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Hidden cost of conservation: A demonstration using losses from human-wildlife conflicts under a payments for ecosystem services program

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ABSTRACT

As global efforts to protect ecosystems expand, there is increasing concern about conservation costs borne by rural communities. To date, these costs have often been narrowly estimated in terms of foregone livelihood opportunities directly caused by conservation, while unintended human burdens that accrue with ecological gains from conservation are often ignored. As a first attempt to quantify this previously hidden cost, we estimated the impact of converting cropland to forest under one of the world's largest conservation policies, China's Grain-to-Green Program (GTGP), on crop raiding in a demonstration site using the matching approach. We found that GTGP afforestation was responsible for 64 % of the crop damage by wildlife on remaining cropland, a cost worth 27 % of GTGP's total payment to farmers. Our study highlights that the conservation cost to communities through influencing human-wildlife conflicts can be substantial, which should be quantified and considered in global conservation efforts to avoid unintended burdens on rural communities.

1. Introduction

Since the start of the 21st century, a remarkable international agreement on the urgency of poverty alleviation has made the conservation costs borne by rural communities an important concern (Andam et al., 2010; Colglazier, 2015). In response, there has been a growing search for conservation strategies that integrate mechanisms (e.g., direct payment) to avoid worsening livelihoods of rural communities (Adams et al., 2004; Roe and Elliott, 2006). So far, however, it has often been found difficult to achieve wins for both ecosystem conservation and welfare of communities in conservation areas (Muradian et al., 2013; Rasolofoson et al., 2017). Previous studies show a likely approach to address this challenge is to identify, then mitigate, the costs conservation efforts impose on local people (e.g., arrangements that truly compensate) (Ando et al., 1998; Ansell et al., 2016; Kremen et al., 2000). To date, however, conservation costs to communities have often been narrowly estimated based on direct impacts of conservation on livelihoods (e.g., forgone revenue due to cropland retirement or logging ban), while indirect impacts accruing with ecological gains from conservation have often been ignored.

A striking example of such indirect impacts involves the intensification of human-wildlife conflicts. Global conservation efforts over the past decades have generated many ecological gains, as evidenced by the forest transition in China (Viña et al., 2016), the comeback of gray wolves in the USA (USFWS, 2013), and the population growth of carnivores in Europe (Chapron et al., 2014). While these efforts have enhanced the provision of ecosystem services (i.e., benefits people obtain from ecosystems (Millennium Ecosystem Assessment, 2005)), they may unexpectedly threaten human well-being by increasing human-wildlife conflicts (Bonacic et al., 2016; Linkie et al., 2007) such as livestock depredation, crop raiding, damage to property, and spread of diseases. Although it is believed that conservation gains can increase human-wildlife conflicts and ecological factors shaping human-wildlife conflicts have been extensively studied (Linkie et al., 2007; Naidoo et al., 2006; Treves et al., 2006), the impact of a specific conservation intervention on human-wildlife conflicts has rarely been quantified. Quantification of the wildlife damage caused by conservation policy is important because it can provide crucial information for the design of effective management actions (e.g., setting a fair compensation scheme) to avoid worsening the lives of poor rural people

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(Ceaușu et al., 2019).

As a first attempt to quantify this previously hidden cost, we estimated the effect of afforestation promoted by China's Grain-to-Green Program (GTGP) on crop damage by wild animals using household survey data from Wolong Nature Reserve (Wolong hereafter). GTGP is one of the world's largest programs of payments for ecosystem services (PES, incentives offered to landowners in exchange for managing their land to provide some ecosystem services) (Liu et al., 2018). It is a Pigouvian PES program financed by the Chinese government, and the government pays land stewards for provision of ecosystem services, which distinguishes it from Coasean PES programs under which the beneficiary of ecosystem services pays the service provider directly (Schomers and Matzdorf, 2013). GTGP began its pilot study in three provinces (Sichuan, Shanxi, and Gansu) in 1999 and was expanded to 25 provinces in 2002 (Liu et al., 2008). It aims to increase the provision of ecosystem services (e.g., water and soil retention) through paying rural farmers to convert their cropland to forest or pasture land (Liu et al., 2008). In addition to its primary goal of ecosystem conservation, GTGP has a secondary goal of alleviating poverty (SFA, 2002). To offset the associated forgone crop production, GTGP designed a payment scheme to compensate participating households (SFA, 2002). Under GTGP, the government offers farmers 3,150 yuan (or 505 USD as of 2014) per ha per year for converted crop land in the upper reach of the Yangtze River Basin and 2,100 yuan in the upper and middle reaches of the Yellow River Basin. In addition, a one-time subsidy of 750 yuan per ha for seeds or seedlings was provided (Feng et al., 2005). The duration of the subsidy depends on the cropland conversion outcome: 8 years if the crop land is converted to ecological forest by using tree species such as pine and black locust; 5 years if converted to economic forests by using fruit trees; and 2 years if converted to grassland. In 2007, the government extended payments for GTGP. The annual subsidy during the extension are half of the amounts in the initial program, but the durations of the annual payments for different types of cropland conversion are the same (Liu et al., 2008). By the end of 2014, the program had converted about 9.27 million hectares of cropland from more than 30 million households to forest land or pastureland with a total investment of 405.66 billion yuan (Liu et al., 2008; Wu, 2015).

