

MSc. Thesis Economics of Rural Development - MID

Water for Forest:

*Potential impact of PES-like programs at village and farm levels
in the mountainous areas of Vietnam*



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Abstract

The uplands of Northern Vietnam are home to the poorest of the rural poor. Inhabitants of these areas are faced with low agricultural productivity and the ecosystem services such as food production for marginalized populations, biodiversity reservoirs, and watershed regulating functions have been under increasing pressure due to decollectivisation and the following redistribution of the land, liberalization of markets and a rapid population growth. To partly reverse the threat posed to the ecosystem services, we analyzed the impact of alternative schemes on farm revenues that would set aside cultivated land for forest natural re-growth. Using mathematical programming we developed a farm household model in which we investigated scenarios where some land in the sloping area of the catchment is set aside for forest natural re-growth (which aims at restoration of watershed functions), while additional land is made irrigable in the lowland compartment of the farms. In the first part of this thesis we will impose different implementation and compensation schemes for this land set-aside schemes and analyze their effects on both a household as well as a village level. In the second part of this thesis we will analyze the different land set-aside schemes with the help of the theory on Payment for Environmental Services (PES) that examines the cut-off point where farmers will voluntarily set-aside sloping land in order to get more access to water in the bottom valleys. The compensation schemes are analyzed from two perspectives; on the one hand they will improve collective water infrastructures so that more water is made available in the lowlands; on the other hand they will individually reward farm households by allocating new terrace land. The impacts on land use, individual farm revenues, per head revenues and village revenues were analyzed. This led us to conclude that relatively small increases in irrigable land in the lower compartments are necessary to compensate for the revenues lost of land set-aside on the sloping land. Moreover, some of the scenarios comprehend a better wealth distribution among members of the villages. However, this would require some coordination at village or commune levels, and a deliberate choice to help the poorly endowed households.

Key Words: farm household modeling, non-separable models, Vietnam, subsistence farming, payment for environmental services

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1. Introduction

Over the past decades, life has changed dramatically for the people of Northern mountainous areas of Vietnam. The two main drivers of change were the shift from collectivism towards a market system and the rapid population growth. These led to a return to slash-and-burn cultivation in the uplands with increasingly short fallow periods, which in turn caused increased deforestation (Castella *et al.*, 2005). These practices pose a threat to the important ecosystem services available in the region; besides food production for marginalized populations, the ecosystems also provide important functions as biodiversity reservoirs and watershed regulation. If current practices continue, the ecosystems will most likely deteriorate, which will pose large dangers on the existence of all living beings and the food supply of future generations in the areas (Castella and Dang, 2002).

To protect or restore forest resources, local authorities have proposed farmers to set-aside some of their cultivated land in sloping areas to re-establish natural or productive forests. For example, as part of national policies, the authorities of Giang Cay village in Van Chan district have successfully prohibited the cultivation of upland rice by better-off farmers. The implementation of these policies has however been faced by mixed success. At least in the short run, setting-aside sloping land is costly for the farm households involved, as they get even less access to already scarce land. In the long run, however, more forests in the upper part of the catchment could indirectly benefit the households, because they may result in increased availability of irrigation water for the lowlands. Moreover, the improvement of ecosystem services to the region justifies supporting policies to compensate some of the costs. A suitable policy could be the improvement of collective irrigation infrastructures or allocation of additional terrace land for the lowlands.

Before deciding on possible set-aside regulations and compensation policies, policymakers need to gain ex-ante knowledge on their costs and benefits at the household level, as these will greatly affect acceptance and compliance. Our main objective is therefore to analyze the household and village-level impact of alternative schemes for setting-aside cultivated land for forest natural re-growth in combination with different options for improved irrigation. In the first part of this study, we distinguish various possible distributions to set-aside upland area and improve lowland water availability aimed at different types of farmers in order to gain insight in the potential distribution of costs and benefits. In the second part of this study the different set-aside schemes are applied to the theory of Payment for Environmental Services (PES). With the help of this theory, we examine the effects of two possible PES-like programs. In the first one the set-aside of upland area and payments shaped by the construction of water infrastructures are collectively organized at the village level. In the second one, the PES-like program is organized via individual resource flows between the users of environmental services that pay a tax in order to construct new terraces and the providers of environmental services that set-aside upland area.

Smallholder farmers in developing countries are not simple profit maximizers. As they face multiple market imperfections, they have to balance factors such as availability of land and family labor, food consumption requirements, and market access. In such a setting, a change in resource availability will affect the entire farming system, and its consequences can not be assessed using cost benefit analysis. Because we measure the impact of an *ex ante* change in resource endowments for farmers, statistical analysis that is characterized by measuring impacts *ex post* would not be a correct methodology to be used in this study either. We therefore use a farm household modeling (FHM) approach. This approach explicitly models the objectives, resources, possible activities and the socio-economic environment of the farm household and has been used extensively over the past decades to assess the effects of policy measures on farm households (e.g., Holden and Shiferaw, 2004; Kruseman and Bade, 1998; Laborte *et*

al., 2009; Van den Berg *et al.*, 2007).

This study contributes to the existing literature on farm household modeling and Payments for Environmental Services (PES). It assesses the effects of policy-induced land set-aside schemes and introduces possible compensation schemes for its adoption. The model results allow for an *ex ante* analysis of land set-aside and water addition schemes under the assumption that farm households are rational units who behave in an income-maximizing way. Obviously, all decisions made by the farm household are taken within the constraints (land, labor, credit etc.) and opportunities of cropping activities and off-farm work that the households face. The solutions of the model will first show the loss of possible land set-aside schemes and gain of water-addition schemes per type of farm household group in comparison to a base situation, which represents the current situation of farming practices in the area. It will then search for the cut-off points that represent the compensation of different ways of additional irrigation water in return for different set-aside schemes. This study adds to the existing literature on PES by examining the impact of a non-monetary payment regulated from not only an individual farm household, but also a communal perspective.

