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Integrating multiple influencing factors in evaluating the socioeconomic effects of payments for ecosystem services

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ABSTRACT

Integrating multiple external and internal processes into the evaluation of how payments for ecosystem services (PES) programs can affect socioeconomic outcomes allows us to distinguish the relative importance of each factor and identify specific strategies to enhance the desired outcomes of PES programs; yet, the methods available are limited. Based on the framework of metacoupling (human-nature interactions within and across adjacent and distant places), we developed an approach to distinguish the contributions and pathways of multiple influencing factors to socioeconomic outcomes by integrating linkages between influencing factors, livelihood activities, and socioeconomic outcomes. Here, the approach's operationalization is empirically demonstrated by identifying the impact of the Grain for Green Program (GFGP) and other external and internal factors influencing rural household income in China's Loess Plateau. We find that the local economy and investment rather than the GFGP were the dominant factors affecting income. With improved understanding of the pathways, several suggestions are proposed for the design and implementation of GFGP and other PES programs around the world. Our study highlights the necessity of applying integrated factors in evaluating socioeconomic effects of PES — a crucial input for guiding practice of PES programs to support sustainable development.

1. Introduction

Payments for ecosystem services (PES) have been recognized as an innovative way of dealing with trade-offs between environmental and development goals in nature conservation and environmental governance (Zheng et al., 2013; Wunder et al., 2018). They can directly incentivize landowners and other resource stewards to adopt environmentally friendly practices by realigning economic and social costs or benefits among different stakeholders through incentive-based mechanisms (Yang et al., 2013; Ola et al., 2019). In recent decades we have seen a considerable increase in the number of PES programs designed to encourage carbon sequestration, biodiversity or watershed ecosystem services (Salzman et al., 2018) from local and regional, to global scales (Yang et al., 2013). Nowadays, there are over five hundred PES programs around the world, involving payments of over US$36 billion per year (Salzman et al., 2018). Systematic evaluation of the ecological and socioeconomic outcomes of PES programs is crucial if we are to improve the design and implementation of these and future programs (Tallis et al., 2008; Yang et al., 2013; Yang and Lu, 2018).

Numerous studies have evaluated the effectiveness of PES programs in achieving their sustainability goals through comparisons of social-ecological changes before and after PES programs (Ouyang et al., 2016; Alix-Garcia et al., 2018; Bryan et al., 2018; Schirpke et al., 2018) or through cost-benefit analysis of PES programs (Birch et al., 2010; Zheng et al., 2013; Li et al., 2015a). The effect of PES programs on participants' income and livelihoods and their influencing mechanisms is one focus (Li et al., 2011; Ferraro and Hanauer, 2014; Jones et al., 2018). Revealing the pathways through which PES programs directly or indirectly affect target outcomes can provide specific explanations as to why certain outcomes occur, or fail to occur (Ferraro and Hanauer, 2014) — vital information for the PES programs in both theory and practice (Yang et al., 2018).

However, in parallel to PES programs, the socioeconomic outcomes also result from multiple socioeconomic and political factors operating concurrently across space (Liu, 2014; Lu et al., 2015; Ouyang et al., 2016), such as: economic development, industrialization and

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urbanization. These factors also improve household income and change livelihoods (Bryan et al., 2018). Neglecting any of these constituent variables may lead to dramatically different conclusions about the impacts of a PES program (Andam et al., 2010; Ferraro and Hanauer, 2014). Previous studies of the causal mechanisms or pathways of PES programs to socioeconomic outcomes usually controlled for, or blocked the effects of, confounding variables (Ferraro and Hanauer, 2014; Yang et al., 2018), and have mainly focused on the specific impacts of PES programs. Although these studies have generated useful information, current knowledge on how other metacoupled processes [human-nature interactions within and across adjacent and distant places (Liu, 2017)] affect socioeconomic outcomes is still limited in PES studies (Wu et al., 2019a). Integrating metacoupled factors into the evaluation of the socioeconomic effects of PES can distinguish the relative importance of each factor and help us rethink the role of PES programs. Revealing the pathways of multiple factors allows us to identify specific strategies to enhance the desired outcomes of PES programs.

Here, our objective is to develop a framework for distinguishing the contributions and pathways of multiple influencing factors to socioeconomic outcomes in PES studies. To do so, we first expanded the framework of pathways from PES programs to socioeconomic outcomes following Yang et al. (2018), to include multiple external and internal influencing factors based on the metacoupling framework (Liu, 2017). Then we demonstrated operationalization of this expanded approach by identifying the pathways of the Grain for Green Program (GFGP), and other external and internal factors influencing rural household income in China's Loess Plateau (LP).