However, afforestation on cropland prompted by GTGP might have intensified crop raiding on remaining cropland unenrolled in GTGP, a cost that was not considered in GTGP's payment scheme. In many rural areas like Wolong, cropland parcels close to forests are often susceptible to damage by wild animals (Linkie et al., 2007; Yang et al., 2018a) and were more likely to be enrolled into GTGP than cropland farther from forests (Fig. 1). But the conversion of cropland to forest may make it new habitat for crop raiders and make remaining cropland more vulnerable to crop raiding (Fig. 1). In addition, crop damage previously borne by cropland enrolled in GTGP may be displaced to nearby remaining cropland and increase crop damage there (Fig. 1).

In this study, we aim to estimate the impact of GTGP on crop damage by comparing the observed crop damage on remaining cropland with the counterfactual crop damage that would have occurred on the same remaining cropland if the GTGP were not implemented. For practical reasons, we cannot observe this counterfactual crop damage directly. Instead, we estimated the impact by comparing damage on remaining cropland parcels close to and affected by GTGP afforestation with their counterparts that are far from and were not affected by GTGP afforestation using the matching method (Stuart, 2010). The difference in crop damage between remaining cropland affected by GTGP and their counterparts unaffected by GTGP represents GTGP's impact on crop damage.

2. Materials and methods

2.1. Study area

Wolong is a flagship protected area in Southwest China and within one of the world's top 25 global biodiversity hotspots (Fig. 2) (Liu et al., 2016a). It is 2000 km^2 in size (Tuanmu et al., 2011; Bai et al., 2018). Besides providing sanctuary to hundreds of wildlife species (including the iconic giant panda (*Ailuropoda melanoleuca*)), Wolong houses about 4900 residents, most of whom are farmers (Liu et al., 2016a). To restore and protect ecosystems, a series of conservation programs have been implemented since the early 2000s, including GTGP (Yang, 2018, 2013).

In Wolong, GTGP enrollment began in 2000, and additional contracts were signed in 2001 and 2003. No more cropland was enrolled in GTGP after 2003. Under this program, the government paid households for converting their cropland to ecological forest and keeping it vegetated since the enrollment (Yang, 2013). In total, about 56 % of cropland was converted to forest. The majority of cropland parcels enrolled in GTGP were close to the forest edge and were susceptible to crop raiding (Chen et al., 2010). Like many other rural areas, crop damage by wild animals, such as wild boar (*Sus scrofa*), sambar deer (*Rusa unicolor*), and hedgehog (*Erinaceinae*), is common in Wolong (Yang, 2013). Households take various preventative measures to mitigate the impact of crop raiding such as building fences, tying their dogs to stakes on the edge of cropland, and sending a household member to patrol cropland when crop damage was most likely to occur.

2.2. Study design

To evaluate the impact of GTGP afforestation on crop damage on remaining cropland, it is necessary to identify the corresponding counterfactual crop damage under a without-GTGP scenario. This counterfactual can be approximated using crop damage in similar areas where GTGP was not implemented (thus was unaffected by GTGP), or the crop damage on the remaining cropland before the implementation of GTGP. In this study, we used crop damage on cropland unaffected by GTGP afforestation to construct the counterfactuals (or controls). We chose this approach rather than comparing the crop damage on remaining cropland before and after the implementation of GTGP because the change from this before-after comparison might be partly caused by factors other than GTGP. Previous studies (Tuanmu et al., 2016; Yang et al., 2013a) show that human-wildlife conflicts in Wolong have been increasing since the early 2000s. In addition to GTGP, other synchronous factors such as the implementation of Natural Forest Conservation Program (Yang et al., 2013b), tourism development (Liu et al., 2016a,b) and labor migration (Chen et al., 2016) in Wolong might have also contributed to this trend through reducing human disturbances such as fuelwood collection and logging (Chen et al., 2012; Yang et al., 2018b). However, how much each of those factors contributed to the crop damage change was unclear. Furthermore, the crop species on the same cropland parcel may vary across years. Therefore, the observed changes in crop damage on remaining cropland after the implementation of GTGP is a joint effect of multiple factors and cannot reliably reflect the effect of GTGP.

