improved water quality) are 12,387 yuan per ha. The program's costs (the opportunity costs of the upstream farmers plus transaction cost) are 8,154 yuan per ha. Overall, the benefit–cost ratio of the program is 1.5 (Fig. 4). Program payments allow both the upstream providers and the downstream beneficiaries to gain from program implementation.

**Transitions in Household Livelihoods.** We explore how the PLDL program impacts livelihoods in two subsections: changes in livelihood portfolios and changes in household production and consumption activities. We report these changes with two variants of "difference-in-differences" (DID) techniques, which reflect changes in the reported values of participants in the PLDL program relative to those who do not participate in the program in 2010 (after project was implemented) versus 2006 (before the project was implemented). The results report "simple" DID estimates ($Z_{DID}$) as well as estimates that control for differences in observable household characteristics as they might impact program outcomes through "matching" techniques ($Z_{DIDM}$) (*SI Text*).

***Changes in livelihood portfolios.*** Both PLDL participating households and nonparticipating households report an approximate doubling of their household income between 2006 and 2010 (Table 1). However, PLDL participant households' agricultural income decreased by around 2,000 yuan relative to nonparticipant, presumably from converting productive rice paddies to less lucrative cornfields. The difference between participant and nonparticipant earnings in 2010 is of a similar magnitude to the mean PLDL payment reported ($\mu = 1{,}768$, $\sigma = 1{,}257$). The decrease in agricultural income seems to be offset by an increase in migrant earnings relative to nonparticipants of more than 3,000 yuan on average.

These changes are also reflected in differences in the share of income from these categories. Table S2 shows that participants become 25% less reliant on agricultural income relative to nonparticipants between 2006 and 2010. However, their reliance on migrant income increases.

***Changes in household production and consumption activities.*** We also look at whether household production and consumption activities differ among participants and nonparticipants in the PLDL program. Table 2 shows that participants' labor allocation decreases relative to nonparticipants as they move from more intensively cultivated rice to less time-demanding corn production. However, participants do significantly increase their rate of nutrient application, especially phosphorus, compared with nonparticipants. Both groups started at somewhat similar application rates in 2006, but participants' application rates rose faster than those of nonparticipants. This is due, at least in part, to PLDL participants' dramatic and disproportionate increased investment in corn inputs—expenditures on seed, fertilizer, and pesticide among program participants were much less than nonparticipants in 2006, but surpassed nonparticipants by 2010 (Table S3).

Although the program seems to have sparked increased fertilizer use, the amount of nutrients that enter nearby waterways is largely governed by the type of agricultural land use. In particular, nutrient export coefficients for flood-irrigated paddy land are high, but for dryland corn cultivation are low. Estimating nutrient export to surface water using export coefficients (*SI Text*), our data suggest that the program still has an overall positive effect on nutrient export (both TP and TN export to waterways decrease) despite the increase in application rates.

In terms of consumption activities (Table S4), there is some evidence that participants increased their spending on education relative to nonparticipants. There have been large overall decreases in fuelwood use and increases in consumption of coal and liquefied petroleum gas. Although not statistically significant, these trends do seem more pronounced in households that participate in the PLDL. We also see increased investment in material assets like motorcycles, cars, televisions, refrigerators, and washing machines when using matching estimators, likely due to nonlinear income effects on acquiring these goods.

## Discussion

The challenges in Miyun Reservoir watershed resemble those in China and beyond: intensifying competition over water resources, competing development priorities between upstream and downstream communities, and finding feasible policy solutions

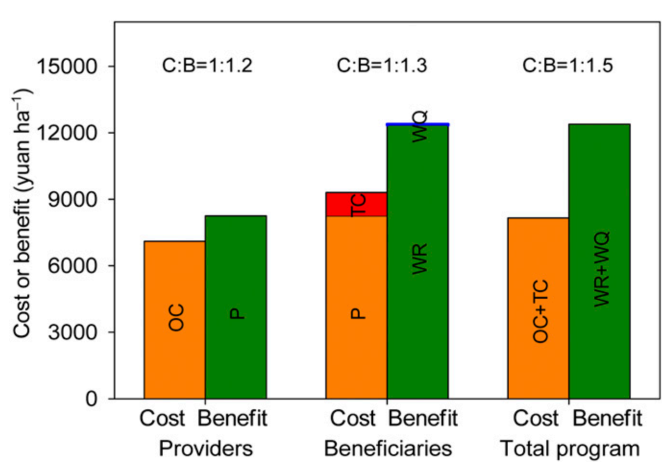


**Fig. 4.** Comparison of cost (C) and benefit (B) for ecosystem service providers, beneficiaries, and the total program. Costs and benefits that accrue to the different groups include farmers' opportunity costs (OC), payments (P) and program implementation/transaction costs (TC), the value of water resources (WR), and the value of improved water quality (WQ). Each category's cost–benefit ratio is displayed above.