2. Material and methods

2.1. Framework

2.1.1. Conceptual framework

Fig. 1 shows the framework developed to reveal the pathways through which multiple factors affect socioeconomic outcomes. The framework contains three major components: influencing factors, livelihood activities, and socioeconomic outcome. Linkages between these interrelated components constitute pathways through which multiple factors affect socioeconomic outcome while livelihood activities act as intermediary variables. This process means that influencing factors affect livelihood activities first; then livelihood activities affect socioeconomic outcome. Because different livelihood activities may be interrelated, linkages between them can constitute additional pathways (Yang et al., 2018). The award-winning metacoupling framework has been successfully applied to a number of important issues such as global marine fishing (Carlson et al., 2020) and impacts of international trade on UN Sustainable Development Goals (Liu et al., 2018; Xu et al., 2020). It can help uncover hidden systemic connections that may not be apparent when focusing on a particular system (Liu, 2017). Based on this framework, different external and internal influencing factors can be selected for different cases. Because the payments are mainly from beneficiaries outside conservation regions (Yang et al., 2018), PES programs can be seen as external factors. Other adjacent or distant factors or flows outside the conservation regions such as tourism, investment, trade, and human migration, are also external factors. On the contrary, factors within the conservation region, such as the local economy and local urbanization, are treated as internal factors.

In reality, the influencing factors affect socioeconomic outcomes through many different processes, and some of them may be difficult to specify due to some reasons like lack of data to describe related influencing factors or livelihood activities. Moreover, the indicators chosen to measure the livelihood activities may not capture all their dimensions (for example, the number of laborers involved in a livelihood activity may not be effective in reflecting the actual labor hours worked or the economic gains of that activity). Therefore, we used "unspecified pathways" — direct linkages between influencing factors and socioeconomic outcomes — to represent the pathways that influencing factors affect socioeconomic outcomes through other processes rather than livelihood activities chosen in the framework (Yang et al., 2018). For reliable estimation of these hypothesized pathways, control variables that may affect one or more variables along the pathways should also be properly considered in the analysis; including these variables avoids bias in the estimation of the linkages between components (Yang et al., 2018).

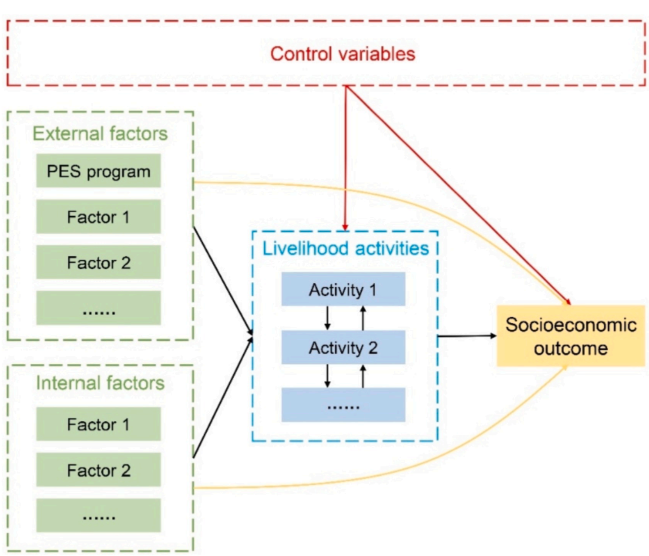

Fig. 1. Framework for analyzing the socioeconomic effects of PES programs from multiple factors. Arrows represent linkages through which variables affect other variables. Black arrows are the linkages that constitute the specified pathways. Yellow arrows represent the unspecified pathways. Red arrows represent the linkages through which control variables affect other components.

2.1.2. Demonstration of the framework

GFGP in China's LP (Fig. 2) was selected to demonstrate the operationalization of our approach. GFGP is one of the world's biggest PES programs (Liu et al., 2008; Wang et al., 2017) and addresses a range of environmental issues as well as socioeconomic challenges (Daily et al., 2013); this combination gives it global importance. The LP is a region with a fragile environment; in the past it has experienced severe environmental degradation. Considering these issues, the LP was prioritized as a pilot region for GFGP in 1999. It is the area where GFGP has been most intensively implemented (Lü et al., 2012), and is well recognized as being the most suitable case for analysing the ecological and socioeconomic outcomes of GFGP. Previous studies showed that application of the GFGP in the LP achieved the "win–win" gains of restoring the environment and promoting socioeconomic development. From 2000 to 2015, the normalized difference vegetation index (NDVI) of the LP increased by 21.7%, and soil retention and carbon sequestration services improved significantly. Simultaneously, grain output from the LP has increased by 56.7% (Wu et al., 2019a).

