Impact of Market Imperfection on the Efficiency of PES Program

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Abstract:

We apply existing farm household model to public goods to study how off-farm labour market imperfection affects environmental service provision. By comparing the results under two scenarios, with and without off-farm labour market, we find the impact of off-farm labour market accessibility on aggregate level of environmental service production depends on factor endowment ratio of the landowner and relative factor intensity of the service production compare to existing agricultural activity. Its impact is contingent upon consumption preference and real off-farm wage rate when it comes to marginal impact of PES payment.

1. Introduction

Payment for environmental service (PES) has been widely applied to renewable natural resource conservation, such as environmental services, namely, water services, carbon sequestration, biodiversity conservation and landscape beauty (Mayrand and Paquin, 2004). Although most PES programs are still in the pilot stage, it has been adopted in both developing and developed countries. For instance, water resource protection in Ecuador, Costa Rica (e.g. Pagiola, 2008), France and Australia; forest resource in Mexico (Munoz-Pina , *et.al.*, 2008) and China (Bennett, 2008). Engel, *et. al*.(2008) provides an overview of PES program and Wunder, *et. al* (2008) gives a comparative analysis of PES programs between developed and developing countries.

However, not much attention has been paid to the impact of off farm labour market imperfection on efficiency of PES programs. Considering limited off farm labor market accessibility is acknowledged as a common phenomenon in developing countries, where child labour or family labour with low access to labour market or facing discrimination is usual (Sadoulet and de Janvry, 1995), and a lot of upstream environmental service providers *are*

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located in watersheds or marginal areas (Engel, *et. al*., 2008), off farm labour market imperfection may have an impact on PES program efficiency, particularly in developing counties.

Some empirical studies in PES literature have lately started to estimate the correlation between PES program and off-farm labour supply. One strand of the literature tries to explore the impact of PES programs on off-farm labour participation (e.g. Uchida, 2007; Bennett *et.al* 2008b). While the other line of study focuses on how off-farm labour market accessibility affect the effect of PES program. Fewer studies are available according to our knowledge. One study is carried out by Mullan (2008) who studies empirically how market failure, including credit market, land market and labour market imperfection, will affect participation decision of landowners. By using Latent Class Fixed-effects Probit model, she found labour market imperfection does matter. When constrained by accessibility to labour market, those with high land-labour endowment ratio are more willing to participate in the SLCP. However, she did not find significant impact of labor market accessibility when using amount of land set aside which may be more directly correlated with environmental service provision. Another study is done by Bennett *et.al* (2008a) who uses Chinese SLCP data from 2003' rural survey to examine the determinants of household provision of environmental services. This is by far the first study which directly examines the program-induced household delivery of environmental service. He finds households with less exposure to off-farm labour markets fare better in managing their planted trees and increases their survival rate, which will lead to higher ecosystem service provision.

However, according to our knowledge, no study available until now provides a theoretical foundation for the impact of labour market imperfection on PES program efficiency especially when upstream providers are both consumer and producer of the environmental service. Zilberman et. al. (2008) admits that "the use of integrated models as in Singh et al. (1986) yields greater realism…" when they use consumption and production separated household model to study the distributional effect of PES among the upstream and the downstream.

When we categorize environmental service by the way it is produced, there are two main types, that is the environmental service provided by changing existing agricultural activity and that produced as a by-product of a new private good. The former is equivalent to *working-*

land program, and the latter is comparable to *Land-diversion* in Zilberman et. al (2008). Organic farming and reforestation are two typical examples for the two type activities respectively. Under reforestation program, upstream landowner not only benefit from PES payment , but also obtains profit from timber production, though at much lower harvesting frequency, or forest products such as pulp and paper, as well as through trading the non-timber forest product (NTFP)[2].

The first type environmental service production is usually labour demanding, for instance, increasing monitory frequency in pest control (Dufour, 2001). Whilst reforestation demands large area of land. Both Bennett *et.al* (2008a) and Mullan (2008) study the Chinese SLCP which belongs to the second type. If off farm labour market does affect environmental service provision or participation through change of on farm labour-land ratio, a more generic model which describes their findings are necessary.

The main purpose of our paper is to provide a more generic theoretical model which encompasses empirical finding of both Bennett *et. al* (2008 a) and Mullan (2008). For the theoretical frame work, we adopt integrated household model to catch non-separation of consumption and production of public good. In order to demonstrate how other factors such as household labour-land endowment ration, input factor intensity between existing crop production and environmental service production would affect PES program, we depart partly from classical shadow price approach of nontradable goods in the household literature, e.g. de Janvry, Fafchamps and Sadoulet (1991)[3]. In stead, we borrow the basic framework in Heckscher-Ohlin model from international trade theory to describe how accessibility to off-farm labour market would affect output (environmental service provision) change.

The main question we will answer is "Will off farm labour market imperfection affect PES program efficiency? Under what circumstances will PES program result in higher environmental service provision?"
We decompose the questions into two stages.

[2]). Bennet et.al (2008b) found amount to 20%-32.2% local households' income increase could be mainly due to increase in NTFPs income. NTFP varies from country to country depending on local climate condition and consumption structure. A range of herbs, fungi, fruits and vegetables could be either collected naturally in local forests or be cultivated on plots adjacent to or within forests in Chinese case.
[3] We expect the same result on the price effect of PES payment could be drawn by using de Janvry, Fafchamps and Sadoulet (1991)'s approach.

1. When PES program is introduced the first time, will off farm market accessibility distort the input allocation decision of the upstream landowners under the program? Will the off farm labour market accessibility affect the change of total environmental service provision?
2. During the implementation stage of the program, is the higher unit PES payment the better?

Our analytical results show that albeit off farm labour market accessibility does not distort upstream landowner's input allocation decision, it does matter for total change in environmental service provision when PES is just introduced as well as the marginal impact of PES payment during the implementation stage. Compare to existing agricultural activity, when environmental service production requires relatively more intensive use of the factor that landowner is not abundant in, introducing PES program will induce more environmental service production when off farm labour market is accessible compare to that when off farm labour market is not accessible. For example, if landowner is land abundant and environmental service production is relatively more labour intensive compare to existing agricultural activity, PES program will induce more environmental service production when off farm labour market is available. When environmental service production uses relatively more intensive the factor that landowner is abundant in, apply PES program in the area without off farm market will induce more environmental service. Similarly, when off-farm labour market is not accessible, increase unit PES payment is efficient. However, when off-farm labour market is accessible, the efficiency of increasing unit PES payment is contingent upon consumption preference of landowner, real off-farm wage rate, and relative labour intensity (relative labour-land ratio) between existing agricultural activities and environmental service production.

Contributions of the paper cover several aspects.
First, we apply existing farm household model to public goods so as to study how input market imperfection (e.g. off farm labour market) will affect public good (e.g. environmental service) provision, including both input allocation efficiency and aggregate level of public good production. We provide a simple theoretical framework to describe how household related factors will affect the public good provision.

Second, the paper extends existing PES literature to the context where upstream landowners are both consumer and producer of environmental service.

Third, we demonstrate geographically how the impact of off farm labour market imperfection on aggregate environmental service provision is contingent upon factors such as relative labour/land ration (labour intensity) between existing agricultural activity and required ES production activity.

The structure of the paper is as follows. Section 2 provides basic assumptions and settings of the models. Section 3 explores the impact of labour market accessibility on production efficiency and on marginal impact of PES payment under two scenarios, i.e. when off farm labour market is not accessible and when it is accessible. Section 4 compare the results from the two scenarios in section 3 so as to check the impact of off farm labour market accessibility.

2. General description of model

Different from most PES literature (e.g. Zilberman et.al, 2008; Alix-Garcia et.al, 2008) , we assume that upstream landowners[4] are both producer and consumer of environmental service, e. As mentioned in section 1, we categorize environmental service into two types, the environmental service provided by changing existing agricultural activity and that produced as a by-product of a new private good.

The environmental service provided by changing existing agricultural activity includes, for example, improvement in biodiversity and high water quality. For instance, pest control helps to reduce pesticide use, hence improve groundwater quality and at the same time increases the biodiversity both above ground and in the soil (Dufour, 2001). More detailed example includes mix planting more than one type of crop (e.g. planting the disease-susceptible rice varieties with resistant varieties in Chinese experiment had 89% greater yield and 94% lower incidence of rice blast/a fungus for the former rice type compared to monoculture) could raise genetic diversity of a particular crop.

The main environmental by-products for reforestation is improvement of water quality and reduction of sedimentation of rivers nearby. For example, “The Green for Grain” program in

[4] We will not directly include the landless in our model. Welfare impact on the landless will be discussed in section 5.

China is aimed to prevent soil erosion and restore erosion, and "Shelterbelt Development Program" designed to combat erosion and desertification. (Zhu et.al , 2004)

Here we model the first type environmental service production. Appendix 4 shows that use the second type environmental service production as a raw sample will not change our result.