Based on the distance to the nearest GTGP land parcel (former cropland enrolled in GTGP and afforested), we placed each remaining cropland parcel in our sample into one of the three ranges: close (< 10 m); medium (10 m–40 m); and far (> 40 m). Cropland parcels in the close and medium ranges were considered as treatment groups whose crop damage was highly and moderately affected by GTGP afforestation respectively, assuming that cropland plots closer to GTGP land were affected more by GTGP afforestation than distant ones. Cropland parcels in the far range were treated as the ones unaffected by GTGP afforestation. We chose 40 m as the threshold distance because we found that for cropland parcels in this range, being closer or farther to GTGP afforestation does not have statistically significant effects on crop damage (Table S9). This indicates that the impact of GTGP afforestation on crop damage in this range is negligible (Supplementary Materials).

We estimated the impacts of GTGP on crop damage of cropland

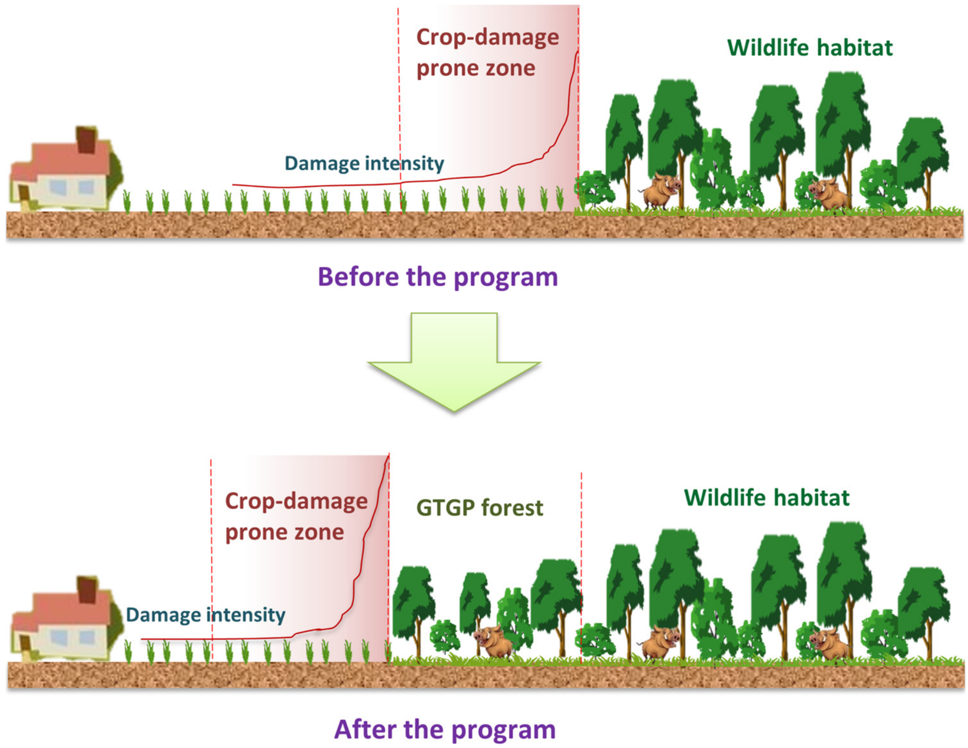

Fig. 1. Illustration of the change of crop damage by wildlife before and after afforestation on cropland promoted by conservation program. Before afforestation, cropland close to wildlife habitat (e.g., forest) is more severely affected by crop damage by wildlife than distant ones. After afforestation, cropland close to wildlife habitat are afforested and the nearby remaining cropland becomes more severely affected by crop damage by wildlife.