The structure of this study is as follows; in the next chapter we will provide a short overview of the study area and its socio-economic conditions. Thereafter, we will link the characteristics of the study area to the existing theory on market imperfections and the implications on the non-separability of the model. In the 4th chapter we will group the data acquired during field research according to an already existing typology. These three chapters together form the basis of the farm household model, as it is explained in chapter 5. The farm household model is first applied to the base run scenario in chapter 6, where after an explanation on the different land set-aside and water addition schemes follows. These scenarios will be imposed to the different types of farm households and the impacts of the scenarios will be analyzed. The theoretical framework of PES in chapter 9 will explain how PES can be applied to the imposed set-aside schemes. The GAMS model will be used to examine the cut-off points between the set-aside of land and additional irrigation for different types of farm households. We will end the study with a conclusion and discussion.

2. Study area

Introduction

The study was carried out in Van Chan district, which is part of the mountainous province of Yen Bai, situated in the North-West of Vietnam (Figure 1). The province is situated 150 km North-East of Hanoi, has a total area of 6900 km² and a population of around 750,000 inhabitants. The highest altitude in the province is 2500 meter and the main crops cultivated are irrigated and rainfed rice, maize and tea. Van Chan district has a total surface of 1205 km² and its 31 communes form a total population of around 140,000 (GSO, 2008). The majority of the people living in this area belong to one of the ethnic minorities of the Thai, Tay, Dao or H'mong and a village is mostly composed of one ethnic group.



Figure 1: Map of Vietnam.



Figure 2: Map of study area

Villages studied

Within the district of Van Chan, four villages in different communes have been selected to gather data on household characteristics, crop production and other activities of farmers. These are represented in Figure 2 above. The villages have been selected based upon the different availability in types of agro-ecological zones, the different ethnicities living in these areas, the different crops grown and the different access to markets.

The first village selected is Pang Cang in the commune of Suoi Giang. This village is chosen for its low amount of irrigated lowland. To compensate for this shortage in irrigated lowland, farmers tend to intensively cultivate the uplands. As for the perennial crops, Suoi Giang is famous for its special variety of tea. The people of this village belong to the ethnic minority group of the H'mong. Earlier research showed that land degradation in the uplands is high in this village, mainly due to the cultivation methods of farmers (Do *et al.*, 2007).

The second village is Giang Cay in the commune Nam Lanh, where the people belong to the ethnic minority Dao. This village is much differentiated in the amount of irrigated lowland that they have available. The village authorities prohibited the cultivation of upland rice as part of a project to preserve the hillsides. After the price drop in tea, the crop has not been cultivated for sale in this village anymore. Two other

cash crops that are cultivated here are ginger and cinnamon.

The third village is Ban Tun in the commune Tu Lé, which is characterized by its relatively large amount of irrigated lowland during the dry and wet season available. The ethnic minority Tai living here do not specialize in any cash crops except for a special variety of sticky rice.

Lastly, the village Nam Chau in the commune Nam Bung has been investigated because of its relatively large amount of newly constructed terraces. Access to water is however low here, which is at least part of the reason that people only cultivate one cycle of irrigated rice per year. The inhabitants of this village also belong to the ethnic minority Dao and cultivate cardamom as an important perennial crop.

Agro-ecological zones

Despite their different availabilities in agro-ecological zones and different altitudes, the households of the villages are largely organized in the same way and at least to some extent possess all types of agro-ecological zones, on which they mainly cultivate the same crops. Figure 3 below shows the typical division in agro-ecological zones within one village.

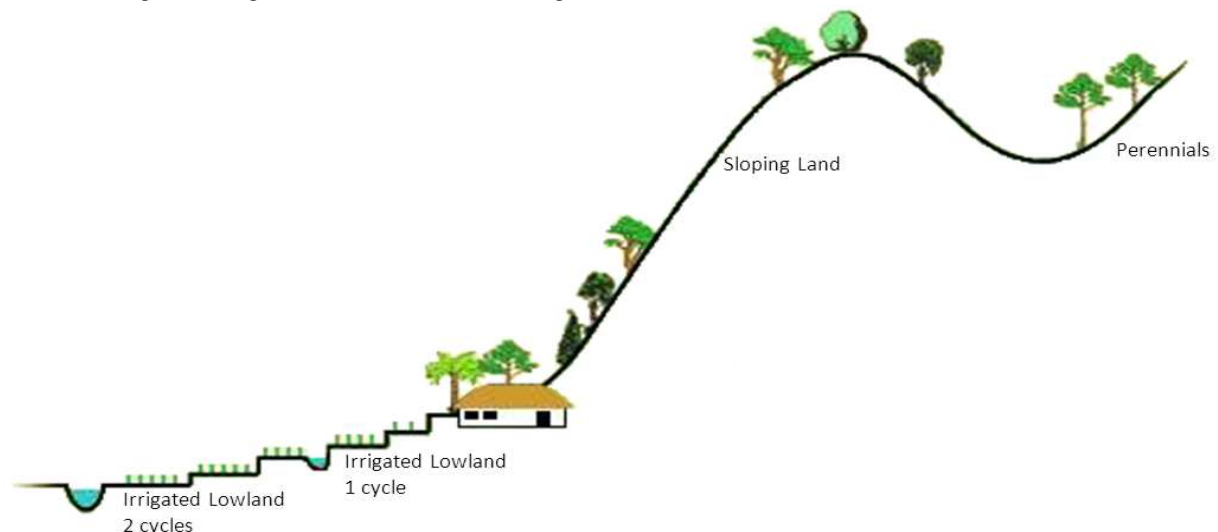


Figure 3. Agro-ecological division within a village.

On the bottom left of Figure 3 we find the first agro-ecological zone; irrigated lowland with access to water during the spring and summer season. This can be either paddy or terrace land and is generally cultivated for a long time and passed from generation to generation. The owner of this land usually possesses a “redbook”, the official document for tenure, for the land. The next agro-ecological zone, irrigated lowland with only access to water during the summer season, is established more recently. This land can be mostly defined as terrace land, but also paddy exists here. Ownership in the form of a redbook is quite common for this type of land. These two types of agro-ecological zones are the only ones that receive access to irrigation water. Currently, the farmers of the villages do not construct new terraces because they are not able to fetch the water. A solution for this, an improvement in water infrastructures, is laid out in Chapter 8. Due to a lack of reliable data, we did not take a specific water balance into account for the lowland agro-ecological zones, but only took into account whether there was access to water during the summer or spring and summer season. The sloping area consists of relatively newly acquired land on which a range of upland crops, often with fallow periods in between, are cultivated. Just before the distant forests perennials are cultivated. For both sloping land as well as perennial land

farmers do not own a redbook. However, the land is passed on from generation to generation and to whom the land belongs is common knowledge for all villagers. Therefore, we will treat all agro-ecological zones as if full ownership would exist.