In our study, we chose annual per capita net income of rural households at county scale as the indicator of socioeconomic outcome, and focus on how external and internal factors affect the income of rural households by different pathways. The external and internal factors were differentiated by their origin. GFGP and tourism were selected as the external factors as the payments and visitors were mainly from outside of the local county. Influencing factors within the county including the local economy, and local urbanization were chosen as the internal factors. Due to the limitation of data at county level, it is difficult to distinguish whether the destination of rural migration is within or outside the local county, and whether the sources of investment and agricultural technology come from within or outside the county. Thus, we treated these three variables as external/internal

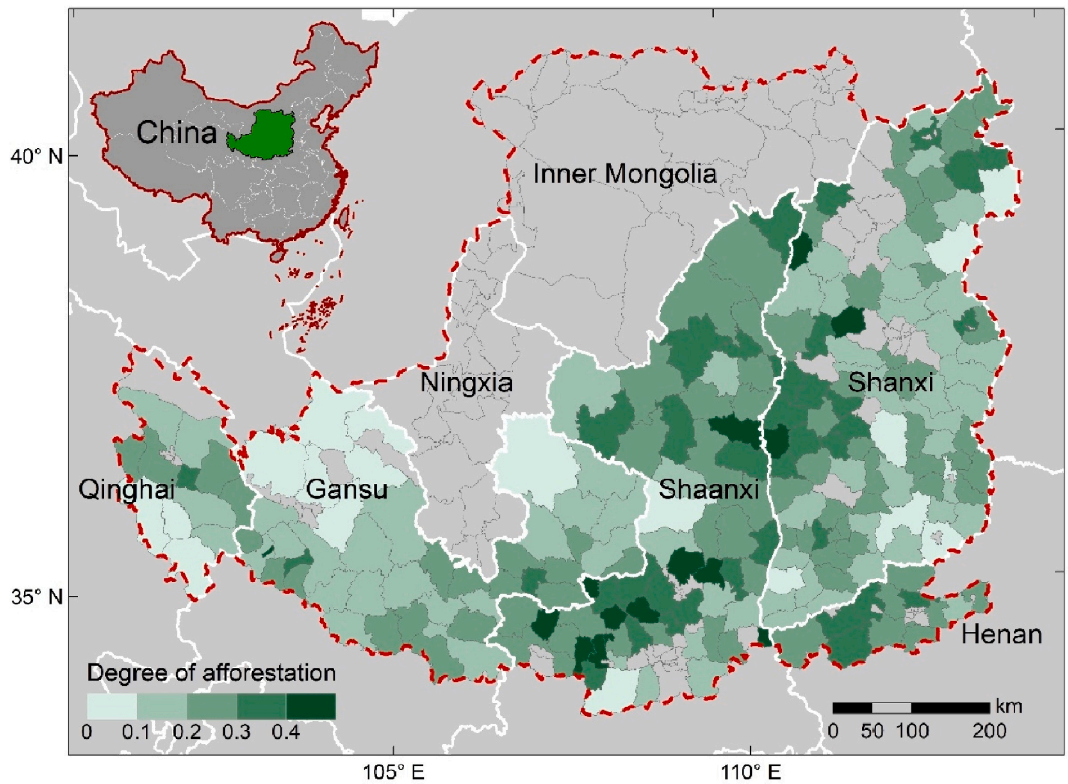

Fig. 2. Location of the Loess Plateau and the degree of afforestation (the cumulative area of afforestation divided by the total area) of the elected counties.

factors in our framework. Three general livelihood activities in the LP that might be intermediary variables to transmit the effects of these influencing factors, including crop production, non-farm work, and orchard fruit production were selected. For reliable estimation, a set of control variables to reflect the livelihood activities and income of rural households before GFGP were also used. The indicators for each variable are summarized in Table 1.