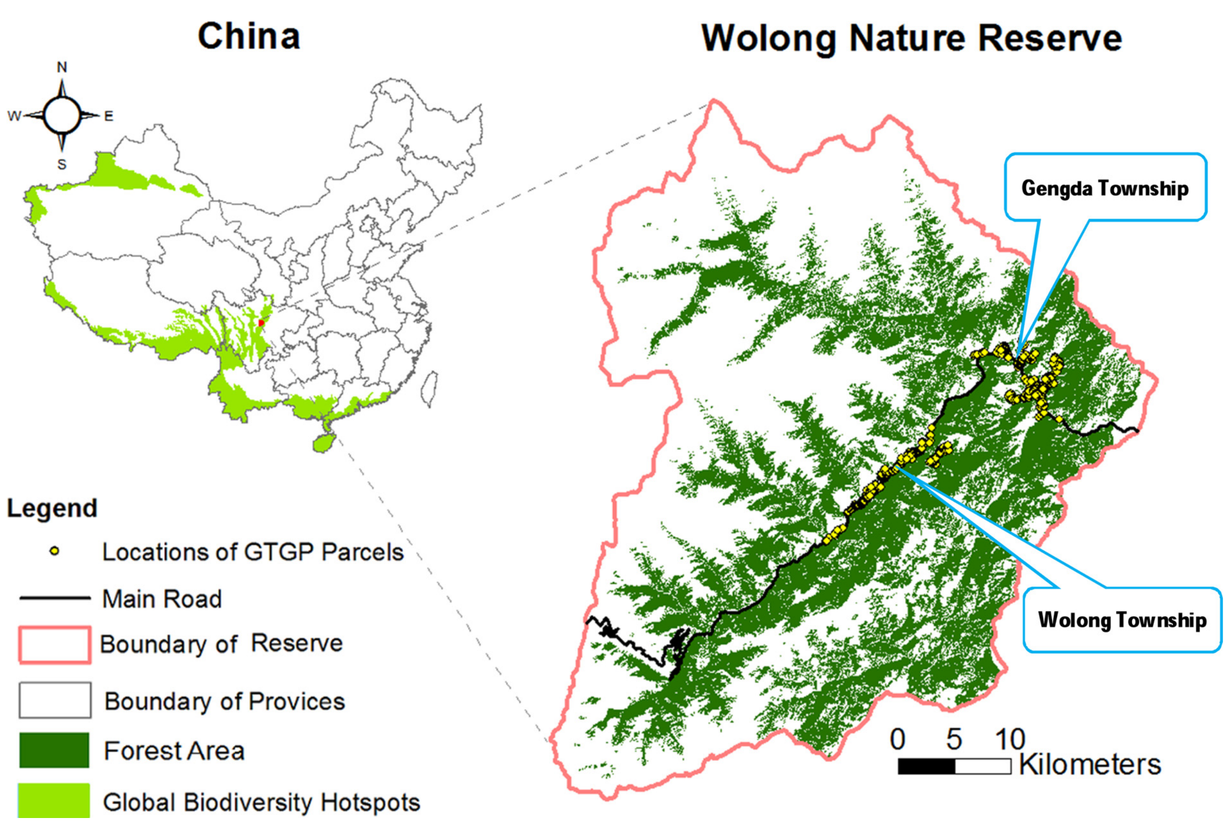

Fig. 2. Wolong Nature Reserve in Southwest China. The reserve was established in 1963 and expanded to its current size of 2000 km^2 in 1975. It is managed by the Wolong Administration Bureau, which is hierarchically structured with two townships under its governance – Wolong Township and Gengda Township, with a total population of about 4900.

parcels in both the close and medium ranges by comparing their crop damage with that on cropland parcels in the far range. To make sure the cropland plots in treatment and control groups are comparable, we controlled a set of attributes using the matching method (Stuart, 2010), including distance to natural forest (forest other than forest on land enrolled in GTGP), slope, distance to the main road, distance to nearest house, crop type, and preventive measure (Table S1). The outcome measure in our comparisons is crop damage intensity: the reported

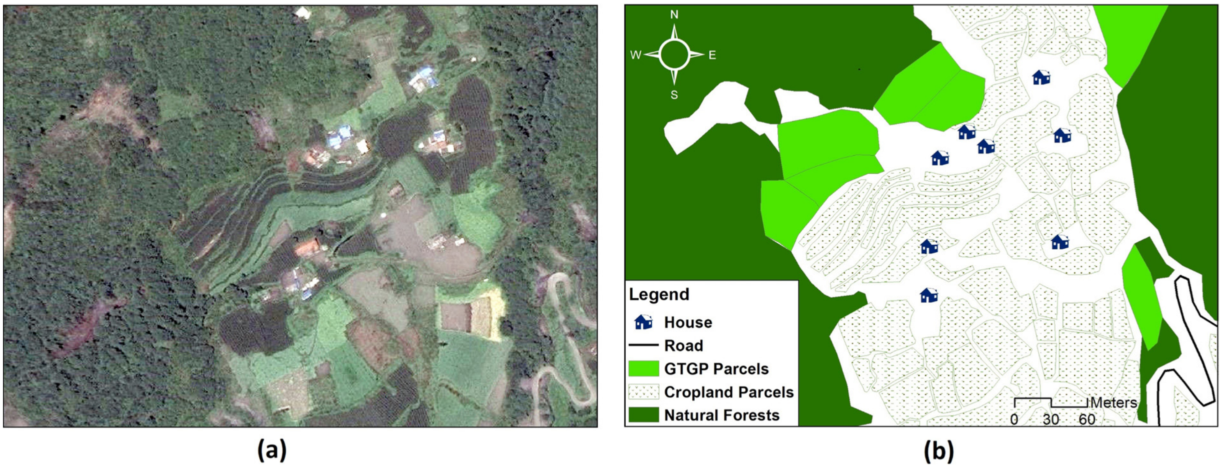

Fig. 3. The spatial pattern of land cover in an example area of Wolong. (a) Google Earth Image of a sample area in Wolong; and (b) the corresponding classification map based on survey results and visual interpretation.

proportion of crop lost in a land parcel due to wildlife damage (see Section 2.3). We estimated the impacts of GTGP on crop damage for all crop types together and for each crop type separately, including corn, potato, and cabbage. Our hypothesis that GTGP afforestation intensified crop damage on nearby remaining cropland would be supported if impact in the close range is larger than impact in the medium range and both of them are positive.