Each landowner is assumed to consume two products: crop (c_C) and environmental service (c_e)[5]. Since the study does not intend to study the impact of transaction cost of PES program nor externality between upstream landowners, but the externality of environmental service between upstream landowners and downstream users, one representative landowner is adopted in the model. Constant elasticity (=1) of substitution between crop and environmental service is conjectured. Utility function of the landowner is defined as $U(c_C, c_e) = \beta \ln c_C + (1-\beta)\ln c_e$.

Each landowner produces two goods: q_C and q_e. Both land (A_i) and labour (T_i) ($i = c, e$) are necessary inputs for the two goods[6] . Cobb-Douglas production function has been long applied in efficiency study for crop production.(e.g.Case studies in different developing countries in Part II in Singh et.al. 1986). In the same vein, the production function of crop and environmental service in the model are assumed to be Cobb-Douglas type[7]. For simplicity we presume constant return to scale in production. Our presumption is supported by some case study. For example, household study in China does show crop productions operates more or less under constant returns to scale with sum of elasticity for land, labour and fertilizer varying from 0.928 to 0.999.(Wu et.al. , 2005) . Crop production function is specified as $f(A_C, T_C) = \alpha A_C^{\tau} T_C^{1-\tau}$ and $g(A_e, T_e) = \theta A_e^{\delta} T_e^{1-\delta}$ for environmental service production.

Coefficient α and θ describe the technology used in crop and environmental service production respectively. τ and δ indicate the elasticity of land in crop and environmental service production.

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5 Our model skips the consumption of leisure for simplicity.
6 For simplicity, we do not include the use of other inputs such as water, fertilizer, herbicide or pesticide or machinery which is covered by study such as Zhang (1999). Since use of chemical fertilizer, herbicide and pesticide could be reduced by adopting biointensive integrated pest management (IPM) such as crop rotation, heat or steam sterilization of soil, cold storage, regular monitoring and rainfall and temperature records checking (Dufour, 2001). All the listed management are labour intensive so that the reduction in these input factors could be included in the increase in labour use.
7

We also assume that there are two types of landowners according to land-labour endowment ratio ($\bar{A}/\bar{T}$), a labour abundant landowner if labour-land ratio is high and a land abundant landowner if labour-land ratio is low. $\bar{A}$ and $\bar{T}$ refers to the total land and labour endowment for the landowner. The representative landowner belongs to one of the types. We also impose an additional assumption based on intuition that labour abundant landowner tends to sell labour in off-farm labour market when the market is accessible. And land abundant landowner tends to hire in labour when she could access off-farm labour market.

The landowner allocates his total labour endowment ($\bar{T}$) among crop and environmental service productions and off-farm activities (T_O), $\bar{T} = T_C + T_e + T_O$. When $T_O = 0$, off-farm labour market is not accessible. When $T_O \neq 0$, the landowner could trade his labour in off-farm labour market. $T_O > 0$ indicates a labour abundant landowner sells labour hour to off-farm activities. $T_O < 0$ implies a land abundant landowner who purchases extra labour hour from off-farm labour market.

For trading in the off-farm labour market actually happen after the labour market is accessible, we impose another assumption on real wage rate, that is the real off farm wage rate is higher than the labour productivity of labour abundant landowner and lower than labour productivity of land abundant landowner when labour market is not accessible.

Similarly, landowner allocates total land endowment ($\bar{A}$) between crop and environmental service production, i.e. $\bar{A} = A_C + A_e$. Crop market is assumed to be perfect competitive and the landowner faces a fixed crop price, p_C. This is a more realistic assumption especially when the crop faces an international or a national market.

For downstream, there are N environmental service users who purchase environmental service.

3. When environmental service is produced by changing agricultural activities

In the section, we will examine the case where environmental service that is produced by changing existing agricultural activities. The shortage of environmental service provision is usually due to the positive externality of the service between upstream producer and down stream users. PES literature view environmental service as a kind of quasi-public good which implies that use of environmental service is *excludable* and this makes price charge feasible. However, consumption of the service is *nonrivalry,* that is consumption by one person will not reduce consumption of the others. For example, water quality improvement in the river basin is available for both upstream farmers and downstream water users, whilst the latter could be charged for the improved water quality in the form of water tariff. Landscape enhancement is another example. Ecotourism is the main source of payment from downstream users, who are mainly from other regions. Due to the special characteristic of quasi-public goods, *nonrivalry*, consumption and production of environmental service cannot be separated. The amount of environmental service consumed by the upstream landowner equals the amount he produces ($c_e = q_e$). The utility function of the landowner could then be rewritten as $U(c_C, q_e) = \beta \ln c_C + (1-\beta) \ln q_e$. In the following subsections, we will study the impact of off-farm labour market accessibility on input allocation decision, on provision of total environmental service, and on the marginal impact of PES payment. We first study the impact of introducing PES program on inputs allocation decision and provision of total environmental service by comparing the two results *ex-ante* and *ex-post* PES program in each of the two scenarios, without off farm labour market and with off-farm labour market. The marginal impact of PES payment after introducing PES program is discussed in both scenarios. Then we compare the two different scenarios so as to provide insight on the impact of off-farm labour market accessibility and under what condition PES program will induce higher environmental service provision.

3.1 Without labour market

3.1.1 Ex-ante PES program

Before PES program is introduced, landowner can not trade environmental service in the market. Consumption pattern of a quasi-public good will not be different from that of a private non-tradable good, namely the landowner consumes all the environmental service he produces.

When off-farm labour market is not accessible, $T_O = 0$. The landowner simply allocates total labour endowment between crop and environmental service production, $\overline{T} = T_C + T_e$.

Budget constraint requires total expenditure of the landowner should not exceed the total income at a given period, $p_C c_C = p_C q_C + \Delta B$, where ΔB catches landowner's exogenous lump sum income and payment which is not dependent upon crop production. $\Delta B > 0$ implies consumption is larger than production for crop and $\Delta B < 0$ for a within household surplus in crop production.

The objective of the landowner is to maximize her utility by consuming crop and environmental service given her budget, land, and labour and production constraints.

$$Max \quad U(c_C, q_e) = \beta \ln c_C + (1-\beta)\ln q_e$$

$$s.t. \quad p_C c_C = p_C q_C + \Delta B \qquad (3.1)$$

$$q_C = f(A_C, T_C) = \alpha A_C^{\tau} T_C^{1-\tau} \qquad (3.2)$$

$$q_e = g(A_e, T_e) = \theta A_e^{\delta} T_e^{1-\delta} \qquad (3.3)$$

$$\overline{A} = A_C + A_e \qquad (3.4)$$

$$\overline{T} = T_C + T_e \qquad (3.5)$$

(3.1), (3.4) and (3.5) can be written as $c_C = q_C + \Delta B / p_C$ (3.1'), $A_C = \overline{A} - A_e$ (3.4') and $T_C = \overline{T} - T_e$ (3.5'). Insert (3.2) into (3.4'), (3.3) into (3.5'), we obtain $q_C = f(A_C, T_C) = \alpha(\overline{A} - A_e)^{\tau}(\overline{T} - T_e)^{1-\tau}$. The simplified objective function therefore reads

$$\underset{\{A_e, T_e\}}{Max} \quad U(c_C, q_e) = \beta \ln[\alpha(\overline{A} - A_e)^{\tau}(\overline{T} - T_e)^{1-\tau} + \Delta B / p_C] + (1-\beta)\ln \theta A_e^{\delta} T_e^{1-\delta} \qquad (3.6)$$

First order condition with respect to A_e and T_e yields

$$U_{A_e} = -\frac{\beta}{c_C}\alpha\tau(\overline{A} - A_e)^{\tau-1}(\overline{T} - T_e)^{1-\tau} + \frac{(1-\beta)\delta}{A_e} = 0, \text{ and} \qquad (3.7)$$

$$U_{T_e} = -\frac{\beta}{c_C}\alpha(1-\tau)(\overline{A} - A_e)^{\tau}(\overline{T} - T_e)^{-\tau} + \frac{(1-\beta)(1-\delta)}{T_e} = 0 \qquad (3.8)$$

(3.7) and (3.8) describe the competition use of land and labour in crop and environmental service production in equilibrium. They implies, respectively, increase in marginal utility when crop consumption rises by raising one unit input of land or labour is equal to decrease in marginal utility when environmental consumption reduces, which is due to one unit less land or labour available for environmental production.

Dividing (3.7) by (3.8), we get the efficiency condition for environmental service production, $\frac{\tau}{1-\tau}\frac{\bar{T}-T_e}{\bar{A}-A_e}=\frac{\delta}{1-\delta}\frac{T_e}{A_e}$ (3.9)[8], which states the technical rate of substitution between labour and land in equilibrium are the same for crop and environmental service production.