We hypothesized that linkages among influencing factors, livelihood activities, and income of rural households constitute different pathways (Fig. 3). As previous studies (Wu et al., 2019b) indicate, we first hypothesized that all the three livelihood activities can increase the income of rural households. We then hypothesized that GFGP, tourism, local economy, local urbanization, rural migration, and investment had positive effects on the participation in non-farm work. This is because previous studies show that the reduction in farmland caused by GFGP can release rural labor from crop production and promote the shift to non-farm activities (Liu et al., 2008; Uchida et al., 2009; Yin et al., 2014), and the urbanization process, development of the local economy and tourism, and investment in the local county can provide more non-farm work opportunities for these surplus laborers (Zhang, 2003; Gu et al., 2010; Yang et al., 2018). The rapid economic growth in China's cities stimulates an ever-growing demand for laborers, which can also help rural laborers find non-farm employment in cities through rural population migration (Yang et al., 2018). We then hypothesized that both GFGP and local urbanization had negative effects on crop production, while agricultural technology had a positive effect. Because GFGP converted some of the farmland to forest or grassland, and because local urbanization also converted farmland to urban use (Gong et al., 2012), less farmland was left for crop production. However, the improvement in agricultural technology increases the grain yield per unit area (Wu et al., 2019a). We also hypothesized that GFGP and agricultural technology had positive impacts on orchard fruit production because part of the farmland enrolled in GFGP was converted to fruit tree plantations (Liu et al., 2008), and orchard fruit yield per unit area should increase as technology improves. These linkages above form two-step pathways by which influencing factors affected three livelihood activities, which in turn affected the income of rural households (Fig. 3). Furthermore, we hypothesized longer pathways by linking these three livelihood activities. We hypothesized that non-farm work had negative effects on crop production and orchard fruit production. This is because non-farm work is often labor-intensive and more profitable, which means less labor is available for agricultural production such as crops or orchard fruit production (Yang et al., 2018).

The pathways of the influencing factors were analyzed by the structural equation modeling (SEM) approach using statistical data at county scale. Considering that these influencing factors may be interconnected, we also established correlation among exogenous variables in the SEM. To demonstrate the improvement of our approach in evaluation, we also compared the results from our expanded framework with that from a framework which only considered GFGP as the influencing factor, while other components in the two frameworks and the data used in the SEM were the same.

2.2. Study area

The LP is the deepest and largest loess deposit in the world (Fu et al., 2017). It covers an area of 640,000 km^2 comprising 334 county-level administrative regions of seven provinces, including Shanxi, Shaanxi, Gansu, Qinghai, Henan, Ningxia, and Inner Mongolia (Fig. 2). Previously, the LP suffered from serious soil erosion due to the highly erosion-prone characteristic of the loess, together with periodic high-intensity rainstorms, sparse vegetation cover, and a long history of inappropriate agricultural management (Zhao et al., 2013). It was the largest sediment source for the Yellow River (Wang et al., 2015). For a long time, the LP was notorious for its severe erosion, sparse vegetation, low agricultural productivity, and the poverty of local farmers (Fu et al., 2017).

Recognizing the seriousness of the issues facing the LP, several land management programs to reverse the deterioration of the environment (Lü et al., 2012) and promote sustainable rural development (Daily

Table 1
Variables of each county used in the structural equation model.

	Description	Mean	SD
Socioeconomic outcome			
Income of rural households	Log-transformed annual per capita net income of rural households in 2015 (yuan)	8.994	0.350
External factors			
GFGP	The ratio of accumulative afforestation area between 2002 and 2014 to total area of each county	0.239	0.113
Tourism	Log-transformed number of visitors (10^4) estimated by number of different-level scenic spots	4.180	1.941
Internal factors			
Local economy	Log-transformed per capita GDP in 2015 (yuan)	10.141	0.625
Local urbanization	Urbanization rate in 2010	0.326	0.121
External/internal factors			
Rural migration	(Population of agricultural registered permanent residence - rural population)/ population of agricultural registered permanent residence in 2010	0.224	0.110
Investment	Log-transformed total investment in fixed assets in 2015 (10^4 yuan)	13.722	0.790
Agricultural technology	Log-transformed per capita consumption of chemical fertilizer of rural households in 2015 (tonnes/person)	−3.068	0.778
Livelihood activities			
Crop production	Log-transformed per capita output of grain crops of rural households in 2015 (tonnes/person)	−0.674	0.553
Orchard fruit production	Log-transformed per capita output of orchard fruits of rural households in 2015 (tonnes/person)	−2.375	2.129
Non-farm work	The ratio of number of rural non-farm work laborers to number of rural laborers in 2015	0.413	0.128
Control variables			
Crop production (01)	Log-transformed per capita output of grain crops of rural households in 2001 (tonnes/person)	−1.335	0.800
Orchard fruit production (01)	Log-transformed per capita output of orchard fruits of rural households in 2001 (tonnes/person)	−3.322	1.669
Non-farm work (01)	The ratio of number of rural non-farm work laborers to number of rural laborers in 2001	0.277	0.102
Income (01)	Log-transformed annual per capita net income of rural households in 2001 (yuan)	7.284	0.418