2.3. Data collection

We conducted a household survey in Wolong in 2015. Household heads or their spouses were interviewed because they are familiar with household affairs (e.g., locations of cropland and losses due to wildlife damage). We had 245 households (about 21 % of the total) randomly sampled and completed our survey. On Google Earth Imagery of Wolong (Google Earth V 7.1.5, 2015), we digitized boundaries of all cropland parcels owned by each surveyed household with respondents' help. For each cropland parcel, we asked questions about characteristics of the land plot, including type of crop, the yield, crop loss due to wildlife damage, crop price, and whether preventative measures (e.g., building fences) were taken to avoid damage by crop raiders. In total, we collected information on 423 cropland parcels, of which 169, 97, and 157 fell into the close, medium and far ranges, respectively, and 176 experienced crop raiding in 2014.

Before administering the formal survey, we pretested and revised the questions to enhance data reliability. The pretest involved a sequence of one-on-one cognitive interviews (Willis, 2004) with 33 individual interviewees. The goals of our pretests included assessing respondents' comprehension of our survey questions, the questions' difficulty, and the quality of respondents' answers. As the cognitive interviews progressed, we iteratively updated our questions and improved our survey instrument before administering the formal survey.

Regarding crop loss due to wildlife damage, we designed the questions to be easy for respondents based on feedback from the pretests. Our pretest interviewees told us it was easy to report crop raiding because the size of each cropland plot in Wolong is small (average area is about 2.5 mu or 0.16 ha) and each household does not have much cropland (average area is about 2.9 mu or 0.19 ha) to care for. Therefore, if damage by crop raiders occurred on their cropland, it would be easy for them to know and differentiate that from losses caused by other factors such as insects, diseases, and drought.

In our pretests, we explored alternative ways of eliciting crop damage intensity for each cropland parcel and probed interviewees for ways to avoid biased estimation, which led to several refinements including two major ones. First, before the interview, we determined it was important to explain clearly that the survey information would be used for research purposes only, otherwise some respondents may think the reported loss would be used for damage compensation purposes and thus tend to report a higher loss than the actual amount. Second, it was crucial to ask crop loss in an understandable way for local households. Instead of asking how many kilograms of crop was lost due to crop raiding, our interactions with interviewees led to our approach of asking for the zero-yield area (equivalent area with no yield due to crop raiding) for each cropland parcel. We found respondents could visually estimate the extent to which each part within a land plot was affected. Since the total area of a plot is small, the respondents could easily aggregate damages occurred at different parts of a plot to zero-yield area of that plot by adding up the areas of different parts affected by crop raiding weighted by their levels of damage (damage intensities). We can formally represent this thought process using the following equation:

$$\text{Zero-yieldArea} = \sum_{i}^{N} Area_i \times DamageIntensity_i \tag{1}$$

where N is the number of damage intensity levels occurred within the land plot; $DamageIntensity_i$ and $Area_i$ represent the damage intensity level i and the corresponding area within the land plot affected by this level of damage respectively. For example, assume the area of a potato land parcel is 1 mu. Of it, 0.2 mu was affected by crop raiding, with 0.1 mu seriously affected (all potatoes were eaten by crop raiders) and 0.1 mu was moderately affected (half of the potatoes were eaten by crop raiders). The corresponding zero-yield area would be 0.15 mu (= 0.1 × 1 + 0.1 × 0.5). Zero-yield area of a cropland parcel divided by the parcel's area is the parcel's crop damage intensity (i.e., proportional crop loss) used in our impact estimation analysis.

Using Google Earth Imagery, we also obtained boundaries of all GTGP parcels in Wolong by interviewing village leaders familiar with the distribution of GTGP land. In addition to the above information, we mapped the distribution of all houses, the main road, and forest areas in Wolong based on visual interpretation of Google Earth Imagery (Fig. 3). Average slopes of cropland parcels were calculated using ArcGIS (version 10.4, ESRI Inc., CA) with elevation information from Shuttle Radar Topography Mission. The survey instruments and data collection procedures we used in this study were reviewed and approved by the Institutional Review Board of Michigan State University (https://hrpp.msu.edu/).