By inserting $T_e(A_e)$ into (3.7), we derive optimal land A_e^* and labour T_e^* used in environmental production, which satisfy the equations

$$\frac{1}{\beta\tau}(\bar{A}-A_e^*)+\frac{\Delta B}{p_C\beta\alpha\tau}[\bar{T}\delta(1-\tau)]^{\tau-1}[\delta(1-\tau)(\bar{A}-A_e^*)+A_e^*]^{1-\tau}=\frac{A_e^*}{(1-\beta)\delta}$$ [9]and

$$T_e^*=\bar{T}/[\frac{\delta}{(1-\delta)}\frac{(1-\tau)}{\tau}(\bar{A}/A_e^*-1)+1].$$ [10]

Optimal output of environmental service reads $q_e^*=\theta A_e^{*\delta}T_e^{*1-\delta}$.

3.1.2 Ex-post PES program

After introducing PES program, the landowners could sell environmental service to N downstream users, for example, municipality citizens in the case of water quality improvement and eco-tourists for landscape enhancement. However introducing PES program does not change the *non-rivalry* of environmental service, therefore, consumption and production of environmental service for the landowner is still non separable.

The budget constraint for the landowner (3.1) becomes $p_C c_C + p_e q_e = p_C q_C + N p_e q_e + \Delta B$. Other constraints keep unchanged. The simplified objective function yields

$$\underset{\{A_e,T_e\}}{Max}\quad U(c_C,q_e)=\beta\ln[\alpha(\bar{A}-A_e)^{\tau}(\bar{T}-T_e)^{1-\tau}+(N-1)\theta A_e^{\delta}T_e^{1-\delta}p_e/p_C+\Delta B/p_C]+(1-\beta)\ln\theta A_e^{\delta}T_e^{1-\delta}$$

First order conditions with respect to A_e and T_e are put as follows:

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8 $\frac{\partial T_C}{\partial A_C}=\frac{\partial T_e}{\partial A_e}$, where $\frac{\partial T_C}{\partial A_C}=\frac{\tau}{1-\tau}\frac{\bar{T}-T_e}{\bar{A}-A_e}$ and $\frac{\partial T_e}{\partial A_e}=\frac{\delta}{1-\delta}\frac{T_e}{A_e}$

9 The equation may indicate the existence of multi equilibra. However, the result depends on the parameter value τ .

10 The two equations could be rewritten as $\frac{\alpha(\bar{A}-A_e^*)^{\tau}(\bar{T}-T_e^*)^{1-\tau}+B/p_C}{\beta\alpha\tau(\bar{A}-A_e^*)^{\tau-1}(\bar{T}-T_e^*)^{1-\tau}}=\frac{A_e^*}{(1-\beta)\delta}$ (3.10)

$$U_{A_e} = \frac{\beta}{c_C}\left[-\alpha\tau(\bar{A}-A_e)^{\tau-1}(\bar{T}-T_e)^{1-\tau} + (N-1)\theta\delta A_e^{\delta-1}T_e^{1-\delta}\frac{P_e}{P_C}\right] + \frac{(1-\beta)\delta}{A_e} = 0 \text{, and} \quad (3.11)$$

$$U_{T_e} = \frac{\beta}{c_C}\left[-\alpha(1-\tau)(\bar{A}-A_e)^{\tau}(\bar{T}-T_e)^{-\tau} + (N-1)\theta(1-\delta)A_e^{\delta}T_e^{-\delta}\frac{P_e}{P_C}\right] + \frac{(1-\beta)(1-\delta)}{T_e} = 0 \quad (3.12)$$

The same efficiency condition as (3.9) can be derived from the above two conditions. Therefore, introducing PES payment will not distort landowner's input allocation decision. Since PES payment acts as a lump sum income for landowner, her input allocation decision does not depend on demand for environmental service, N , nor on payment p_e.

The optimal land (A_e^*) and labour use (T_e^*) in environmental service production will satisfy

$$\frac{1}{A_e^*}[(1-\beta)\alpha\delta(\bar{A}-A_e^*) - \beta\alpha\tau A_e^*]\left(\frac{\frac{\delta}{1-\delta}\frac{1-\tau}{\tau}}{\frac{\delta}{1-\delta}\frac{1-\tau}{\tau}(\bar{A}-A_e^*)+A_e^*}\bar{T}\right)^{1-\tau}$$

$$+(N-1)\frac{p_e}{p_C}\theta\delta\left(\frac{1}{\frac{\delta}{1-\delta}\frac{1-\tau}{\tau}(\bar{A}-A_e^*)+A_e^*}\bar{T}\right)^{1-\delta} + (1-\beta)\frac{\delta B}{A_e^* p_C} = 0 \quad (3.13)$$

[11]

and $T_e^* = \bar{T}/[\frac{\delta}{(1-\delta)}\frac{(1-\tau)}{\tau}(\bar{A}/A_e^*-1)+1]$

Change in total environmental service production after introducing PES program compare to that *ex-ante* PES program is not straight forward from analytical results, (3.10) and (3.13). However, as long as PES payment is higher than shadow price for environmental service *ex-ante* PES program, more land and labour will be allocated to environmental service production, henceforth higher total environmental service.

Apparently, after introducing PES program, optimal land (A_e^*) and labour (T_e^*) input depends on PES payment p_e. Appendix 1 shows $\partial A_e^*/\partial P_e > 0$ and $\partial T_e^*/\partial P_e > 0$. That is, one more unit

[11] The two equations could be rewritten as

$$\frac{\alpha(\bar{A}-A_e^*)^{\tau}(\bar{T}-T_e^*)^{1-\tau} + (N-1)\theta A_e^{*\delta}T_e^{*1-\delta}p_e/p_C + B/p_C}{\beta\alpha\tau(\bar{A}-A_e^*)^{\tau-1}(\bar{T}-T_e^*)^{1-\tau} - \beta(N-1)\theta\delta A_e^{*\delta-1}T_e^{*1-\delta}} = \frac{A_e^*}{(1-\beta)\delta} \quad (3.14)$$

increase in PES payment will lead to higher land and labour use in environmental service production for the extra payment than that of the former unit payment.

Therefore, we reach *Result 0*:

<u>Result 0:</u> *When environmental service is a quasi- public good and when off-farm labour market is not accessible, introducing PES program* ***i)*** *will not distort the landowner's input allocation decision,* ***ii)*** *will increase provision of environmental service.* ***iii)*** *Marginal impact of PES payment on environmental service provision is positive.*

3.2 With off-farm labour market

When the off-farm labour market is accessible, landowners could trade their labour hour in the off-farm labour market. [12] Labour used in off-farm activity is now non zero, i.e. $T_O \neq 0$.

3.2.1 Ex-ante PES program

Budget constraint becomes, $p_C c_C = p_C q_C + wT_O + \Delta B$ (3.16), where w is wage rate in off-farm labour market and is assumed to be fixed. Off-farm activity brings either additional income when selling labour ($T_O > 0$) or a cost when hiring in labour ($T_O < 0$). Landowner's maximization problem is similar to that *without off-farm labour market* except budget constraint is replaced by (3.16) and labour constraint by (3.17) $\bar{T} = T_C + T_e + T_O$.

The objective function now reads

$$\underset{\{A_e, T_e, T_O\}}{Max} \quad U(c_C, q_e) = \beta \ln[\alpha(\bar{A} - A_e)^{\tau}(\bar{T} - T_e - T_O)^{1-\tau} + wT_O / p_C + \Delta B / p_C] + (1-\beta)\ln \theta A_e^{\delta} T_e^{1-\delta}$$

First order condition with respect to A_e, T_e and T_O yields

$$U_{A_e} = -\frac{\beta}{c_C}\alpha\tau(\bar{A} - A_e)^{\tau-1}(\bar{T} - T_e - T_O)^{1-\tau} + \frac{(1-\beta)\delta}{A_e} = 0, \text{ and} \qquad (3.18)$$

$$U_{T_e} = -\frac{\beta}{c_C}\alpha(1-\tau)(\bar{A} - A_e)^{\tau}(\bar{T} - T_e - T_O)^{-\tau} + \frac{(1-\beta)(1-\delta)}{T_e} = 0 \qquad (3.19)$$

$$U_{T_O} = \frac{\beta}{c_C}[-\alpha(1-\tau)(\bar{A} - A_e)^{\tau}(\bar{T} - T_e - T_O)^{-\tau} + \frac{w}{p_C}] = 0 \qquad (3.20)$$

[12] We assume that off-farm labour hour is perfect substitutable with on-farm labour hour.

(3.20) indicates marginal cost of off-farm labour participation (i.e. marginal productivity of off-farm labour T_O if hired on farm) equals real marginal wage ($\frac{w}{p_C}$). (3.19) could be simplified as (3.19') $\frac{w}{p_C} = \frac{U_{q_e}}{U_{C_C}} q_{T_e}^e$ [13]. $q_{T_e}^e$ is the marginal productivity of labour used in environmental service production. $\frac{U_{q_e}}{U_{C_C}}$ states how much more environmental service consumption is necessary so as to keep utility unchanged with one unit decrease in consumption of crop. When environmental service is not tradable, substitution rate between the two goods can be regarded as a shadow price for environmental service consumption. Thus (3.19)' implies marginal cost of labour used in environmental service production ($\frac{w}{p_C}$) equals its marginal benefit ($\frac{U_{q_e}}{U_{C_C}} q_{T_e}^e$). Our analytical result is consistent to the result in Singh *et. al* (1986).