et al., 2013) have been implemented by the Chinese government. Among these programs, GFGP is the biggest and best known (Liu et al., 2008). Starting in 1999, GFGP has returned a large area of sloping farmland to forest and grassland. By the end of 2014, 37.38 billion yuan (in 2015 6.28 yuan = US$1) had been invested in the Shanxi and Shaanxi provinces, the total forested area in the two provinces was 39.37×10^3 km^2 (Supplementary Fig. s1). Previous studies have found that the main ecosystem services improved after the implementation of GFGP (Lü et al., 2012; Bryan et al., 2018); with the socioeconomic effects being mostly positive (Liu et al., 2008; Li et al., 2011). The social-ecological system in the LP is affected by multiple external flows and factors. Taking the Shaanxi province as an example, there were 2.93 million person-visits from overseas visitors, 382.74 million person-visits from domestic visitors, 5.8 billion US dollars of foreign investments, and 189.5 billion yuan of imports and exports in 2015 (Supplementary Table s1). In 2010, about 1 million people migrated in and 2 million people migrated out of Shaanxi province, accounting for 2.6% and 5.3% of the total population, respectively. How these distant interactions like tourism, investment, trade, and human migration affect the local social-ecological system remains unknown.

2.3. Data sources

Data used in our study contain GFGP and socioeconomic statistics. The annual areas of afforestation for each county from 2002 to 2014 were obtained from the Chinese Forest Statistical Yearbook. The per capita net income of rural households, output of grain crops, output of orchard-grown fruits, rural population, the number of rural laborers, and the number of rural employees in farming, forestry, animal husbandry and fishery in 2001 and 2015, as well as consumption of chemical fertilizer (by 100% effective component), per capita GDP, and total investment in fixed assets in 2015 at county level were collected from the Statistical Yearbook of each province and prefecture, provided by Loess Plateau Data Center (http://loess.geodata.cn). The population of each county in 2000 and 2010 was obtained from the 5th and 6th national censuses. Numbers of different-level scenic spots in each county were collected from the website of the Department of Culture and Tourism for each province. Numbers of visitors in each county were then estimated by the number of scenic spots and the average number of visitors to different spots collected from statistics.

Variables used in the SEM were transformed from the raw data (Table 1). To reflect the socioeconomic effect of GFGP in rural areas rather than urban areas, we excluded those counties for which the urbanization rate exceeded 50% in 2000. Counties with incomplete data were also removed. A total of 221 counties were analyzed by the SEM (Fig. 2).

2.4. Structural equation modeling

We used structural equation modeling (SEM) to test the hypothesized linkages between influencing factors, livelihood activities, and income of rural households. SEM is used to understand causal relationships in systems by evaluating the statistical fit between abstract theories and empirical data. The method has provided insightful results when used to test hypotheses about causal interactions in ecological or social systems (Bollen and Noble, 2011; Lehmann et al., 2014). All variables in our framework could be treated as observable. The structural model framework is shown in Fig. 3. We conducted the statistical modeling and analyses with Mplus 7. The variance inflation factor (VIF) of each independent variable is less than 3.0, which means that the multicollinearity can be ignored.

A set of goodness-of-fit indices were used to test how well the data support the hypothesized pathways. All of the indices suggested that our empirical data supported the hypothesized pathways well (Supplementary Table s2, s4). We calculated standardized path coefficients to compare the strength of each linkage. The statistical significance of each of these coefficients was also tested.

3. Results

The effects and statistical significances of each linkage in our hypothesized framework are shown in Fig. 4. The effects of all the three livelihood activities on income of rural households are positive, but the effect of crop production is not statistically significant ($p > 0.1$) (Supplementary Table s3). GFGP positively affected non-farm work ($p < 0.01$) and orchard fruit production ($p < 0.05$), but negatively affected crop production ($p < 0.01$). Tourism ($p < 0.01$), rural migration ($p < 0.05$), and investment ($p < 0.05$) positively affected non-farm work. Agricultural technology had a significantly positive impact on crop production ($p < 0.01$). Non-farm work negatively affected crop production ($p > 0.1$) and orchard fruit production ($p < 0.05$). For the unspecified pathways in the framework, only local economy and investment significantly increased income ($p < 0.01$) through other processes that were not specified in this study.