2.4. Estimating the impact of GTGP on crop damage

We estimated the impact of GTGP on crop damage using the matching method (Stuart, 2010). The matching method is a popular approach for evaluating the impact of policy interventions in social science and is gaining momentum in the field of conservation ecology. There have been many example applications of this approach in conservation ecology (e.g., Andam et al., 2008, 2010; McConnachie et al., 2015). The logic of matching in our analysis is straightforward. For each cropland parcel in the treatment group (either in the close or medium range), the matching method finds a cropland parcel in the far range as control that is similar in terms of the observable attributes that may correlate to closeness to GTGP land and crop damage (called confounding factors). After controlling these observable cropland attributes using matching, the difference in crop damage intensities between cropland parcels in the treatment group (units in the close or medium range) and the control group (matched units in the far range) will reasonably represent the effect of GTGP afforestation on crop damage. As compared with other approaches, such as generalized linear model, the matching method is more robust to model misspecification, have less strict assumptions, and is more reliable for estimating the effect of GTGP afforestation on crop damage on nearby remaining cropland (see *Matching method for impact estimation* in Supplementary Information).

Based on our knowledge of Wolong and literature on crop damage, we controlled for a rich set of variables commonly found to affect crop damage, including crop type, slope, preventive measures, and distances to main road, natural forest edge, as well as the nearest house (Table S1). We used a one-to-one matching method with replacement to estimate the impacts. A genetic search algorithm (Diamond and Sekhon, 2013) and caliper (0.5 standard deviation of each matching covariate) were used to improve the matching quality. After matching, the differences of these covariates between treatment and control groups move dramatically toward zero (Tables S2 and S3), indicating good matching quality (Ho et al., 2007). For example, after matching, the average distance to the natural forest between cropland in close and far ranges decreased from 35.2 m to 2.5 m and the average distance to the nearest house decreased from 31 m to 1.7 m (Table S2). We then estimated the impacts of GTGP on crop damage intensities using a bias-adjustment estimator (Abadie and Imbens, 2006) which can address imperfect matching in our sample (i.e., remaining covariate differences between treatment and control groups). Since different crop types may have different levels of susceptibility to crop damage by wild animals, we estimated the impacts of GTGP on crop damage for all crop types together and for each crop type separately, including corn, potato, and cabbage. Despite our efforts to control for observable sources of bias, there might still be some unobserved differences between the treatments and controls that can lead to a correlation between closeness to GTGP land and crop damage. We therefore performed sensitivity analyses (see *Robustness Checks* in Supplementary Information) to evaluate how strong the hidden bias needs to be to alter the conclusion of our study. We performed the matching and sensitivity analysis in R (R Development Core Team, 2013) using the packages named 'Matching' (Sekhon, 2011) and 'Rbounds'(Keele, 2011) respectively.

After estimating the impacts of GTGP on crop damage intensities in the close and medium ranges, we further estimated the average proportion of observed crop damages attributable to GTGP for all crops together and each crop type separately using:

$$\text{Proportion}_i = \frac{In_{close,i} \times A^s_{close,i} + In_{medium,i} \times A^s_{medium,i}}{I_{close,i} \times A^s_{close,i} + I_{medium,i} \times A^s_{medium,i} + I_{far,i} \times A^s_{far,i}} \tag{2}$$

where $i \in \{corn, potato, cabbage, all\ crops\ together\}$; $In_{close,i}$ and $In_{medium,i}$ represent average increases of crop damage intensity caused by GTGP for cropland units of crop type i in the close and medium range respectively; $I_{close,i}$, $I_{medium,i}$ and $I_{far,i}$ represent average crop damage intensities for cropland units of crop type i in the close, medium and far ranges respectively; $A^s_{close,i}$, $A^s_{medium,i}$ and $A^s_{far,i}$ represent the total areas of sample units of crop type i in the close, medium and far ranges respectively.

2.5. Estimating the forgone crop revenue due to GTGP-induced crop damage

Based on the impacts of GTGP on crop damage intensities of each crop type in the close and medium ranges, we assessed foregone crop revenue due to crop damage attributable to GTGP in Wolong using:

$$\text{Forgone Revenue}_i = (In_{close,i} \times A_{close,i} + In_{medium,i} \times A_{medium,i}) \times Productivity_i \times Price_i \tag{3}$$

where $i \in \{corn, potato, cabbage\}$; Forgone Revenue$_i$ represents the forgone revenue due to the GTGP-induced wildlife damage to crop type i; $In_{close,i}$ and $In_{medium,i}$ represent average increases in crop damage intensity caused by GTGP for crop type i in the close and medium range respectively; $A_{close,i}$ and $A_{medium,i}$ represent total cropland areas of crop type i in close and medium ranges in Wolong estimated based on our sample cropland parcels respectively; $Productivity_i$ represents the average productivity (reported yield divided by area) of crop type i on cropland units that were not affected by crop damage in 2014; $Price_i$ represents the average price at which households in our sample sold crop type i in 2014.