Crops cultivated

For the cultivation of the main staple crop in the lowlands, irrigated rice, there are two distinct seasons: a dry (December till May) and a wet (June till October) season. Upland crops are generally cultivated between March and November and can have two cropping seasons. The upland crops cultivated in this region are upland rice, maize, peanuts, cassava, soybean, sweet potato and ginger. Apart from those, three perennial crops are grown; tea, cardamom and cinnamon. These crops can be cultivated in different rotations and while using different levels of inputs. The exact crops cultivated and their periods of cultivation differ somewhat between communes, but the sequence of activities and practices was the same in all communities. This allowed us to establish a general cropping calendar for each crop, as can be seen in Figure 4.

	T1	T2	T3	T4	T5	T6	T7					T1
CROPPING SYSTEM	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
IRRIGATED LOWLAND 2 SEASONS												
[Irrigated] Rice-Rice	PL	TR	WE		HA	PL TR	WE			HA		PL
IRRIGATED LOWLAND 1 SEASON												
[Irrigated] Rice				PL	PL	TR	WE			HA		
SLOPING LAND												
Cassava	HA		HA	SE	HA		HA		HA		HA	
Upland Rice					PL	SE		WE	WE		HA	
Ginger			PL	PL	SE	WE		WE				HA
Maize-Maize				PL	SE		WE HA	PL	SE			WE HA
Maize-Peanuts				PL	SE		WE HA	PL	SE		WE HA	
Soybean-Soybean			PL	SE	WE	HA		PL	SE	WE	HA	
Sweet Potato			PL	SE		WE	HA					
PERENNIALS												
Cardamom			WE	HA		HA		HA	HA			
Cinnamon			WE				WE			HA		
Tea			WE	HA							HA	

PL = Prepare Land, TR = Transplanting, WE = Weeding, HA = Harvesting, SE = Seeding / Planting

Figure 4: General Cropping Calendar

Irrigation Systems

An earlier study conducted in the research area highlighted the complexity of irrigation systems and its influences on the cultural practices of farmers (Vidal, 2009). Water usage in Van Chan broadly serves three purposes: for domestic use, to generate hydroelectricity and for agricultural use. For domestic use it is important that we do not only pay attention to the quantity of water available, but also to the quality. In certain areas of Van Chan, people have been forced to move due to returning diseases for reasons of poor water quality. Within the whole of Vietnam, hydroelectric plants have been built. This has also been the case for Van Chan, which caused a reasonable amount of damage to the fields of some farmers. Farmers did get compensated for this damage (a non-recurrent compensation between €0.60 and €0.90 per m²). The last function of the water is agriculture; farmers are organized in 'blocks' of around six families in which they collectively manage access to water to their fields and the maintenance of the collective irrigation system. In these watershed regulation systems, there is often a distinction between upstream and downstream economic agents, where the upstream farmers have to take downstream effects into account when making decisions on their land use. Per block, upstream and downstream farmers coordinate their cropping calendars (preparation of land, transplanting etc.) where upstream farmers practice their farming activities just before downstream farmers. However, this collective structure

sometimes goes hand in hand with individual actions that may lead to conflict. Moreover, irrigation is generally not equally distributed between different types of farm households.

Previous studies on sustainable cultivation

The local governments in Yen Bai province aim for a more sustainable management of the ecosystems. In line with this aim is the closing down of the uplands for the cultivation of upland rice in Giang Cay. Food self-sufficiency is however one of the main strategies of the farmers in the province. Possible ways to sustain the ecosystems while at the same time trying to meet food self-sufficiency have been extensively investigated in the area with the help of conservation agriculture such as mulch-based cropping systems (Affholder *et al.*, 2010). However, this research led to the conclusion that cropping systems based on mulching techniques still need quite a number of improvements in order to be adopted by farmers.

Jourdain *et al.* (2009) showed that a possible set-aside program in Van Chan, aimed at a reduction of 25% of upland area available for cultivation, *ceteris paribus*, would lead to a sharp decrease in soil fertility in the remaining cropping areas. Moreover, because of the likelihood that degradation will shift instead of stop, overall environmental effects may be negative as well. Only with compensation, these negative effects could be turned into positive ones. In order for farmers to meet their food needs, they have to be compensated for their loss in food production resulting from a possible land set-aside. Possible ways of compensation mentioned in the article are direct provision for part of their food requirements, in-kind insurance mechanisms that act upon farmer's risk-averse behavior regarding staple food production or the provision of improved agricultural technologies that would increase yields. Unless farmers are being compensated, they are obviously unlikely to take part in a land set-aside program voluntarily (Jourdain *et al.* 2009).

Market constraints

In the late '80s, economic reforms, also referred to as "Doi Moi", initiated a transition from the collective system to market liberalization in the mountainous areas of Vietnam (Castella, Dang, 2002). However, the four villages investigated still face some major market constraints. These are related to the factor (labor, land, capital) and product markets. For the labor market, only a certain amount of labor can be hired-out. Moreover, there is a transaction cost on hiring-in and hiring-out labor representing the costs needed for the farmer and employer to find each other. A land market does not exist in the area, which means that transactions in terms of sale or renting of land do not occur. There is no official market for credit; however, farmers found alternatives for this imperfection as will be explained in the next section. Therefore, the market is assumed to function perfectly. Regarding imperfections in the product market, some crops can only be sold in limited quantities and for all crops there is a large gap between the farm-gate price and the consumer (retail) price. In the following chapter, we will explain these imperfections and price bands with the help of the theory on market failures and non-separability and examine their implications on the mathematical model to be established.

3. Market Failures and Non-Separability

Introduction

Farm households maximize profits subject to (1) the trade-offs with other goals, (2) resource constraints and (3) working of markets (Ellis, 1988). Farmers in developing countries are often both producer and consumer. Producers try to maximize net revenues relative to their product and factor levels, given the market price, fixed factors and technology restrictions that they face. Consumers aim at maximizing their utility of the bundles of goods that they can consume, given the market price, disposable income, household characteristics and other constraints that they have to overcome (Sadoulet, de Janvry; 1995). In this section we will explain how these goals can be interrelated and how they apply to the farmers cultivating the uplands of Northern Vietnam.