Standardized path coefficients of the linkages (Fig. 3) can be used to

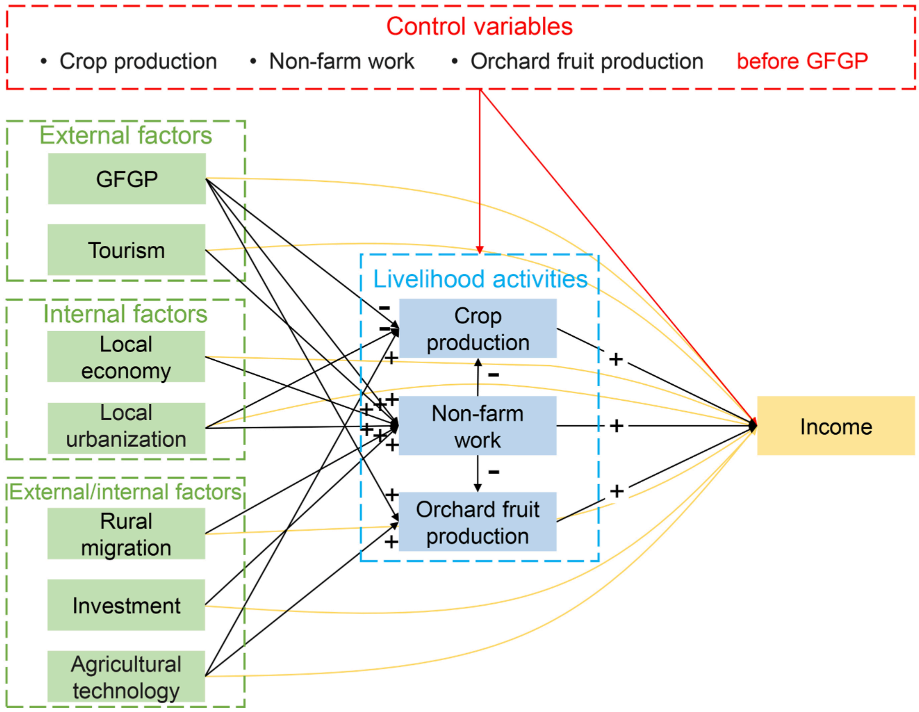

Fig. 3. Illustration of hypothesized linkages between influencing factors, livelihood activities, control variables, and income of rural households. Arrows in the diagram represent linkages. "+" and "−" represent hypothetical positive and negative effects of the linkage, respectively. The yellow arrows represent the unspecified pathways. For clarity, the correlation between exogenous variables are not presented in this diagram.

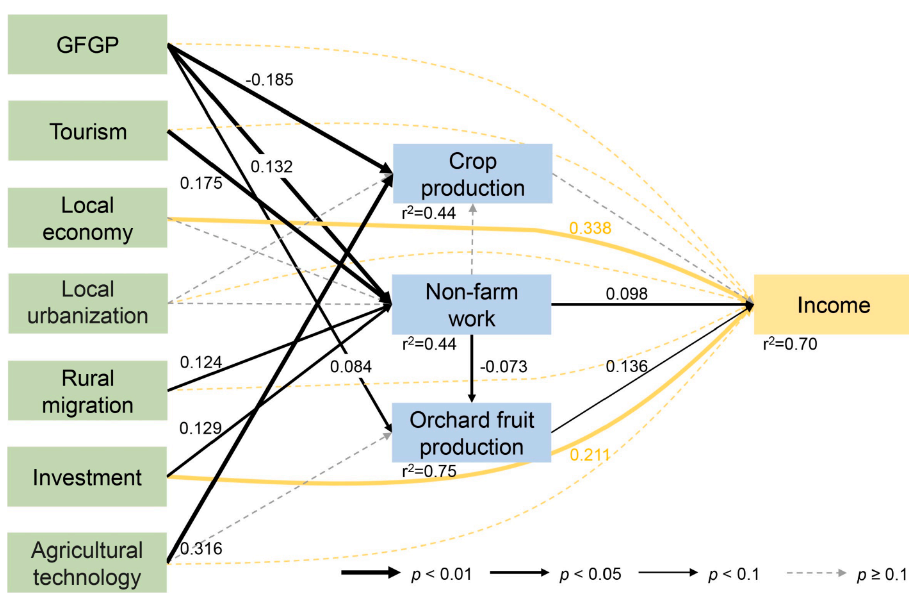

Fig. 4. Visualization of the structural equation model results. Values associated with arrows are standardized path coefficients of the statistically significant linkages. For clarity, the correlations between exogenous variables and the control variables are not presented in this diagram.

compare the strengths of effects. The unspecified effects of the local economy and investment on income of rural households are larger than that of non-farm work and orchard fruit production. The effect of the local economy is larger than that of investment. The sequence of significantly positive effects on non-farm work from high to low is: tourism, GFGP, investment, and rural migration. As for crop production, the positive effect of agricultural technology is larger than the negative effect of GFGP.