3. Results

Impact estimates (Fig. 4) show that afforestation on GTGP land significantly intensified crop damage on remaining cropland, especially in the close range. The overall impact of GTGP on crop damage intensity (the reported proportion of crop lost in a land parcel due to wildlife damage) of cropland parcels in the close range (Fig. 4) was 0.189, implying the crop loss increased by18.9 percentage points due to GTGP. Impacts of GTGP on crop damage varied across different crop types. On average, GTGP afforestation increased the crop damage intensity on corn and potato parcels in the close range by 0.244 and 0.198 respectively ($p < 0.001$). As compared with corn and potato cropland, GTGP's impact on damage on cabbage cropland in the close range is smaller (0.022, $p < 0.05$).

The impacts of GTGP on crop damage intensity of cropland units in the medium range is smaller than in the close range (Fig. 4). On average, afforestation from GTGP increased crop damage intensity in the medium range by 0.044 ($p < 0.001$), which is about 25 % of that in the close range (0.189). GTGP increased damage intensity of potato and corn cropland in the medium range by 0.07 and 0.068 respectively ($p < 0.001$), which are about 28.7 % and 34.3 % of the corresponding impacts in the close range, respectively. This pattern that GTGP caused more wildlife damage on cropland in the close range than in the medium range further supports our hypothesis that GTGP afforestation

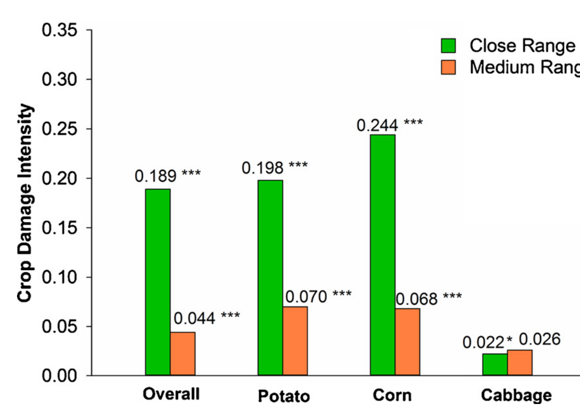

Fig. 4. Impacts of the GTGP on crop damage intensities of cropland in the close and medium ranges. Tabular presentation of these results can be found in Tables S4–S7. *, **, and *** indicate significance at $p < 0.05$, 0.01, and 0.001 levels respectively.

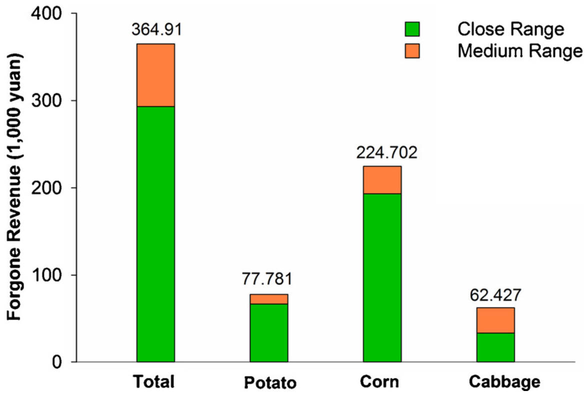

Fig. 5. Foregone revenue of crop damage in Wolong attributable to GTGP for each crop type and the total of them.

increased crop damage on nearby remaining cropland.

Based on the impact estimates above, we calculated the proportion of crop damage that occurred on remaining cropland attributable to GTGP (using Eq. (2) in *Methods*). The results suggest that had there been no GTGP afforestation, the overall crop damage on remaining cropland would be 64 % less. For corn, potato, and cabbage, the crop damage would be 63 %, 74 %, and 40 % less respectively if GTGP were not implemented.

With the estimated impacts of GTGP on crop damage for each crop type (Fig. 4), we further estimated the forgone revenue (using Eq. (3) in *Methods*). The total foregone revenue of crop damage attributable to GTGP in Wolong is 364,910 yuan (Fig. 5), a cost that amounts to 27 % of total annual payments farmers received from GTGP in Wolong. The revenue loss occurs mostly due to GTGP's impact on corn cropland (224,702 yuan), followed by potato land (77,781 yuan), and cabbage land (62,427 yuan).

4. Discussion

Our study suggests that China's sweeping conservation effort in returning cropland to forest might have done so with an until-now hidden consequence: it increased the wildlife damage to remaining cropland and thus caused unintended cost that whittled away at the program's compensation for farmers. Consideration of this previously hidden cost has important implications for conserving ecosystems ethically and sustainably. PES are increasingly implemented to reduce negative impacts of conservation on livelihoods of rural communities (Fischer et al., 2012; Naeem et al., 2015). To date, however, payment levels of PES programs are largely designed based on the foregone productive uses (e.g., farming) of the land being targeted (Liu et al., 2013). This would be unfair if a PES program brings other unacknowledged or undisclosed economic loss to communities in target areas. In the case of GTGP, the current payments are solely based on the amount of cropland afforested. The potential impact of GTGP on remaining croplands was not considered. The ignorance of this impact might leave local communities undercompensated under the program and potentially weaken the program's goal of alleviating poverty. Such problems may ultimately compromise the sustainability of conservation. As losses due to human-wildlife conflicts increase, farmers may increasingly resent conservation efforts.