Separable and Non-Separable Models

In perfect markets, where all products and factors can be traded, the opportunity cost of a product or factor of the household is equal to the buying price (Sadoulet, de Janvry; 1995). In the perfect neoclassical market scenario there are no market failures and prices for all goods are determined exogenously through the markets. The market prices reflect the opportunity costs for food production and consumption and free time. Households choices on crop production and leisure consumption do not depend on each other, because they can hire in labor for the same price as reflected by their own opportunity cost for crop production. Similarly, as long as perfect markets exist, the farmer is indifferent between consuming its own produced food or buying it from the market. Food can be sold at the market, whereby the farmer will gain more profits, can hire in labor from the money obtained and decide to devote more time to leisure. Hence, the farmer now buys free time, valued at the market wage rate. Therefore, the optimal situation of the farmer is one where markets are fully functioning because in this situation farmers are free to choose whether or not to use the market and do not have to deal with the market constraints (Taylor, Adelman; 2002). The farm household acts as a profit maximizing unit, where all decisions can be taken by first considering production decisions that lead to a certain profit level and in turn will affect consumption, but consumption does not influence the production decisions (Janvry, Sadoulet; 2006). This is what defines the classical separable household model.

In reality however, there are often market failures that lead prices to become endogenous. According to de Janvry *et al.* (1996), market failures occur *“when the disutility created from the cost of a transaction through the market is greater than the utility gain that it produces, which leads to people not using the market for the transaction”*. In order to overcome this disutility, farm households may invent alternative institutions to replace the market failures or the transaction simply does not occur. If the cost of a market imperfection become that high that participating is not viable anymore, the optimal strategy of the household may become self-sufficiency. Hence, market failures may lead farmers to seek the objective of reaching food self-sufficiency.

If markets for both labor and food are non-existent, farmers are confronted with a direct trade-off between producing food and consuming leisure and will produce till the point where the shadow value of producing one more unit of food is equal to the valuation of household time. Shadow values represent the point of equality between the marginal utility of food and leisure consumption and the marginal productivity of labor. When the farmer makes a decision on production, labor allocation and consumption, he may make producer and consumer decisions that are dependent upon each other (Taylor, Adelman; 2003). Under these circumstances, farmers are not able to separate their production and consumption decisions anymore. Influential in these kind of non-separable models are Singh, Squire and Strauss (1986). Non-

separable models occur when there are imperfections in more than one market. They imply that consumption characteristics influence production decisions. We will discuss two types of market failures; (1) a transaction cost / price band that leads to a difference between the buying and selling price, (2) a limited possibility to engage in the market that leads to a limitation on the amount that can be bought or sold, of which the most extreme case is a non-existing market.

Transaction Costs and Price Bands

Transaction costs may include the distance from the market, poor infrastructure that increases transportation costs, mark-ups by intermediaries, opportunity costs involved in searching for the buyer and the seller to meet each other and more household specific transaction costs. These costs are variable, meaning that they change according to the volume of units produced or bought. They drive a wedge between the farm-gate and consumer price, the so-called price band. This is a positive price interval that may lead farmers to decide not to engage in the market. When the selling price of the farmer falls within this interval, the household will adjust production and consumption decisions to each other and start cultivating for own-consumption (Janvry, Sadoulet; 2006). For the producer side of the household, the selling price is larger than the market price minus transaction costs, so it can better supply the good to itself. For the consumer side of the household, the selling price is lower than the market price, so it can better purchase the good from itself (Taylor, Adelman; 2003). Logically, the price band that an individual household faces fluctuates from year to year; when harvests are good, the lower bound of the price band falls and when harvests are bad, the upper bound of the price band rises.

Quantity Restriction

There may be a limited possibility to engage in market activities up to the point where the market does not exist. The constraint to market participation works in the following way; once the maximum level of participation has been reached, the household must find its internal equilibrium between the demand and supply that is leftover. This equilibrium defines a shadow value that acts upon the resource endowments, demand characteristics and the level of the constraint of the household. This internal equilibrium is again non-separable (de Janvry *et al.*, 1996).

Application to the Study Area

In our case, the market failures are that important, that a non-separable household approach should be followed. This because the market failures occur in both the factor (labor, land and capital) and the product market. A market for land does not exist, which means that participation in any form (sell, buy, hire-in or hire-out of land) is not possible. For the market of capital, we assume a perfectly working market. There is a limitation on the amount of labor that can be hired out whereas there is no limitation on the amount of labor that can be hired-in by farmers. Transaction costs do however occur in the whole labor market. A price band between the farm-gate and consumer (retail) price in the product market exists. We will here analyze these market imperfections per factor and product market and their implications for non-separability.

Factor Market

Market failures in the labor market occur in the study area, amongst others because the position of the villages is isolated from outside labor markets and because almost all inhabitants belong to ethnic minorities, a typical household characteristic that does not seem to help them in finding off-farm work. For the labor market, there is not only a transaction cost on hiring-in and hiring-out labor from the farm, but also a constraint on the amount of labor that can be engaged in off-farm work. The transaction costs are lower for labor that is hired-in and -out between farmers within the same village than for labor that is hired-out to engage in off-farm work outside the village. The marginal productivity of labor may be much

differentiated across farm households, which may lead the labor market to fail for only those types of farm households where the shadow value of labor is larger than the price band.

Opportunities to engage in off-farm work are often restricted to certain periods of the year, depending on the village and the type of farm household. Where market access for some farm households may be better than for others, none of the households could decide to fully engage in off-farm work and give up on cropping activities. Furthermore, there are certain members of the household who cannot participate in the labor market due to reasons of tradition, age and gender. Female labor is generally used to work on the farm. Child labor is usually spend to do some tasks in and around the house and herd animals. The limited possibility for off-farm work is likely to leave the farmers, due to the very restricted area of land that they have, with an abundance of labor in the household. This will lower the shadow wage of the household and stimulate farmers to produce for food production and/or devote more time to leisure consumption. The lower shadow wage can transform a previously non-tradable, for example cash crops, into a tradable (Taylor, Adelman; 2002).