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Table 1. Changes in sources of income (yuan per household) between PLDL participants and nonparticipants

| Income sources | PLDL participating households | Nonparticipating households | Simple difference | Difference-in-difference ($Z_{DID}$) | Difference-in-difference with matching ($Z_{DIDM}$) |
|---|---|---|---|---|---|
| Income sources in 2006 (before PLDL) | A | B | A − B | | |
| All income | 13,227 | 12,816 | 411 | | |
| Agricultural income | 5,068 | 2,293 | 2,775 | | |
| Nonfarm income | 1,018 | 1,824 | −806 | | |
| Migrant income | 6,891 | 8,424 | −1,533 | | |
| SLCP income | 250 | 275 | −25 | | |
| PLDL income | — | — | — | | |
| Income sources in 2010 (after PLDL) | C | D | C − D | (C − D) − (A − B) | |
| All income | 28,419 | 24,865 | 3,554 | 3,143 (1.40) | 6,501 (3.21)*** |
| Agricultural income | 4,331 | 3,658 | 673 | −2,102 (−3.27)*** | −1,704 (−2.89)*** |
| Nonfarm income | 2,490 | 3,302 | −812 | −6 (−0.01) | 1,048 (1.52) |
| Migrant income | 19,579 | 17,630 | 1,949 | 3,482 (1.80)* | 5,396 (2.98)*** |
| SLCP income | 250 | 275 | −25 | 0 (0.00) | −70 (−0.21) |
| PLDL income | 1,768 | 0 | 1,768 | — | |

For DID results, *t* stats are shown in parentheses. *, **, and *** denote the differences are significant at $P < 0.1$, $P < 0.05$, and $P < 0.01$, respectively. SLCP, Sloping Land Conversion Program.

to secure sustainable development (17, 18). By aligning economic activities with environmental goals and increasing coordination between upstream and downstream communities, the PLDL program helps address some of the Miyun Reservoir watershed's challenges: coordinated management, win–win outcomes, and household livelihood transformation.

In China, top-down strategies dominate, but strengthening intersectoral and interprovincial coordination efforts, such at the PLDL program, are important components of sustainable water management (19). Due to regional water scarcity around Beijing, China is investing in a massive water transfer program called the South-to-North Water Transfer Project (20). Such transfer programs are expensive and the cost of supplying water to Beijing is much higher than the cost of water from Miyun Reservoir. Although solutions like the PLDL program cannot fully resolve the water supply challenges facing Beijing, this case shows the potential value in regional coordination alternatives (21). However, such programs can also give rise to equity concerns when participants have little bargaining power. Still, in this case farmers successfully lobbied for an increase in the PLDL program's payment rate after several years to ensure fair compensation. Furthermore, 90% of the participating households surveyed ($n$ =394) say they support continuation of the PLDL policy (Fig. S1), demonstrating the program's broad favorability.

The results show that PLDL participants' agricultural income decreased relative to nonparticipants over the study period, but remittance income increased (Table 1). Participants also increased spending on material assets and invested in education at a slightly higher rate (Table S4). The change from labor-intensive rice to corn production also decreased the amount of household labor required to farm those plots (Table 2). These changes in the structure of household income and labor can help relax constraints on overall household welfare, enabling greater investment in agricultural productivity or allowing for greater mobility of labor. Addressing such institutional and market constraints at the household level likely helps enhance overall regional sustainability and improve the livelihood effects of PLDL program in the long run (7, 22, 23).