To mitigate these negative impacts, integrated management strategies should be considered. So far, compensating households that experienced wildlife damage (including crop damage and livestock predation by wildlife) has been a common mitigation strategy (Nyhus et al., 2005). However, previous studies indicate that the use of compensation schemes has mixed results due to issues such as inefficient governance (e.g., corruption) and shortage of necessary resources (e.g., financial and human resource to handle all cases) (Nyhus et al., 2005; Storie and Bell, 2016). In Wolong, our survey shows that of all the cropland that experienced crop damage by wildlife, only 2 % received compensation because of the lack of necessary funds to handle all the cases. Therefore, other complementary measures such as preventative strategies and systematic land-use planning should be jointly considered to mitigate wildlife damage under circumstances like Wolong (Bulte and Rondeau, 2005; Gross et al., 2016). For example, given the relatively small size of the remaining cropland area in Wolong (< 0.15 % of the whole reserve), establishing fences around the remaining cropland may be a cost-effective way to reduce crop damage without much influence on the connectivity of panda habitats. In addition, switching to crop types less likely to be affected by wildlife damage may also help to address this issue. For example, plum has been introduced to Wolong in recent years and become a promising new type of cash crop. Unlike corn and potato, plum is not susceptible to wildlife damage. Planting plum on cropland close to forest may help reduce the losses due to wildlife damage and the negative impacts of GTGP. More generally, policy design could include consideration of damage mitigation approaches to moderate potential impacts on crop damage.

It should be noted that GTGP may generate some indirect benefits to offset the losses from its impacts on crop damage. For example, studies in other areas show that labor released from agricultural production due to cropland enrollment in GTGP has prompted the shift from on-farm to off-farm activities such as working in local tourism industry or out-migrating to work in cities (Liu et al., 2008). In addition, the associated ecological improvements may generate some beneficial services to households. For example, a previous study in Wolong (Chen et al., 2009) found the planted forests from GTGP offered a new fuelwood source for households, and thereby may reduce households' expenditure for electricity. Future research should be conducted to evaluate the potential trade-offs among different positive and negative effects of GTGP. The impacts of GTGP on crop damage quantified in this study lay a foundation for a future comprehensive cost-benefit analysis of GTGP.

Despite our efforts to control for sources of bias, the results of this study should be interpreted with two possible limitations borne in mind. First, minor differences in some relevant but unobserved factors might exist between matched treatment and control cropland units, which may form a potential source of bias in our impact evaluations. We estimated the impact of GTGP afforestation on crop raiding by comparing the losses on cropland in far range (i.e. far from GTGP afforestation) with matched units in the close or medium range. However, crop raiding is affected by many ecological and biophysical factors and it is impractical to measure and match the cropland units over all of them. Second, as with any other analyses based on survey data, some inaccuracy may remain in the reported information (e.g., crop damage intensity), though we have taken measures to improve the data reliability. To quantify how sensitive our estimates are to those uncertainties, we performed the Rosenbaum sensitivity analysis (Rosenbaum, 2002) to evaluate how likely it is that the conclusion of this study would be overturned due to those limitations. In addition, we performed a set of analyses to evaluate the robustness of our results to variability in study design (e.g., the threshold distance differentiating cropland highly and moderately affected by the GTGP) and assumptions (e.g., no systematic switch in crop types after the GTGP). Results of the robustness analyses show that all these possible sources of uncertainties are unlikely to change our conclusion (see *Robustness Checks* of Supplementary Information).

Although our analysis here is restricted to GTGP in China, similar hidden costs are likely to occur in regions where similar conservation efforts have been implemented. For example, in the United States, about 9.52 million hectares of cropland has been enrolled in the Conservation Reserve Program and become vegetated (USDA, 2016). In Europe, the Common Agricultural Policy has afforested about 8 million hectares of cropland (European Commission, 2013). In the Russian Federation, about 2.74 million hectares of cropland has been afforested for conservation (Kulik et al., 2015). The specific effects of these conservation efforts on human-wildlife conflicts may vary across different places, but the general trends may be similar. For example, in areas where populations of wildlife species that damage crops are smaller than in Wolong, the size of the effect of GTGP on crop damage might also be smaller because there would be less crop damage shifted from cropland enrolled in the program to remaining cropland that were not enrolled. To truly understand conservation costs to rural communities, more interdisciplinary studies are needed to quantify different sources of costs and understand the underlying processes across different contexts. Armed with such knowledge, conservation practitioners may be able to design more effective conservation programs for win-win outcomes such as the ones targeted by the United Nations Sustainable Development Goals (United Nations, 2016).

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Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.ecolecon.2019.106462.

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