In our study area, a market for land does not exist. This means that transactions in terms of sale, buy or renting of land do not occur. Furthermore, there is no official credit market to which farmers have access. If farmers face food constraints during certain time periods of the year, the most common way of solving these is by borrowing rice from friends and relatives. For credit constraints on the use of inputs, lending from traders can be a possibility for farmers, where repayment normally occurs after the harvest. Hence, farmers have access to short term credit; i.e. for the period of one cropping year. It would however be difficult for farmers to obtain long term credit composed of more than one year. Therefore, farmers do not have access to complete credit mechanisms that allow them to smoothen their consumption between years. Therefore, they are likely to reduce exposure to risk through the adjustment of income strategies. This may lead the farmer to adopt less risky activities such as greater diversification of income sources, food security considerations and lower levels of investments in soil conservation. In our case, income strategies to reduce risk are the choice of activities and production decisions. Especially the poor farm households adopt a more diversified crop portfolio and use less high yielding varieties that are more profitable but also more risky. This leads food self-sufficiency to become a second goal of farm households against price risks in food markets (de Janvry, Sadoulet, 2006). Our analysis composes one cropping year and therefore does not take long term credit into account and assumes a perfect working market for credit.

Product Market

There is a price band between the selling and buying price for all crops produced. The market failure constrain the abilities of farmers to respond to price incentives and modernization opportunities and lead them to shift to food and labor that they cannot trade (de Janvry *et al.*, 1996). One of the reasons for this is that the land allocated to food crops can only be minimally reduced, which leads to a reduction in the supply response of more favorable cash crops such as ginger and the cross-price elasticity of the food crop with respect to the cash crop. Therefore, the positive supply response for cash crops can only lead to a small substitution of cash crops by staple food crops and farmers only give a minimal response to price changes.

As will be explained in the next chapter, the households of this study are very diversified. Therefore, using the product markets may represent a gain for some households, but a loss for others, leading only those households that gain from trading via the product market to use it. However, the more shallow the local food and labor markets, the more the prices are correlated with shadow price movements, which leads farmers to be more likely to produce for self-sufficiency.

For some crops, such as ginger and sweet potato, there is also a constraint on the quantity that can be sold on the market. For ginger, the market is easily satiated. Because it is often not directly clear how much of the crop is exactly cultivated within the village, prices fluctuate highly from year to year. This would lead a risk-averse farmer to only spend a very limited amount of his resources to the cultivation of ginger, since he would probably only be able to sell a very limited amount for a reasonable price.

Conclusion

This chapter showed that the farm households of our study area do not just act as pure profit maximizers. They face market and resource constraints that lead them to not be able to separate production and consumption decisions anymore. Moreover, they adopt the goal of food self-sufficiency next to their primary goal of income maximization. In order to overcome the market imperfections that farmers face, they build different institutional arrangements to act as surrogates for what the markets do not provide; farmers exchange labor among each other in periods of intensive cultivation, they borrow rice from each other that will be paid back after harvest or pay sellers of farm inputs with part of the harvest.

The simulation of farm household's behavior with a linear programming model allows the analysis of farmers behavior beyond analytical results. The use of it in this study is to understand the impact of an exogenous shock in land endowments on farm household behavior. In a farm household model, we can only change the exogenous variables that will in turn influence the endogenous shadow values that the farmers face. Here, we proved that the decision of the farmer to engage in a market is an endogenous one that is shaped by the shadow values of the household and the market imperfections.

Furthermore, we showed that non-separability is a distinct farm household and village characteristic and not a market characteristic. Namely, the shadow values that a farm household faces are determined by their own characteristics and that of the village. Therefore, it is extremely important to consider the heterogeneity between households and the specific village characteristics. The characteristics of a farm household lead it to decide whether or not to participate in the market and to be a net-buyer or a net-seller of food (de Janvry, Sadoulet; 2006). In the following chapter, we will make the distinction between different types of households based on an existing household typology.

4. Farm Household Typology and Data

Introduction

During the transition from collectivism to a market economy, lowland fields were redistributed among members of cooperatives. These changes in land tenure policy caused a very unequal distribution of lowland among different ethnicities (Erout, Castella, 2004; Castella *et al.*, 2005; Jourdain *et al.*, 2010; Sikor, Doa, 2000) and different households in the region. Moreover, the transmission of land between generations, induced by gender differences and the informal rule that prohibits the construction of new terraces upstream of existing terraces without the approval of potentially affected persons, has contributed to an increased differentiation in landholdings among farm households.

Farm Household Typology

In order to measure the differences in endowments between farm households, a typology of different types of households was constructed in an earlier study (Jourdain *et al.*, 2010). For this typology, the two communes of Nam Bung and Suoi Giang were selected based on their contrasting access to markets. Within these two communes, two catchments were selected, based on their differences in lowland area available; Sai Luong in Nam Bung and Pang Cang in Suoi Giang with respectively a large and small amount of lowland available. Within each of the catchments, 60 households were randomly selected using a semi-closed questionnaire aimed at collecting data on household characteristics such as the number of adults and children, production factors such as land and capital endowments, participation in labor and product markets and the access to water and level of control of households in irrigation water. With the help of a Principal Component Analysis (PCA) on all variables, the most discriminating combinations of variables were selected. Thereafter, a hierarchical ascending classification (with Ward links) on centered and reduced retained variables using the procedure hcluster of software package R was conducted (Everitt, 2005). Two indicators, the Caliński-Harabasz statistics, and the Silhouette index were used as a numerical aid to determine the number of groups. The groups were then visually confirmed through a second PCA. Subsequently, the typological groups were analyzed in details with a broader set of variables describing the households. This led to a selection of six contrasted typological household groups with different endowments and related strategies:

Group 1: Water and Land Scarce is characterized by a small landholding, no irrigation water and a low human capital (lowest adult education index of all groups). They could be considered as the most vulnerable group; their landholding is very small, with almost all their land situated in the sloping areas. In order to meet their food requirements, they cultivate almost all their land with staple crops, which is likely to decrease soil fertility. Because these households are generally also the ones with a very restrictive access to markets, their opportunities to work off-farm are limited as well.

Group 2: Water Scarce, Land Rich. This group is faced with a very limited access to water, but does have large areas of sloping land and tea available. Contrary to the previous group, they are connected to the market and are therefore able to sell a large amount of their products, which they mainly seem to do in order to offset their lack of access to water.