Dividing (3.18) by (3.19), we obtain the efficiency condition

$$\frac{\tau}{1-\tau}\frac{\bar{T}-T_e-T_O}{\bar{A}-A_e} = \frac{\delta}{1-\delta}\frac{T_e}{A_e} \tag{3.21}$$

(3.21) shows that with perfect off-farm labour market, technical substitution rate between labour and land equates between crop and environmental services.

Optimal provision of environmental service is determined by the above first order conditions. Optimal labour and land use in environmental service production are

$$T_e^* = \frac{\tau(1-\delta)}{\tau-\delta}\left\{\bar{T} - T_O - \bar{A}\left[\frac{\alpha(1-\tau)p_C}{w}\right]^{\frac{1}{\tau}}\right\} \text{and } A_e^* = \frac{\delta(1-\tau)}{\tau-\delta}\left\{(\bar{T}-T_O)\left[\frac{\alpha(1-\tau)p_C}{w}\right]^{-\frac{1}{\tau}} - \bar{A}\right\}$$

respectively.

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[13] As (3.19) implies $U_{C_C} q_{T_O}^C + U_{q_e} q_{T_e}^e = 0$ and $q_{T_O}^C = -\frac{w}{P_C}$, (3.19) is equivalent to $\frac{w}{P_C} = \frac{U_{q_e}}{U_{C_C}} q_{T_e}^e$.

3.2.2 Ex-post PES program

After introducing PES program, the landowner could trade environmental service in the market, his budget constraint hence is (3.22) $p_C c_C + p_e q_e = p_C q_C + N p_e q_e + wT_O + \Delta B$.

Simplified objective function of the landowner becomes

$$\underset{\{A_e, T_e, T_O\}}{Max} \quad U(c_C, q_e) = \beta \ln[\alpha(\bar{A} - A_e)^{\tau}(\bar{T} - T_e)^{1-\tau} + (N-1)\theta A_e^{\delta} T_e^{1-\delta} p_e / p_C + wT_O / p_C + \Delta B / p_C]$$
$$+ (1-\beta)\ln \theta A_e^{\delta} T_e^{1-\delta}$$

First order condition with respect to A_e T_e and T_O yields

(3.23) $$U_{A_e} = \frac{\beta}{c_C}\left[-\alpha\tau(\bar{A} - A_e)^{\tau-1}(\bar{T} - T_e - T_O)^{1-\tau} + (N-1)\theta\delta A_e^{\delta-1} T_e^{1-\delta} p_e / p_C\right] + \frac{(1-\beta)\delta}{A_e} = 0$$

(3.24)

$$U_{T_e} = \frac{\beta}{c_C}\left[-\alpha(1-\tau)(\bar{A} - A_e)^{\tau}(\bar{T} - T_e - T_O)^{-\tau} + (N-1)\theta(1-\delta)A_e^{\delta} T_e^{-\delta} p_e / p_C\right] + \frac{(1-\beta)(1-\delta)}{T_e} = 0$$

(3.25) $$U_{T_O} = \frac{\beta}{c_C}[-\alpha(1-\tau)(\bar{A} - A_e)^{\tau}(\bar{T} - T_e - T_O)^{-\tau} + \frac{w}{p_C}] = 0$$

3.2.2.1 Input allocation decision

From the above first order conditions, the same efficiency condition as (3.21) can be derived. Hence we conclude that introducing PES program does not distort production decision of the landowner when off-farm labour market is accessible.

3.2.2.2 Aggregate environmental service provision

Optimal land (A_e^*), labour use (T_e^*) in environmental service production and off farm labour use (T_e^*) satisfy the above first order conditions.

3.2.2.3 Marginal impact of PES payment

After introducing PES, marginal impact of PES payment on environmental service is also of our interest. Appendix 2 shows $\partial A_e^* / \partial P_e > 0$ if (3.27) $1-\delta+\delta\beta-2\beta > 0$ and $\partial T_e^* / \partial P_e > 0$ if $\delta(1-\beta)(1-3\tau) - \tau\beta > 0$. Condition (3.27) and (3.28) imply the impact of PES payment, P_e, is contingent upon landowner's preference for crop (β) and environmental service ($1-\beta$), output elasticity of land in environmental service production (δ) and crop production (τ). Since input allocation efficiency condition (3.21) is satisfied, production function with constant return implies direct correlation between δ, τ and relative labour intensity, i.e. relative labour-land ratio of environmental service production (T_e / A_e) and crop production (T_C / A_C).

Appendix 3 (I) demonstrates that when landowner prefer crop more than environmental service ($1-\beta < \beta$), higher PES payment will increase environmental service provision when real off-farm wage (w/P_C) is sufficiently high and environmental service production is relatively more land intensive ($\frac{T_e}{A_e} < \frac{T_C}{A_C}$). If real off-farm wage (w/P_C) is sufficiently low and environmental service production is relatively more labour intensive ($\frac{T_e}{A_e} > \frac{T_C}{A_C}$), the marginal impact of PES is ambiguous.

In another words, only if real off-farm wage (w/P_C) is high and environmental service production is more land intensive than environmental service production ($\frac{T_e}{A_e} < \frac{T_C}{A_C}$), will increase in PES payment lead to more environmental service provision.

If real off-farm wage (w/P_C) is low enough and environmental service production more land intensive ($\frac{T_e}{A_e} < \frac{T_C}{A_C}$), reduction in environmental service provision when increasing PES payment is possible.

The other situation that the landowner prefer environmental service more than crop ($1-\beta > \beta$) is less normal in developing countries where average household income is still very low. Detail discussion of marginal impact of PES payment on environmental service provision under this situation is in Appendix 3 (II).

4. Impact of off-farm labour market accessibility

In the section, we compare input allocation decision, aggregate environmental service provision change after introducing PES program and marginal impact of PES payment in the two scenarios, when off-farm labour market is available and when it is not.

4.1 *Impact of off-farm labour market accessibility on input allocation efficiency*

Compare result in 3.2.2.1 to i) in *Result 0*, we find that introducing PES program will not affect landowner's input allocation decision in both scenarios, *without off-farm labour market* and *with off-farm labour market*. Therefore, it is reasonable for us to reach *Result 1*:

<u>Result 1</u>*: off-farm labour market accessibility has no impact on input allocation decision of the landowner*.

The result seems contradict to the intuition that externality embedded in environmental service will distort resource use. We attribute the contradiction to the fact that we only focus on allocation decision made by upstream landowners and do not compare it with a social planner's decision which will try to maximize joint utility of both upstream landowners and downstream environmental service users.

4.2 *Impact of off-farm labour market accessibility on aggregate environmental service provision*

Due to the difficulty in comparing analytically environmental service provision change after introducing PES *with* off-farm labour market to that *without* off-farm labour market, we, in turn, draw upon geographical expression. We consider four different situations in terms of input factor abundance of the landowner and relative input factor intensity in crop and environmental service production. The four different situations are listed in Table 1: (1) *labour* abundant landowner & environmental service production is relatively more *land* intensive compare to crop production; (2) *Labour* abundant landowner & environmental service production is relatively more *labour* intensive compare to crop production; (3) *Land* abundant landowner & environmental service production is relatively more *labour* intensive compare to crop production; and (4) *Land* abundant landowner & environmental service production is relatively more *land* intensive compare to crop production. Graph 1 to Graph 4 depicts the four situations respectively. Each graph contains optimal crop and environmental service production and consumption decision by landowner under two scenarios, the scenario when off-farm labour market is not accessible, which we refer to as *Autarky*, and the scenario when off-farm labour market is accessible.

Table 1: Four different situations under geographic expression

		Input factor abundance	
Relative input factor Intensity of environmental service		Labour	Land
	Land	(1)	(4)
	Labour	(2)	(3)

Note: In our geographical approach, we assume $\Delta B = 0$ for (1) and (2); $\Delta B > 0$ for (3) and (4) for simplicity.

(1) Labour abundant landowner & environmental service production is relatively more *land intensive* compare to crop production (Graph 1)

Autarky

We refer *Autarky* to the scenario when off-farm labour market is not accessible. As shown in section 3.1, when $\Delta B = 0$, before PES program is introduced, consumption and production are not separated for both crop and environmental service, $q_C^0 = c_C^0$ and $q_e^0 = c_e^0$. [14]After introducing PES program, consumption and production are still not spreadable for environmental service, $q_e^1 = c_e^1$. As long as PES payment (P_e) is higher than shadow price (λ_e), will landowner produce more environmental service. Meanwhile, total PES payment shifts the budget constraint (I) upwards to (I'). Higher environmental service payment reduces crop production to q_C^1 (*substitution effect)*, Higher income increases crop consumption to c_C^1 (*Income effect)*.

When off-farm labour is accessible

Production feasible set (PFS)

We have an intuitive assumption that labour abundant landowner always sell labour ($T_O > 0$) in the off-farm labour market. The assumption is reasonable when shadow price of labour in *Autarky* is very low and lower than wage rate in off-farm labour market when it is accessible. Labour available for on farm activity is then reduced. The new production feasible set (PFS) is located within side production possibility frontier (PPF). After selling labour, landowner's labour –land ratio decreases. As environmental service production is relatively more land intensive, PFS skews towards environmental service production.