The total effects of all influencing factors are positive, but only the local economy and investment significantly affected income ($p < 0.01$) (Table 2). The results suggest that per standard deviation increase in per capita GDP of local county and investment in local county would increase per capita net income of rural households by 0.336 and 0.223 standard deviations, respectively. Although the total effects of GFGP and tourism on income are not statistically significant, there still are significant pathways — the pathway through which GFGP boosted participation in non-farm work, which then led to increase in income ($p < 0.1$) and the pathway through which tourism increased participation in non-farm work and then increased income ($p < 0.1$).

There are obvious differences between the results of our expanded

Table 2
The standardized effects of pathways through which the influencing factors affected income.

Influencing factor		Pathway	Effect
External factors	GFGP	GFGP → Crop production → Income	−0.012
		GFGP → Orchard fruit production → Income	0.011
		GFGP → Non-farm work → Income	**0.013***
		Unspecified pathway (GFGP → Income)	−0.006
		Total	0.006
	Tourism	Tourism → Non-farm work → Income	**0.017***
		Tourism → Non-farm work → Orchard fruit production → Income	−0.002
		Unspecified pathway (Tourism → Income)	0.006
		Total	0.021
Internal factors	Local economy	Local economy → Non-farm work → Income	−0.003
		Unspecified pathway (Local economy → Income)	**0.338*****
		Total	**0.336*****
	Local urbanization	Local urbanization → Crop production → Income	−0.004
		Local urbanization → Non-farm work → Income	−0.007
		Unspecified pathway (Local urbanization → Income)	0.021
		Total	0.011
External/ internal factors	Rural migration	Rural migration → Non-farm work → Income	0.012
		Unspecified pathway (Rural migration → Income)	0.043
		Total	0.054
	Investment	Investment → Non-farm work → Income	0.013
		Unspecified pathway (Investment → Income)	**0.211*****
		Total	**0.223*****
	Agricultural technology	Agricultural technology → Crop production → Income	0.020
		Agricultural technology → Orchard fruit production → Income	0.007
		Unspecified pathway (Agricultural technology → Income)	−0.001
		Total	0.026

*** $p < 0.01$; ** $p < 0.05$; * $p < 0.1$. Only the pathways with higher than 0.001 coefficient of effect are shown.

framework and the framework that only considers GFGP as the influencing factor (Fig. s2, Table s4–s6). The total standardized effect of GFGP on rural household income is 0.088 if just GFGP was regarded as the influencing factor (Table s6), which is an overestimate compared to the value 0.006 from our approach. However, both of them are non-significant. As for statistically significant pathways, the positive effect of GFGP on income through non-farm work is also overestimated in the latter approach (Table s6). The strengths of other linkages are also affected. For example, without considering the effect of agricultural technology on crop production, the negative effect of GFGP on crop production is underestimated in the latter approach (Fig. s2). On the contrary, our expanded framework indicates that the positive effect of agricultural technology is larger than the negative effect of GFGP on crop production (Fig. 4). The net effect is that enhanced crop productivity caused by development of agricultural technology offset the reduction in crop production caused by GFGP. This process has been proved in previous studies which showed that both grain yield per unit area and total grain output in the LP increased after GFGP (Lü et al., 2012; Wu et al., 2019a).

4. Discussion

Understanding the mechanisms through which a conservation program achieves desirable outcomes or not is crucial to its successful design and implementation (Ferraro and Hanauer, 2014; Yang et al., 2018). Our study illustrates that analysis of integrating linkages between influencing factors, livelihood activities, and socioeconomic outcomes can identify the contributions and pathways of multiple influencing factors to socioeconomic outcomes in PES studies.

Our findings prove that statistical data can be used for identifying the socioeconomic outcomes of PES in a region where the program is intensively implemented (Ferraro and Hanauer, 2014). The effects of GFGP on income evaluated by our expanded framework are consistent with the results of a previous study in a watershed in the LP, which used data collected at the household level (Wu et al., 2019b) — although the total effect of GFGP on the income of rural households is not statistically significant, GFGP still significantly increased the income through the increase in non-farm work. This is because a large number of surplus laborers were generated by GFGP and these laborers switched from farming to more profitable non-farm work such as construction, transportation, and industry (Liu et al., 2008; Yin et al., 2014; Li et al., 2015b). The evaluation of the specific effects of PES programs is also improved by taking multiple influencing factors into account. Although non-significant, the effect of GFGP on income may be overestimated if just considering it as the influencing factor. In addition, the negative effect of GFGP on crop production would be underestimated without considering the enhanced crop productivity caused by the development of agricultural technology.