Group 3: Off-Farm Work represent a small group of households that have been established for a long time, are endowed with a large workforce and therefore a low amount of irrigated lowland per head. Therefore, they have largely turned towards off-farm work.

Group 4: Terraces and Uplanders are large households, which have been established for a long time. They have a large area of terraces in their possession, but these areas generally do not get a lot of water during the spring season and the household is faced with a large amount of mouths to feed, which leaves them with a rice production per head of the household that is close to self-sufficiency.

Group 5: Terraces and Perennials. This group has a large share of terraces available with good access to water. The slopes are mainly cultivated with staple crops, but they also have a large amount of perennial crops available.

Group 6: Paddy Rich. This group has a large area of paddy land available, which receives a lot of water during the spring season. Furthermore, this group cultivates staple and perennial crops on the slopes.

Farm Household Data

The differentiation in endowments of farm households, based on the different agro-ecological zones, distribution of land and access to markets, will lead different farm households to react differently on policy-induced changes such as the land set-aside and water improvement schemes analyzed in this study. In order to get more detailed data of the farmers living in the four villages of our study area, we interviewed 45 households with the help of a semi-structured questionnaire. This concerned an in-depth analysis on their household characteristics, livestock, crops cultivated on each plot of land, the activities and inputs that those crops require and the yield they obtained during the calendar year 2008-2009 on the specific plots, the off-farm and non-farm activities, assets possessed and a food balance on whether or not self-sufficiency in rice and other staple crops was obtained. To cover all these aspects, three rounds of questionnaires with each farm household were conducted, which also gave us the chance to check data that appeared unclear or incorrect. A representative member of each household was interviewed, where we tried to get a sample of male and female respondents, but for traditional and cultural reasons in Vietnam, this was often the head of the household, who, in almost all cases, was male. The households have been selected via a stratified random sample in which we focused on whether the household was classified as a poor household or not and on their amount of paddy and terrace land available, since we assumed that this latter criteria is highly correlated with the well-being of the household.

The data collected were then grouped according to the six types of farm households identified in the typology. Within each typology group, one representative farm household was selected for the farm household model. Their main characteristics and the proportions according to the typology data are shown in table one below.

Table 1: Farm household's main characteristics

	Water and Land Scarce	Water Scarce, Land Rich	Off-Farm Work	Terraces and Uplanders	Terraces and Perennials	Paddy Rich
N ^{a)}	37	16	7	14	16	22
Proportion (%) ^{a)}	33	14	6	13	14	20
Household size (pers.)	4	5	7	6	8	6
Family labor force (man-year)	2	2	5	3.5	5	3.5
Land available in each zone per farm household (m ²)						
Paddy (spring and summer irrigation)	0	0	200	100	200	1500
Paddy (summer irrigation)	0	0	1500	250	250	3000
Terraces (spring and summer irrigation)	0	0	0	1000	300	0
Terraces (summer irrigation)	200	500	800	3000	2100	0
Sloping land	6500	14000	7800	16000	8000	15000
Perennials	600	6000	200	5000	9000	4500
Total Area (m2)	7 300	20 500	10 500	25 350	19 850	24 000

^{a)} of all households based on a hypothetical village according to typology data

Cropping Systems

The diversification in land endowments for different types of farm households is also reflected in the land use patterns that they adopt, as can be seen in Figure 4 below. Farmers use all the land that they have available for the cultivation of crops. If water on irrigated lowland is available during two seasons, farmers will cultivate two cycles of irrigated rice on the land. If water is only available during the summer season, the lowland will remain fallow during the spring season and will be cultivated with irrigated rice during the summer season. Upland rotation systems are mainly adopted by those farm households that cannot meet their food requirements by the cultivation of rice in the lowlands. These crop rotations allow those farmers to acquire additional rice yields by the cultivation of upland rice. Other main crops cultivated by farmers include maize and cassava, which is mainly used as feed for livestock. The perennial crops tea, cardamom and cinnamon are highly dependent on the altitude and climatic conditions and therefore differ per village investigated and not per farm household type. For this reason, these perennials are aggregated in the Figure below.

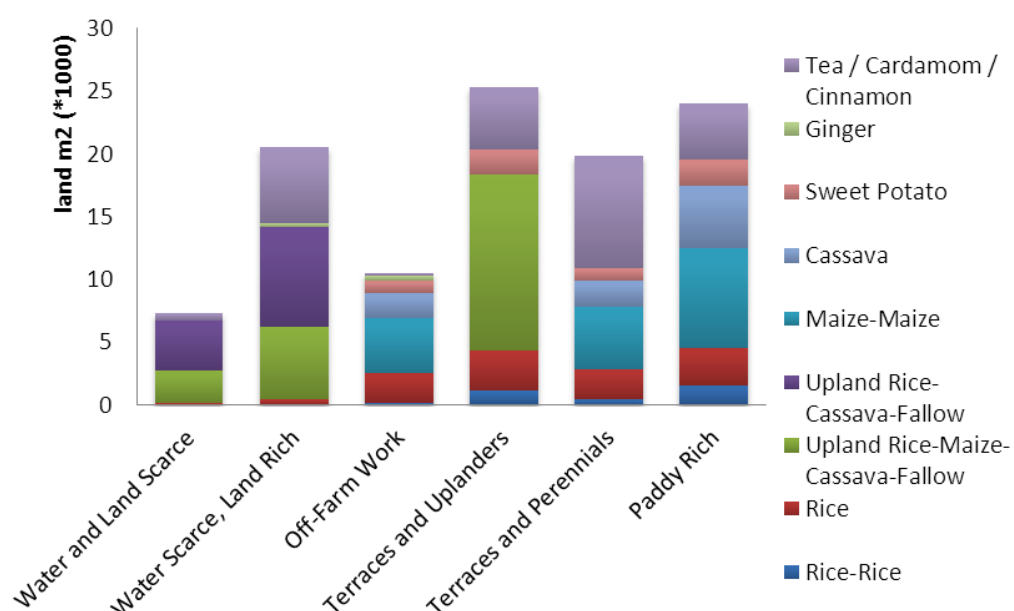


Figure 5: Survey results of cropping systems cultivated

5. Farm household model

Introduction

The whole-farm model is built using mathematical programming (Hazell Norton, 1986) and developed on a GAMS-platform (Rosenthal, 2007) of which a mathematical description can be found in annex 1. This model was designed in order to reproduce the behavior of farm households that have to select a set of crop and off-farm activities under constraints with respect to available production factors, technical opportunities and food consumption requirements; and how these would change with changing endowments in sloping land and a changing access to water. Therefore, we developed optimization models that incorporate essential characteristics of each representative farmer and the environment in which they operate per type of farm household grouped according to the typology above.