[14] Non seperation of consumption and production in crop production is a special case here. Main reason is that environmental service production and consumption is non spreadable.

Shadow price of environmental service

As PFS skews towards environmental service production, shadow price of environmental service (λ'_e) is lower than that in *Autarky* (λ_e).

Environmental service provision

Apparently, when off farm labour market is not accessible, landowner produces less environmental service than that in *Autarky* due to the lower shadow price, i.e $q_e^{0-with} < q_e^0$.

After introducing PES program, as PFS skews towards environmental service production, the same PES payment will induce more environmental service than that in *Autarky* as long as landowner does not sell too much labour hour in off farm labour market, i.e $q_e^{1-with} > q_e^1$.[15]

Therefore, aggregate change of environmental service after introducing PES program is larger when off farm labour is available ($q_e^{1-with} - q_e^{0-with} > q_e^1 - q_e^0$).

(2) *Labour abundant* landowner & *environmental service* production is relatively more *labour intensive* compare to crop production (Graph 2)

Autarky

Similar to situation (1), after introducing PES program, the environmental service production increases as long as the PES payment (P_e) is higher than shadow price of environmental service (λ_e).

When off-farm labour is accessible

Since we assume labour abundant landowner always sell labour ($T_O > 0$),the PFS is still located within side PPF. After selling labour, landowner's labour –land ratio decreases. As environmental service production is relatively more labour intensive, the PFS skew towards crop production.

As PFS skews towards crop production, shadow price of environmental service (λ'_e) is higher than that in *Autarky* (λ_e).

[15] If landowner sells large amount labour hour so that PFS shifts inwards significantly, environmental service production *ex-post* could be lower than that in *Autarky*.

When shadow price of environmental service (λ'_e) is sufficiently high[16], landowner produces more environmental service when off farm labour market is not accessible than that in *Autarky,* i.e $q_e^{0-with} > q_e^0$. After introducing PES program, the same PES payment will induce more environmental service than that in *Autarky* , i.e $q_e^{1-with} < q_e^1$. Hence, change in total environmental service provision after introducing PES program is smaller when off farm labour is available ($q_e^{1-with} - q_e^{0-with} < q_e^1 - q_e^0$).

(3)*Land abundant* landowner & *environmental service* production is relatively more *labour intensive* compare to crop production (Graph 3)

When off-farm labour is accessible, PES shift outwards and is located outside PPF as we assume land abundant landowner will always hire in labour in off farm labour market ($T_O < 0$). After hiring in labour, on farm labour-land ratio increases. Together with environmental service is relative more labour intensive, PFS expands more to the direction of environmental service production than PPF. Similarly to (1), shadow price for environmental service (λ'_e) is lower than that in *Autarky* (λ_e) and $q_e^{0-with} < q_e^0$. Nevertheless, after PES shift outwards, the same PES payment will always result in more environmental service than that in *Autarky*. Hence, PES program will bring larger environmental service when off farm labour is available ($q_e^{1-with} - q_e^{0-with} > q_e^1 - q_e^0$).

(4)*Land abundant* landowner & *environmental service* production is relatively more *land intensive* compare to crop production

When off-farm labour is accessible, PES shifts outwards for the same reason as in (3). Since environmental service is relative more land intensive, PFS expands more to the direction of crop production than PPF. Similarly to (2), $q_e^{0-with} > q_e^0$ as long as shadow price of environmental service (λ'_e) is sufficiently high. While *ex-post* PES program, the same PES payment will always result in less environmental service than that in *Autarky*. Thus, PES program will lead to lower environmental service when off farm labour is available. ($q_e^{1-with} - q_e^{0-with} < q_e^1 - q_e^0$).

[16] The curvature change of PES compare to PPF is smaller than the slope change of shadow price of environmental service.

The result is consistent with Bennett, *et.al.* (2008b) and Mullan (2008)[17]'s findings, where those landowners with higher land-labour endowment ratio are more willing to participate the PES program and care planted tree better when off farm labour market is not accessible.

Based on above discussion (1) to (4), we reach *Result 2*:

Result 2:When landowner is labour abundant and environmental service production is relatively more land intensive compare to existing agricultural activity (e.g.crop production) or when landowner is land abundant and environmental service production is relatively more labour intensive, PES program will induce more environmental service production when off farm labour market is accessible. The first half result is valid only when landowner does not sell too many labour hour in off farm labour market.

When labour abundant landowner & environmental service production is relatively more labour intensive or when land abundant landowner & *environmental service* production is relatively more *land intensive*, *PES program will induce less environmental service production when off farm labour market is accessible. The second half result holds when shadow price of environmental service (λ'_e) is sufficiently high when off farm market is accessible.*

4.3 *Impact of off-farm labour market accessibility on marginal effect of PES payment*

In order to see how access to off-farm labour market affect marginal impact of PES payment *ex-post* PES program, we compare our result in 3.2.2.3 with *Result 0 (iii)* when there is no off-farm labour market. We put our comparison result in *Result 3*:

Result 3: Off-farm labour market accessibility does matter for marginal impact of PES payment on environmental service provision. When off-farm labour market is not accessible, marginal impact of PES payment on environmental service provision is always positive. When off-farm labour market is accessible, marginal impact of PES payment on environmental service provision is contingent upon preference of landowner for crop and environmental service consumption, real off-farm wage rate, and relative labour intensity (relative labour-land ratio) between crop and environmental service production.

[17] If we do not consider any uncertainty between participation and environmental service production and rule out all the possible information asymmetry, we could approximate use participation rate to measure the future environmental service provision.

5 Policy implications

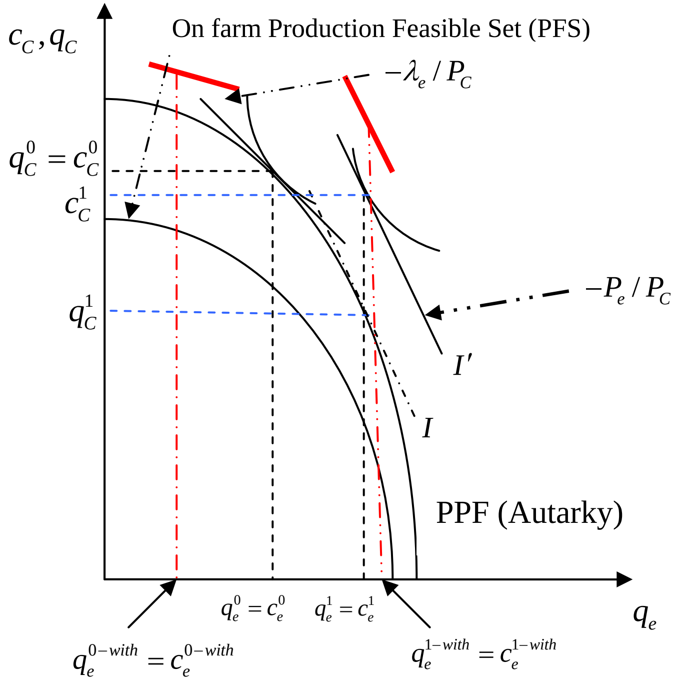
This paper applies existing farm household model to public goods and studies how off farm labour market imperfection will affect environmental service provision under PES program. Through a simple theoretical framework, we describe how household related factors will affect the environmental service provision by upstream landowners who are both consumer and producer of environmental service.

Our analytical result shows that off farm labour market accessibility does not distort upstream landowner's input allocation decision. Our geographical analysis reveals aggregate provision of environmental service provision differs where off farm labour market is accessible and where it is not. The impact of off farm labour market imperfection depends on factors such as relative labour/land ration (labour intensity) between existing agricultural activity and required environmental service production activity. During the implementation stage, marginal impact of PES payment also hinges upon off-farm market accessibility. When Increase unit PES payment is efficient when off farm labour market is not accessible. When off-farm labour market is accessible, the efficiency of increasing unit PES payment is contingent upon consumption preference of landowner, real off-farm wage rate, and relative labour intensity (relative labour-land ratio) between existing agricultural activities and environmental service production.