By integrating multiple metacoupled factors into the evaluation of socioeconomic outcomes of PES programs, we found that the local economy and investment rather than GFGP played dominant roles in increasing the income of rural households in the LP. To our knowledge, this is the first report of the relative importance of different metacoupled factors on socioeconomic outcomes in PES studies. The pathway analysis combined with the metacoupling framework uncovered some hidden processes that may not be apparent when focusing only on the specific impacts of PES programs. Our findings indicate that the socioeconomic outcomes of GFGP can be enhanced by the local economy and investment. For the time dimension, this suggests that the rapid economic growth of China in the past few decades has played an important part in improving rural household income and achieving the development goals of GFGP (Bryan et al., 2018; Yang et al., 2018). For the space dimension, this means that if two households are participating equally in GFGP, the income increase of the household in a developed area with more investment is larger than that in an underdeveloped area, even though the changes in participation in non-farm work caused by GFGP and payments from GFGP are the same. Investment can generate more non-farm work opportunities for the rural laborers (Zhang, 2003) and then increase their incomes (Wu et al., 2019b) (Fig. 4). The explanations of the unspecified pathway of the local economy and investment have two aspects: first, economic development will increase the wages of laborers (Zhang et al., 2006), which means laborers in developed areas can earn more than those working in the same business in economically backward areas; second, the optimizing and upgrading of industry, which accompanies economic development and more investment (Wu and Xu, 2001; Lin, 2011), leads to more profitable industry.

Based on the improved understanding of pathways of multiple metacoupled factors to socioeconomic outcomes, we argue that the design and implementation of PES programs should be improved. First, multiple confounding factors should be taken into account in the evaluation of the socioeconomic outcomes of PES programs, which can not only improve the accuracy and reliability of the specific effects of PES programs (Ferraro and Hanauer, 2014) but also reveal some hidden processes and distinguish the contributions of different factors. The influences of metacoupled processes on PES outcomes found in our study may also occur in other PES programs and other countries (Yang et al., 2018). Second, policymakers can enhance the desired socioeconomic outcomes of PES programs while mitigating negative ones based on the understanding of pathways of multiple internal and external factors. For example, our study shows that the socioeconomic outcomes of GFGP in the LP can be enhanced by internal factors such as the local economy — the payment criteria should reflect these differences. Existing payment criteria of GFGP just take into account the different grain reductions caused by GFGP in the Yangtze and the Yellow River basins (Liu et al., 2008), the differences in gains caused by GFGP in different regions should also be considered in the further design of payment criteria. As for external and external/internal factors, we find that investment directly increased rural household income while tourism, investment, and rural migration boosted participation in non-farm work, which then effectively uses the surplus laborers generated from GFGP and can increase income. Thus, local governments should promote tourism development, attract more visitors and investment from outside, and incentivize the creation of more local non-farm jobs (Cao, 2011). Barriers of rural labor migration should be overcome by providing training initiatives to develop new earning skills and offering equal opportunities and information services for migrant workers in urban areas (Yin et al., 2014; Yang et al., 2018), especially for rural laborers in an underdeveloped area with less investment, where local job opportunities are lacking and wages are low. In this way, the benefit that participating households gain from non-farm work can be enhanced.

Our study has several limitations. First, statistical data at county level cannot distinguish households who participated in GFGP from those who did not; nor can they distinguish between incomes from GFGP from those from other sources. This inability may influence the accuracy in the estimation of pathways. Second, our data rely on official government-reported statistics which may be subject to inherent potential for error and bias (Liu and Yang, 2009). Third, as the origin of some factors cannot be distinguished due to the limitation of data, they were treated as external/internal factors in this study. The distinction of influencing factors should be improved when more accurate data is available.

In conclusion, we applied the metacoupling framework and developed an approach to distinguish contributions and pathways of multiple influencing factors to socioeconomic outcomes in PES studies. Its operationalization was demonstrated by analyzing the socioeconomic outcome of multiple external and internal factors including GFGP in the LP. Our framework can be easily adapted to analyze the effects of other PES programs and conservation policies that are also clouded by multiple interactions across space. Ultimately, more elaborate theories like the metacoupling theory need to be developed to guide the PES practices. We hope our framework and its operationalization will help develop these theories and provide empirical evidence about the effects of metacoupled factors. With such knowledge, specific strategies for PES programs can be identified to support sustainable development.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ecoser.2021.101348.

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