Objectives

In this study, we analyzed the impact of land set-aside and water addition schemes on different types of farm households by focusing on two objectives. The first objective of the farm household model is maximization of the discretionary income. With this objective, it is assumed that farmers can reach their highest possible welfare. We formulated a cash balance that is composed of incomes coming from the sale of crop products and wages of off-farm activities, the purchase of staple food crops, inputs for crops cultivated and wages paid for labor that is hired into the farm.

The second objective included in the model is food self-sufficiency. Farmers have a preference for rice, which is reflected by a linear weight loss in the objective function; a positive rice shortage will negatively affect the objective function. Hereby, the second objective of food self sufficiency is included in a second objective function of utility maximization. The total income, outputs, capital, land and labor allocation to each possible activity can be derived from the objective functions of the model.

Resources

A different initial endowment of working capital was appointed to each type of farm household. Furthermore, farmland was classified in six types of agro-ecological zones based on topography and surface irrigation, as explained in Chapter 2 and listed in table 2.1 of annex 2. Surface irrigation only occurred on paddy or terrace land and can be available either during the spring and summer season or only during the summer season. As explained before, there is no restriction on the use of water per period, only an indication on the availability of irrigation water on the lowland per season. Apart from irrigated lowland, we identified sloping land and land that belongs to perennial crops. Table 1 above shows the endowments in land per agro-ecological zone and the family labor available per farm household type.

Activities

The simulation horizon over which farmers based their decisions on crop cultivation and off-farm activities to undertake was the cropping year 2008-2009. All data on crop production is acquired via farm household surveys and later on checked and where necessary corrected with community officials and agronomists. The most important data that is entered in the linear programming model can be found in annex 2. These are the products produced, corresponding to land use systems and agro-ecological zone (table 2.2), the technologies per land use system available (table 2.3), the labor requirements per land use system (table 2.4) and the yields per product produced, given the technology and land use system (table 2.5). Livestock activities were not included in the model as an income generating activity, since it was not a main activity in any of the surveyed farm types and is unlikely to have a large effect on the results of our simulations. Depending on the type of land, we identified 28 feasible cropping systems, all

with a set of data on output and required labor and technologies (inputs). The 28 cropping systems included in the model were composed of 11 crops: 14 single-crop systems, 10 double-crop systems of which four are not rice-based and four specified rotation systems for crops that cannot be grown continuously. The composition of these crops is shown in table 2.2 of annex 2. The rotation systems are composed of several years but modeled according to their average yields and requirements per year.

Regarding the cultivation of these crops, all farm households face some major labor peaks at certain time periods. Therefore, we divided the year into seven time periods corresponding to the main labor patterns in crop cultivation identified by the surveyed farmers, which can be found in Figure 4 above and table 2.7 of annex 2. In each time period, the household allocates its available time between different cropping activities and off-farm opportunities. If family labor is not sufficient to fulfill all tasks needed on the farm, additional labor can be contracted.

Market constraints

As explained in the theory on non-separable models, a perfectly working market for capital in the short-term is assumed. This means that we allowed negative cash balances during the season in the model, and therefore included the possibility of borrowing between different time periods. There are however also several market imperfections that lead the farm model to become a non-separable one. These market imperfections are implemented by several constraints in the model: First of all, different types of farm households face different proportions on the likelihood to find wage employment in the non-farm sector. This is represented by an equation limiting the possibility to engage in off-farm work to 40 percent of the total labor available within the household for all types of farm households except for the group “Off-Farm Work”. This latter group is characterized by their better access to markets and therefore faces a limitation on non-farm work of 60% of their total labor available. Furthermore, we included a 10% transaction cost for hiring-in and hiring-out labor for all types of farm households. These costs represent the expenses of finding off-farm work and making the transition to the job and back beyond the actual salary that the farmer either receives or has to pay. Because a land market does not exist, transactions in terms of sale or renting of land were not included as possible options for the modeled farmers. Regarding the product market, a price band between the buying and selling price of the crops produced represents the shallow market opportunities and will force farm households to produce for home consumption and try to reach food self-sufficiency (De Janvry et al., 1991). This price band is enforced by a unique difference between the buying and selling price for the staple crops that can be both produced and consumed, as is indicated in table 2.6 of annex 2. Lastly, there is a restriction on the sale of certain cash crops. Therefore, a constraint on the maximum amount of land to be cultivated with these crops was included.

Consumption

The crops produced by the farmers can either be sold or consumed. Moreover, if food requirements are not met by crop cultivation, crops can also be bought. This led to the establishment of a product balance, in which the household buys, sells or consumes the products that are available. For the consumption of staple crops, we set a constraint on the minimum consumption for the farm household and assumed that, in order to meet food requirements, the minimal intake of rice for one person should be 0.5 kilogram per day. This is in line with theory on rice needs that states that from 180 kilogram of rice per person per year, 1576 calories per day or 75% of the requirements need to be obtained (ILO, 2000). In order to meet the same amount of calories, 0.45 kilogram of maize or 2.6 kilogram of fresh cassava leaves need to be consumed (Falcon *et al.*, 1984). However, in order to include the utility consuming rice as opposed to consuming maize and cassava, we assumed that one kilogram of rice can be replaced by two kilograms of maize and one kilogram of maize in turn can be replaced by two kilograms of cassava. This leads to a hierarchy in the preferences for staple crops; only if food requirements cannot be met by the consumption

of rice, and farmers do not choose to buy additional rice, they will switch to the consumption of maize. Only if the consumption requirements cannot be met by consuming rice and maize (or by buying additional rice or maize), farmers will switch to the consumption of cassava. However, not all rice can be substituted for maize and cassava; according to agronomists from the area, at least 45% of food requirements has to be met by the consumption of rice. These constraints comprehend the energetic needs of the farm household and a preference in consumption without having to develop a full energetic balance (including energy, protein and other nutrition needs) to rightfully describe the consumption function.