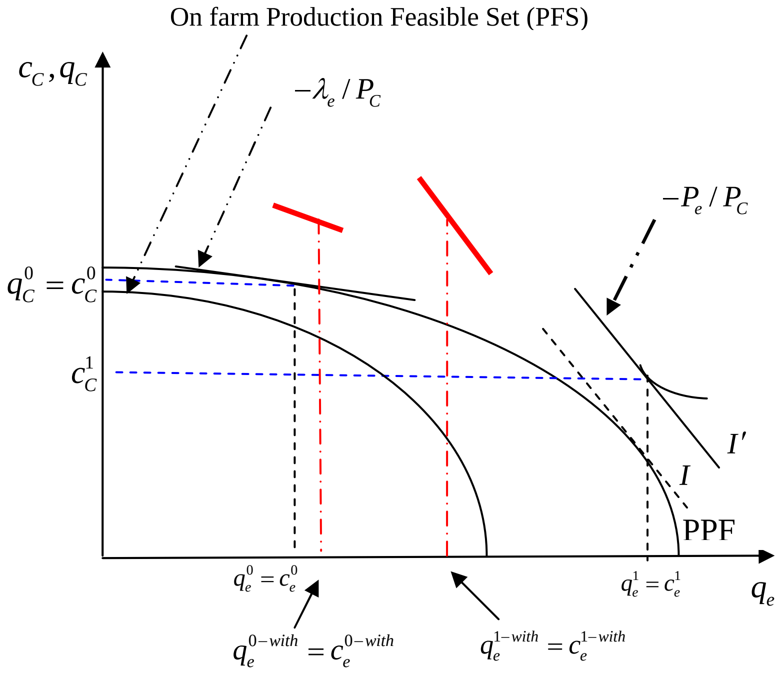
Our results convey very important policy message that before implementing PES program and before changing the PES payment in the region where the program is already adopted, it is important to first distinguish whether off farm labour market is accessible or not. Then, policy decision makers need to check factors such as relative labour or land intensity between PES required activities and existing agricultural activities, off-farm wage rate if the labour market is available and consumption preference of landowner to ensure adopting PES program or changing in PES payment will lead to efficient environmental service provision by upstream landowners.

Certainly, we admit that we do not consider the heterogeneity of landowners such as land quality, location neither heterogeneity of environmental service users nor information problems between landowners and environmental service providers. These factors might affect our result and need attention in future research.

Graph 1: Labour abundant landowner & environmental service Production is relatively more land intensive compare to crop production



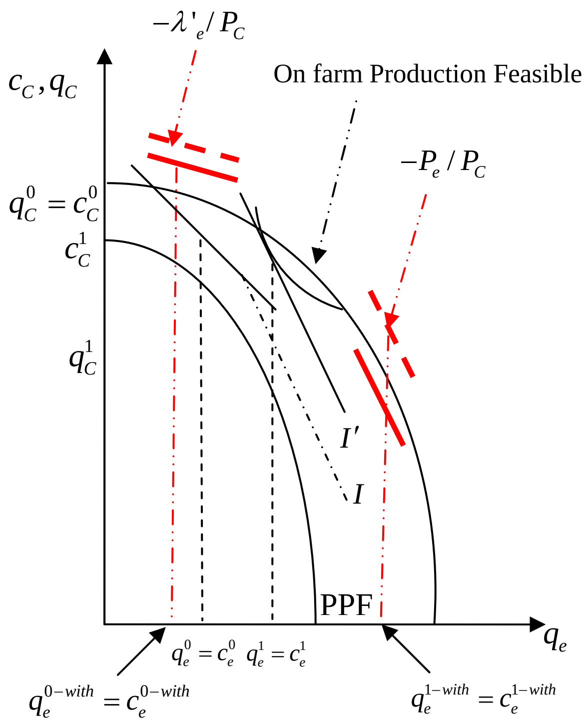
Graph 2:Labour abundant landowner & environmental service production is relatively more labour intensive compare to crop production



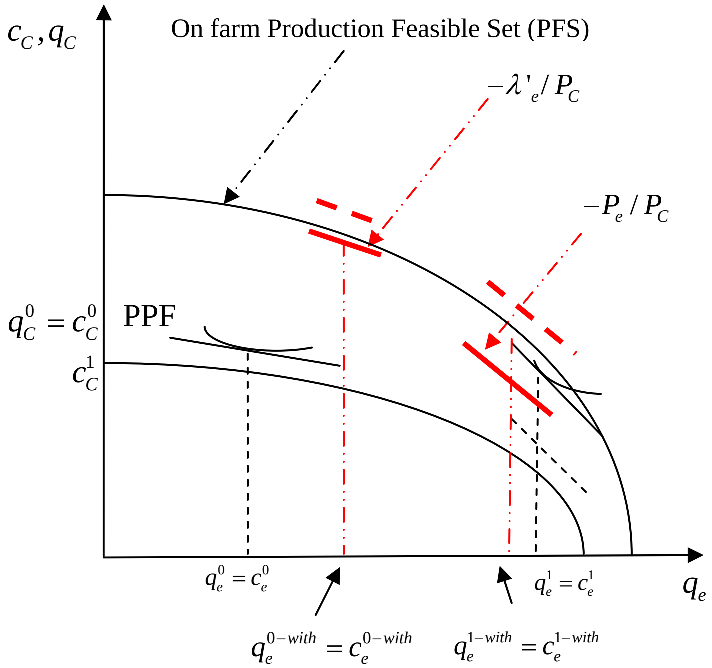
Note: (i) $\Delta B = 0$ for Graph 1 and 2; $\Delta B > 0$ for Graph 3 and 4. (ii) q_e^0, c_e^0 : environmental service provision *ex-ante* PES program when off-farm labour market is not accessible. q_C^0, c_C^0 : crop production and consumption *ex-ante* PES program when off-farm labour market is not accessible.

(iii) q_e^1, c_e^1: environmental service provision *ex-post* PES program when off-farm labour market is not accessible. q_C^1, c_C^1 : crop production and consumption *ex-post* PES program when off-farm labour market is not accessible. (iv) $q_e^{0-with}, c_e^{0-with}$: environmental service provision *ex-ante* PES program when off-farm labour market is accessible. (v) $q_e^{1-with}, c_e^{1-with}$: environmental service provision *ex-post* PES program when off-farm labour market is accessible. (vi) λ_e is shadow price for environmental service in *Autarky*. $P_e > \lambda_e$ (vii) λ'_e is the shadow price for environmental service when off farm labour market is accessible. In Graph 1 and 3, $\lambda'_e < \lambda_e$; in Graph 2 and 4, $\lambda'_e > \lambda_e$.

Graph 3: Land abundant landowner & environmental service production is relatively more labour intensive compare to crop production



Graph 4: Land abundant landowner & environmental service production is relatively more land intensive compare to crop production



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Appendix:

Appendix 1: Marginal impact of PES payment on optimal land and labour use in environmental service production *when off-farm labour market is* *not accessible.*

In order to obtain marginal impact of p_e on A_e^* and T_e^*, we implicitly differentiate (3.11) and (3.12) with respect to p_e. The result shows

$$\begin{pmatrix} a_1 & b_1 \\ a_2 & b_2 \end{pmatrix} \begin{pmatrix} \partial A_e^* / \partial P_e \\ \partial T_e^* / \partial P_e \end{pmatrix} = \begin{pmatrix} c_1 \\ c_2 \end{pmatrix} \qquad (3.15)$$

where

$$a_1 = -\alpha\tau(\bar{A} - A_e)^{\tau-1}(\bar{T} - T_e)^{1-\tau}\left[(\beta + \delta - \beta\delta) + \beta(1-\tau)A_e/(\bar{A} - A_e)\right] + \delta^2(N-1)\theta A_e^{\delta-1}T_e^{1-\delta}P_e/P_C$$

$$b_1 = \alpha(1-\tau)(\bar{A} - A_e)^{\tau-1}(\bar{T} - T_e)^{-\tau}\left[(\beta\tau A_e - (1-\beta)\delta(\bar{A} - A_e)\right] + \delta(N-1)\theta(1-\delta)A_e^{\delta}T_e^{-\delta}P_e/P_C$$

$$a_2 = \alpha\tau(\bar{A} - A_e)^{\tau-1}(\bar{T} - T_e)^{-\tau}\left[(\beta(1-\tau)T_e - (1-\beta)(1-\delta)(\bar{T} - T_e)\right] + (1-\delta)(N-1)\theta\delta A_e^{\delta-1}T_e^{1-\delta}P_e/P_C$$

$$b_2 = \alpha(1-\tau)(\bar{A} - A_e)^{\tau}(\bar{T} - T_e)^{-\tau}\left[-(1-\delta+\delta\beta) - \beta\tau T_e/(\bar{T} - T_e)\right] + (1-\delta)^2(N-1)\theta A_e^{\delta}T_e^{-\delta}P_e/P_C$$

$c_1 = -\delta(N-1)\theta A_e^{\delta}T_e^{1-\delta}/P_C$ and $c_2 = -(1-\delta)(N-1)\theta A_e^{\delta}T_e^{1-\delta}/P_C$

From crammer's rule, $\partial A_e^*/\partial P$ and $\partial T_e^*/\partial P$ follows

$\partial A_e^*/\partial P = (c_1 b_2 - c_2 b_1)/\Delta$ and $\partial T_e^*/\partial P = (a_1 c_2 - a_2 c_1)/\Delta$, where $\Delta = a_1 b_2 - a_2 b_1$. Since the existence of maxima ensures a positive determinant Δ (Proof see appendix), the sign of $\partial A_e^*/\partial P_e$ and $\partial T_e^*/\partial P_e$ depend on the sign of the numerators.

$$c_1 b_2 - c_2 b_1 = (N-1)\theta A_e^{\delta}T_e^{1-\delta}[\beta\alpha(1-\tau)(\bar{A} - A_e)^{\tau}(\bar{T} - T_e)^{-\tau}\left(\delta + \tau\delta T_e/(\bar{T} - T_e) + \tau(1-\delta)A_e/(\bar{A} - A_e)\right)$$
$$+ (1-\delta)^2\delta(N-1)\theta A_e^{\delta}T_e^{-\delta}(T_e - 1)P_e/P_C] > 0$$

and

$$a_1 c_2 - a_2 c_1 = (N-1)\theta A_e^{\delta}T_e^{1-\delta}\beta\alpha\tau(\bar{A} - A_e)^{\tau-1}(\bar{T} - T_e)^{1-\tau} \times$$
$$\left\{1 - \delta + (1-\tau)\left[(1-\delta)A_e/(\bar{A} - A_e) + \delta T_e/((\bar{T} - T_e)\right]\right\} > 0$$

as long as $T_e > 1$.