However, our results also show that changes in livelihood activities may offset some of the desired effects of the program,

Table 2. Changes in agricultural production practices between PLDL participants and nonparticipants

| Production activities | PLDL participating households | Nonparticipating households | Simple difference | Difference-in-difference ($Z_{DID}$) | Difference-in-difference with matching ($Z_{DIDM}$) |
|---|---|---|---|---|---|
| Production activities in 2006 (before PLDL) | A | B | A − B | | |
| P application, kg/mu | 1.98 | 1.96 | 0.03 | | |
| N application, kg/mu | 17.6 | 12.2 | 5.4 | | |
| Estimated P export, kg/mu | 0.022 | 0.003 | 0.019 | | |
| Estimated N export, kg/mu | 0.72 | 0.38 | 0.34 | | |
| Agricultural intensification, person-days/mu | 15.56 | 11.22 | 4.34 | | |
| Production activities in 2010 (after PLDL) | C | D | C − D | (C − D) − (A − B) | |
| P application, kg/mu | 2.66 | 2.11 | 0.55 | 0.52 (2.28)** | 0.51 (2.16)** |
| N application, kg/mu | 20.0 | 12.5 | 7.5 | 2.07 (1.76)* | 1.38 (1.12) |
| Estimated P export, kg/mu | 0.005 | 0.004 | 0.001 | −0.018 (−12.14)*** | −0.15 (−10.37)*** |
| Estimated N export, kg/mu | 0.62 | 0.39 | 0.23 | −0.12 (−2.82)*** | −0.13 (−3.12)*** |
| Agricultural intensification, person-days/mu | 9.15 | 12.17 | −3.02 | −7.36 (−6.53)*** | −7.40 (−6.66)*** |

For DID results, *t* stats are shown in parentheses. *, **, and *** denote the differences are significant at $P < 0.1$, $P < 0.05$, and $P < 0.01$, respectively.



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namely through increased rates of application of nitrogen and phosphorus and increased expenditures on agricultural fertilizers and pesticide (Table 2 and Table S3). Here, the change from flood-irrigated rice cultivation to row-crop corn limits the ultimate export of nutrients to waterways due to the relative export coefficients from land under rice versus corn cultivation, and on balance we estimate households export fewer nutrients to waterways. However, these results emphasize that simply offering payments to households may be insufficient to induce the ultimate socially desired end effect. In this case, increasing fertilizer application rates counters the effectiveness of the PLDL program. Not only is this an unrecognized side effect, these increases in nutrient applications likely contribute to north China's already known overapplication of nutrients (24, 25) and has potential implications for other unincorporated externalities such as nitrates in groundwater, soil acidification, acid rain, and greenhouse gas emissions (26). Better understanding household livelihood dynamics and behavioral responses to policies can help policy makers see not only the direct impacts of policies, but also programs' indirect or dynamic implications.

Additionally, for the water quantity and quality benefits of the PLDL program to persist, providers must maintain the land use change that generates the improvements. However, more than 88% of the participating households say they would revert back to farming rice if the payments stop (Fig. S1). This brings into question the permanence of the PLDL as a long-term solution.

Overall, this study provides a framework for incorporating household livelihood changes in an assessment of a PES program, which has important policy and methodological implications for PES design and assessment, future research on PES, livelihoods, and the environment. We see a need to standardize approaches to these issues, offering easy replication and scalability. However, approaches must also have built-in flexibility so that programs can be tailored to local conditions and constraints, which are influenced by social and economic contexts at national, regional, and local levels. Our example highlights how PES programs can induce activities that could have a positive or negative total effect on environmental outcomes, and serves as a reminder that households react strategically to the incentives they face. PES policy design should carefully consider the right set of institutions that will facilitate long-term positive environmental and livelihood outcomes, while avoiding or minimizing the possible negative ones.

## Methods

**Cost–Benefit Analysis.** ***Providers.*** The crops households choose to grow in the Miyun Reservoir watersheds affect both the quantity and quality of water in the reservoir. Thus, these upstream households are the providers of these ecosystem services. Switching from paddy rice to corn production increases downstream flows and decreases nutrient loadings (as we show below). However, this switch also reduces household income. The opportunity cost (*OC*) per hectare of switching from paddy rice to corn is measured by the difference between the net income of planting rice and the net income of planting corn:

$$OC = (G_r - C_r) - (G_c - C_c),$$

where $G_r$ and $C_r$ are the gross income and cost of planting rice (yuan per hectare), respectively, and their difference is the net income from rice ($N_r = G_r - C_r$). $G_c$ and $C_c$ are the gross income and cost of planting corn (yuan per hectare), respectively, and their difference is the net income from planting corn ($N_c = G_c - C_c$). Data were taken from residents' responses in the household survey. All currency is adjusted to 2010 value, and we use 2006 data for rice because no rice was grown in the watershed in 2010. Descriptive statistics for reported values of these measures are shown in Table S1.