Therefore, $\partial A_e^*/\partial P_e > 0$ and $\partial T_e^*/\partial P_e > 0$. Namely, when off-farm labour market is not accessible, higher PES payment will lead to higher optimal land and labour input in environmental service production ex-post PES program.

Appendix 2: Marginal impact of PES payment on optimal land and labour use in environmental service production *when off-farm labour market is* *<u>accessible.</u>*

Marginal impact of PES payment could be obtained from the implicit differentiation of (3.23), (3.24) and (3.25) with respect to P_e, namely

$$\begin{pmatrix} A_1 & B_1 & C_1 \\ A_2 & B_2 & C_2 \\ A_3 & B_3 & C_3 \end{pmatrix} \begin{pmatrix} \partial A_e^* / \partial P_e \\ \partial T_e^* / \partial P_e \\ \partial T_O^* / \partial P \end{pmatrix} = \begin{pmatrix} D_1 \\ D_2 \\ 0 \end{pmatrix} \qquad (3.26)$$

where

$$A_1 = -(\bar{T} - T_e - T_O) w\tau \left[(\beta + \delta - \beta\delta)/(1-\tau) + \beta A_e / (\bar{A} - A_e) \right] / (\bar{A} - A_e) P_C + \delta^2 (N-1) \theta A_e^{\delta-1} T_e^{1-\delta} P_e / P_C$$

$$B_1 = w\left[(\beta\tau A_e - (1-\beta)\delta(\bar{A} - A_e) \right] / (\bar{A} - A_e) P_C + \delta (N-1) \theta (1-\delta) A_e^{\delta} T_e^{-\delta} P_e / P_C$$

$$C_1 = \left\{ \left[(\beta\tau A_e - (1-\beta)\delta(\bar{A} - A_e) \right] / (\bar{A} - A_e) + (1-\beta)\delta \right\} w / P_C$$

$$D_1 = -\delta (N-1) \theta A_e^{\delta} T_e^{1-\delta} / P_C$$

$$A_2 = -\tau w (\bar{T} - T_e - T_O) \left[(\beta(1-\tau) T_e - (1-\beta)(1-\delta) \right] / (1-\tau)(\bar{A} - A_e) P_C + (1-\delta)(N-1) \theta\delta A_e^{\delta-1} T_e^{1-\delta} P_e / P_C$$

$$B_2 = -w\left[(1-\delta+\delta\beta)(\bar{T} - T_e - T_O) + \beta\tau T_e \right] / (\bar{T} - T_e - T_O) P_C + (1-\delta)^2 (N-1) \theta A_e^{\delta} T_e^{-\delta} P_e / P_C$$

$$C_2 = -w\left[(1-\beta)(1-\delta)(\bar{T} - T_e - T_O + w/P_C) + \beta\tau T_e \right] / (\bar{T} - T_e - T_O) P_C$$

$$D_2 = -(1-\delta)(N-1) \theta A_e^{\delta} T_e^{1-\delta} / P_C$$

$$A_3 = -w\tau / (\bar{A} - A_e) P_C; \; B_3 = C_3 = w\tau / (\bar{T} - T_e - T_O) P_C$$

From crammer's rule, $\partial A_e^* / \partial P$ and $\partial T_e^* / \partial P$ follows

$\partial A_e^* / \partial P = \left[D_1 (C_3 B_2 - C_2 B_3) - D_2 (B_1 C_3 - C_1 B_3) \right] / \Delta$ and

$\partial T_e^* / \partial P = \left[A_3 (D_1 C_2 - D_2 C_1) + C_3 (A_1 D_2 - A_2 D_1) \right] / \Delta$, where $\Delta_3 = \begin{vmatrix} A_1 & B_1 & C_1 \\ A_2 & B_2 & C_2 \\ A_3 & B_3 & C_3 \end{vmatrix}$. The existence of maxima indicates a negative determinant Δ_3 (Proof see appendix). the sign of $\partial A_e^* / \partial P_e$, $\partial T_e^* / \partial P_e$ and $\partial T_O^* / \partial P_e$ will be the opposite to the sign of the numerators.

Since $D_1 (C_3 B_2 - C_2 B_3) - D_2 (B_1 C_3 - C_1 B_3)$

$= -\frac{w^2}{P_C^3} \tau\delta (\bar{T} - T_e - T_O)(N-1) \theta A_e^{\delta} T_e^{1-\delta} \left[1 - \delta + \delta\beta - 2\beta + w/(\bar{T} - T_e - T_O) P_C \right]$, $\partial A_e^* / \partial P_e > 0$ as long as (3.27) $1 - \delta + \delta\beta - 2\beta > 0$ (or $(1-\delta)(1-\beta) - \beta > 0$) is satisfied. That is, increase in PES payment will have a positive impact on optimum land used in *e*-good production as long as elasticity of land input in environmental good production (δ) is small enough and landowner's preference for crop consumption (β)is sufficiently large.

Similarly, we obtain

$$
\begin{aligned}
&A_3(D_1C_2 - D_2C_1) + C_3(A_1D_2 - A_2D_1) = \\
&-(N-1)\tau \frac{\theta A_e^{\delta} T_e^{1-\delta}}{\bar{A} - A_e} \frac{w^2}{P_C^3} \times \{(1-\delta)\left[\delta(1-\beta)(1-3\tau) - \tau\beta\right]/(1-\tau) \\
&+ \tau\delta\beta T_e[1/(\bar{T} - T_e - T_O) + 1/(\bar{A} - A_e)] + \frac{w}{P_C}\delta(1-\beta)(1-\delta)/(\bar{T} - T_e - T_O)\}
\end{aligned}
$$

, which is negative as long as (3.28) $\delta(1-\beta)(1-3\tau) - \tau\beta > 0$. Therefore, $\partial T_e^* / \partial P_e > 0$, namely, higher PES payment will increase optimal labour used in environmental service production when (3.28) is fulfilled.

Therefore, if and only if $1-\delta+\delta\beta-2\beta > 0$ and $\delta(1-\beta)(1-3\tau) - \tau\beta > 0$, will higher PES payment increase environmental service production.

Appendix 3:

(I) When the landowner prefer crop more than environmental service ($1-\beta < \beta$):

1) Condition (3.27) is violated when $1-\beta < \beta$.

Proof: (3.27) implies $1-\delta > \frac{\beta}{1-\beta} > 1 \Leftrightarrow \delta < 0$. It contradicts to our assumption $\delta > 0$.

- If and if only when off farm real wage rate (w/P_C) is sufficiently large, will $\partial A_e^* / \partial P_e > 0$.

2) When environmental service production is relatively more land intensive than crop production input ($\frac{T_e}{A_e} < \frac{T_C}{A_C}$), $\partial T_e^* / \partial P_e > 0$.

  - First, higher PES payment will induce more environmental service provision.

  Proof: Condition (3.28) implies $\delta(1-\beta)(1-3\tau) - \tau\beta > 0 \Leftrightarrow \delta > \frac{\tau}{1-3\tau}\frac{\beta}{1-\beta} > \frac{\tau}{1-3\tau}$. As we asume $0 < \delta < 1$ and $0 < \tau < 1$, we obtain $\frac{\delta}{1-\delta} > \frac{\tau}{1-3\tau} > \frac{\tau}{1-\tau}$ if $0 < \tau < 1/3$. When

$0 < \tau < 1/3$, $\frac{\delta}{1-\delta} > \frac{\tau}{1-3\tau}$ always holds. Meanwhile, since the allocation efficiency condition (3.21) $\frac{\tau}{1-\tau}\frac{T_C}{A_C} = \frac{\delta}{1-\delta}\frac{T_e}{A_e}$ holds, $\frac{\delta}{1-\delta} > \frac{\tau}{1-\tau}$ implies $\frac{T_e}{A_e} < \frac{T_C}{A_C}$. Therefore, when $0 < \tau < 1/3$ and environmental service production is more land intensive ($\frac{T_e}{A_e} < \frac{T_C}{A_C}$), $\partial T_e^* / \partial P_e > 0$.

3) Therefore, *when real off-farm wage (w/P_C) is sufficiently high and environmental service production is relatively more land intensive ($\frac{T_e}{A_e} < \frac{T_C}{A_C}$), will higher PES payment increase environmental service provision.*

4) *If real off-farm wage (w/P_C) is sufficiently low and environmental service production is relatively more land intensive ($\frac{T_e}{A_e} < \frac{T_C}{A_C}$), will higher PES payment may be less efficient in inducing higher environmental service provision.*

(II) When the landowner prefer environmental service more than crop ($1-\beta > \beta$),

1) As long as output elasticity of land in environmental service production is small enough ($\delta < 1 - \frac{\beta}{1-\beta}$) so as to keep condition (3.27) holds, and at the same time environmental service production is more land intensive ($\frac{T_e}{A_e} < \frac{T_C}{A_C}$), so that (3.28) is also satisfied, higher PES payment will increase environmental service provision.

2) If output elasticity of land in environmental service production is so high that $\delta > 1 - \frac{\beta}{1-\beta}$, together with low real off-farm wage (w/P_C), $\partial T_e^* / \partial P_e < 0$. Meanwhile, if environmental service production is relatively more labour intensive ($\frac{T_e}{A_e} > \frac{T_C}{A_C}$), higher PES payment will lead to lower environmental service provision.

Appendix 4:

As in section 3, we still assume that upstream landowners are both consumer and producer of the environmental service. However, provision of environmental service under this category is a proportion (k) of the private good output, q_f (for example, the forest related product in the case of reforestation) produced. Production of the private good is also assumed to use only labour and land input. For simplicity, in our study, landowner does not consume the private good but sell it to the market. Since the environmental service is still a quasi-public good, which indicating non separation between consumption and production, the utility function of the landowner now reads $U(c_C, c_e) = \beta \ln c_C + (1-\beta)\ln c_e$. $c_e = q_e = kq_f$. q_f follows Cobb-Douglas function (4.1) $q_f = \eta A_f^{\gamma} T_f^{1-\gamma}$, where A_f and T_f is the land and labour used in producing the private good. η is the parameter catching the technology used. γ is the output elasticity of land. The landowner allocates total labour and land endowment between crop (C) and the private good production (f), that is (4.2) $\overline{A} = A_C + A_f$ and (4.3) $\overline{T} = T_C + T_f$. In the sections below, we will explore whether off-farm labour market accessibility affects the efficiency of the environmental service provision and how does it influence the impact of PES program on environmental service provision.

A4.1 Without labour market

A4.1.1 Ex-ante PES program versus ex-post PES program

Since the landowner will not produce the private good before introducing PES, the landowner will not provide environmental service. All land ($\overline{A}$) and labour ($\overline{T}$) are used in crop production.

After introducing PES program, the landowner allocates part of his land and labour to the private good (e.g. forest) production. The budget constraint becomes (4.4) $p_C c_C = p_C q_C + p_f q_f + p_e k q_f + B$. Other constraints follow (3.2), (4.1), (4.2) and (4.3) . The simplified maximization problem of the landowner becomes

$$\underset{A_f, T_f}{Max}\, U(c_C, c_e) = \beta \ln\left[\alpha(\overline{A} - A_f)^{\tau}(\overline{T} - T_f)^{1-\tau} + p_f \eta A_f^{\gamma} T_f^{1-\gamma} + Nk\eta A_f^{\gamma} T_f^{1-\gamma} p_e / p_C + B / p_C\right]$$
$$+ (1-\beta)\ln k\eta A_f^{\gamma} T_f^{1-\gamma} p_e / p_C$$

The first order conditions with respect to A_e, T_e and c_e become

$$U_{A_f} = \frac{\beta}{c_C}\left\{-\alpha\tau(\bar{A}-A_f)^{\tau-1}(\bar{T}-T_f-T_O)^{1-\tau} + \left[p_f + (N-1)kp_e\right]\eta\gamma A_f^{\ \gamma-1}T_f^{\ 1-\gamma}/p_C\right\} + \frac{(1-\beta)\gamma}{A_f} = 0$$
(4.5)

$$U_{T_f} = \frac{\beta}{c_C}\left\{-\alpha(1-\tau)(\bar{A}-A_f)^{\tau}(\bar{T}-T_f)^{-\tau} + \left[p_f + (N-1)kp_e\right]\eta(1-\gamma)A_f^{\ \gamma}T_f^{\ -\gamma}/p_C\right\} + \frac{(1-\beta)(1-\gamma)}{T_f} = 0 \qquad (4.6)$$

Where $c_C = \alpha(\bar{A}-A_f)^{\tau}(\bar{T}-T_f)^{1-\tau} + p_f\eta A_f^{\ \gamma}T_f^{\ 1-\gamma} + Nk\eta A_f^{\ \gamma}T_f^{\ 1-\gamma}p_e/p_C + B/p_C$

Apparently, the efficiency condition similar to (3.9) holds, that is (3.9')

$\frac{\tau}{1-\tau}\frac{\bar{T}-T_f}{\bar{A}-A_f} = \frac{\gamma}{1-\gamma}\frac{T_f}{A_f}$, which implies the technical rate of substitution between labour and land are the same for crop and the private good (forest) production in equilibrium. Optimal provision of environmental service satisfies condition (4.5) and (4.6). It depends on the degree of its link to the private good (k), the market price for the private good (p_f), PES payment (p_e). Similar to section 3.1.2, higher PES payment (p_e) will increase environmental service related private good production, hence environmental service as long as labour used in the good production satisfies $T_f > 1$. The impact from other factors such as k and p_f are left for section 5.

Hence, we get the Result A4:

Result A4: When there is no labour market, PES program will increase the provision of environmental service when the service is a by-product of a new private good. The higher the environmental payment, the more is the environmental service provision.

A4.2 With labour market

A4.2.1 Ex-ante PES program versus ex-post PES program

Before PES program, in the sub model, there is still no environmental service provision from upstream landowner. All land ($\bar{A}$) will be used in crop production. Part of labour endowment ($\bar{T}$) will be used in crop production, part is trade in the off-farm labour market.

After PES is introduced, the budget constraint for the landowner reads (4.4')

$p_C c_C = p_C q_C + p_f q_f + p_e k q_f + wT_O + B$. The land constraint is (4.3') $\bar{T} = T_C + T_f + T_O$. Other constraints are the same as (3.2), (4.1) and (4.2). The simplified maximization problem becomes

$$\underset{A_f, T_f, T_O}{Max}\ U(c_C, c_e)$$
$$= \beta \ln\left[\alpha(\bar{A} - A_f)^{\tau}(\bar{T} - T_f - T_O)^{1-\tau} + p_f \eta A_f^{\gamma} T_f^{1-\gamma} + Nk\eta A_f^{\gamma} T_f^{1-\gamma} p_e / p_C + wT_O / p_C + B / p_C\right]$$
$$+ (1-\beta)\ln k\eta A_f^{\gamma} T_f^{1-\gamma} p_e / p_C$$

First order conditions with respect to A_e, T_e and T_O yield

$$U_{A_f} = \frac{\beta}{c_C}\left\{-\alpha\tau(\bar{A} - A_f)^{\tau-1}(\bar{T} - T_f - T_O)^{1-\tau} + \left[p_f + (N-1)kp_e\right]\eta\gamma A_f^{\gamma-1} T_f^{1-\gamma} / p_C\right\} + \frac{(1-\beta)\gamma}{A_f} = 0$$
(4.5')

$$U_{T_f} = \frac{\beta}{c_C}\left\{-\alpha(1-\tau)(\bar{A} - A_f)^{\tau}(\bar{T} - T_f - T_O)^{-\tau} + \left[p_f + (N-1)kp_e\right]\eta(1-\gamma) A_f^{\gamma} T_f^{-\gamma} / p_C\right\}$$
$$+ \frac{(1-\beta)(1-\gamma)}{T_f} = 0 \qquad (4.6)$$

$$U_{T_O} = \frac{\beta}{c_C}\left[-\alpha(1-\tau)(\bar{A} - A_e)^{\tau}(\bar{T} - T_e - T_O)^{-\tau} + \frac{w}{p_C}\right] = 0 \qquad (4.7')$$

Where $c_C = \alpha(\bar{A} - A_f)^{\tau}(\bar{T} - T_f - T_O)^{1-\tau} + p_f \eta A_f^{\gamma} T_f^{1-\gamma} + Nk\eta A_f^{\gamma} T_f^{1-\gamma} p_e / p_C + B / p_C$

By combining first order conditions, crop and private good (forest) production is still efficiency, namely $\frac{\tau}{1-\tau}\frac{\bar{T} - T_f - T_O}{\bar{A} - A_f} = \frac{\gamma}{1-\gamma}\frac{T_f}{A_f}$.

Result of implicit differentiation of A_f, T_f and T_O with respect to p_e in the three first order conditions are similar to those in section 3.2.2 except the environmental good production function is replaced by the production function for environmental service related private good. So the results are similar to that of the first type environmental service which is produced by changing existing agricultural activities.