***Beneficiaries.*** In this government-financed PES program, the Beijing municipal government is the buyer of ecosystem services acting on behalf of the residents of Beijing who are the ultimate beneficiaries of the PLDL program. The benefits to beneficiaries (*B*) in terms of ecosystem service value are as follows:

$$B = ESV_{wr} + ESV_{wq},$$

where $ESV_{wr}$ is the value of increased water resource provision, and $ESV_{wq}$ is the value of improved water quality. The increase in the value of water resources ($ESV_{wr}$) is equal to $P_w * WR$, where $P_w$ is price of the water resource (in yuan per cubic meter) and *WR* is the increase in water resource (in cubic meters). The value of improved water quality is as follows: $ESV_{wq} = P_{TN} * E_{TN} + P_{TP} * E_{TP}$, where $P_{TN}$ and $P_{TP}$ are the cost of TN treatment (in yuan per kilogram) and cost of TP treatment (in yuan per kilogram), respectively; $E_{TN}$ and $E_{TP}$ are the change in export of TN (in kilograms per hectare) and change in export of TP (in kilograms per hectare), respectively. Parameter values were determined by past studies (*SI Text*).

The cost of the program to the beneficiaries includes the direct compensation given to the upstream providers and the transaction costs associated with the operation, maintenance, and administration of the PLDL program for the Beijing Water Authority. The direct payment to providers is 550 yuan per mu. The Beijing Water Authority and Beijing Municipal Finance Bureau (16) report that the transaction costs account for 11.3% of the total program fund, i.e., 1,053 yuan per ha per y.

**Household Livelihood Survey.** In May and June of 2011, we conducted household surveys with 394 households participating in the program and 329 nonparticipating households. We used multistage random sampling to generate the sample. There are 155 villages within 25 rural townships that participated in the PLDL program. We selected about 40 villages in these participating townships and their nearby townships. We conducted the survey with about 18 randomly selected households from each village. Each village had (*i*) substantial participation in the PLDL program, (*ii*) at least as many nonparticipants as participants, and (*iii*) an adequate population size so that our results would be broadly generalizable to the region. Ultimately, we surveyed of 723 households in 41 villages.

The survey focused on livelihood assets, adaptive and productive activities, and the diversity of income sources (6, 27–29). As is common with government programs in China (e.g., ref. 30), design and implementation of the PLDL program was rapid, making it difficult to conduct a representative baseline survey before implementation. Instead of a baseline survey, we asked households to report information about their earnings and livelihoods in 2006 before implementation of the program in addition to their current status in 2010. We also collected information on demographic characteristics, production and consumption activities, household wealth and assets, and respondents' perceptions and satisfaction with the program.

**Methods for Estimating Changes in Livelihoods.** We use DID methods to estimate changes in livelihoods spurred by the PLDL program. Potential unobservable differences between participant and nonparticipant households before implementing the program make a simple comparison of mean differences after the program across the two groups incorrect. DID methods control for overall trends that would affect a random sample of both groups similarly, such as changes in conditions that increase outmigration of labor, nonfarm activity, and income over the study period. These methods assume that, in the absence of the program, the average outcomes for the program participants (the treatment group) and nonparticipants (the control group) would follow similar paths over time. This controls for time-invariant unobservable effects that create differences in the groups that are not due to the program. Given a large enough sample of households, if we find significant differences in trends between the two groups, we can attribute these changes to the program. Formally, the standard DID estimate of impact can be denoted by the following:

$$Z_{DID} = [E(Y_t|D=1) - E(Y_{t'}|D=1)] - [E(Y_t|D=0) - E(Y_{t'}|D=0)],$$

where *Y* is the outcome of interest, *D* represents whether the household is a participant (1) or not (0), *t* denotes the time period when the program is operation, *t′* denotes the time period before the program begins, and *E* is the expectation operator. In words, the DID estimator is the difference in *Y* for participants across the two time periods minus the difference in *Y* among nonparticipants over the two time periods.

Systematic differences between participating and nonparticipating households can impact DID estimators if these differences affect how households react to the program. Given the large cash transfers that the PLDL program provides, we might expect different responses in households' livelihood activities based on observable demographic and asset characteristics of the households. Therefore, we also combine DID estimation with propensity score matching (e.g., refs. 31–33), which places more weight on comparisons across "matched" households that are more similar to one another in the initial time period. Details on the methods used to generated $Z_{DIDM}$ are discussed in *SI Text* and Figs. S1 and S2.

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