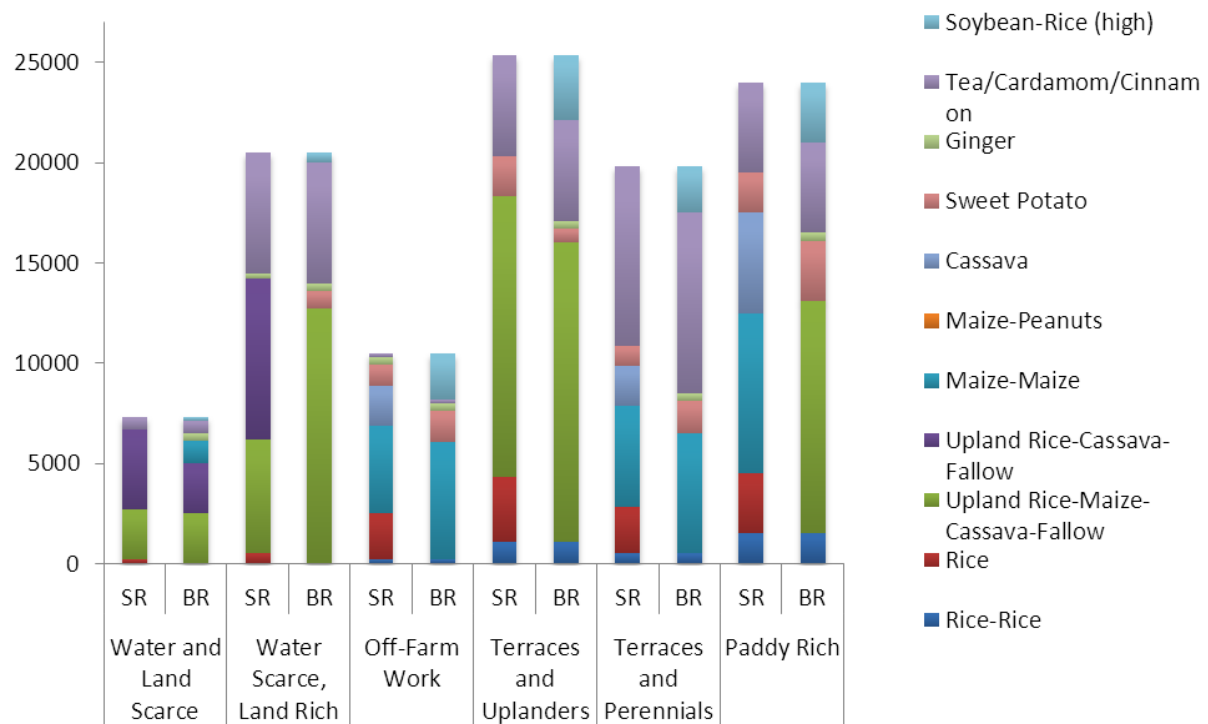
Conclusion

Together, the equations implemented in the farm model, as they can be found in annex 1 , lead to the reproduction of the *status quo* of farm household behavior in the villages examined. In fact, the farm household model represents hypothetical farming behavior, based on an aggregation of farm household and environmental characteristics of the four villages examined. In the next chapter we will explain to what extent the base run results of the model represent current farm household behavior in the study area.

6. Base run results

Introduction

With the knowledge on farm household characteristics, the environment in which they operate and under current endowments, the model results in terms of cropping systems used can be analyzed. These base run model results can be found in Figure 6 below, which compares the base run results with the survey results.



SR = Survey Results, BR = Base Run Results

Figure 6: Comparison of base run and survey results of cropping systems cultivated

Comparison Between Base-Run and Reality

Under current endowments, all modeled types of farm households cultivate all their irrigated land available with soybean-irrigated rice with high inputs if water is only available during the summer season. If water is available in both the spring and the summer season, two cycles of irrigated rice with high inputs will be cultivated. In reality however, as can be seen from the survey results of cropping systems cultivated presented in Figure 5 and Figure 6 under the columns “SR”, farmers who only have access to water during the summer season will leave the land fallow during spring and cultivate rice on it in the summer season. Soybean cultivation on irrigated rice fields is a new cropping system promoted by local authorities. The low rate of adoption of the cropping system by farm households can be due to three reasons; Firstly, risk averse farmers may be reluctant in adopting new cropping systems; the absence of risk considerations in the model may not take this into account. Secondly, the market chain for alternative crops is not yet as developed as that of rice. Thirdly, livestock is allowed to walk freely during the spring season. In order to overcome livestock destroying crops, farm households are reluctant on cultivating spring crops in lowland areas. Simple measurements such as fencing could however prevent this.

Some differences in cropping systems cultivated on the slopes between the base run scenario of the model and the survey results in reality can be analyzed when comparing SR (survey results) and BR (base run results) in Figure 6 above. The survey results show a larger adoption of the short rotation cycle upland rice-cassava-fallow for the poor farm households, especially for the household type water scarce, land rich. Comparison of the results also indicates an adoption of cassava by the richer farm households, which is left out in the base run. The difference in the amount of cassava cultivation identified in the short rotation system and the adoption of cassava can be explained by the fact that livestock is not taken into account in the model. Cassava is one of the main feeds for livestock (together with maize) and therefore necessary to be cultivated by farmers in reality. The two poorest groups of farm households are forced to mainly use the rotation systems on the slopes because of their insufficiency in rice caused by their very low endowments in irrigated lowlands. Only farm households with sufficient area of irrigated lowland seem to relieve pressure on the sloping areas, but this is mainly due to the labor shortages that they face during critical periods of upland crop cultivation (establishment of summer crops in the sloping compartment).

As explained before, perennials are highly dependent on altitude and climate characteristics and therefore, farmers in the different villages studied will cultivate those perennials that are suitable to their environments. For this reason, we aggregated the different perennials cultivated in Figure 5 and 6 representing survey results. The base run result of the model do however show that the cultivation of tea, where possible, would bring the highest revenue.

When comparing farmers land endowments with the survey and base run results, we can conclude that for all types of farm households, all land in possession is either cultivated or left fallow as part of rotation systems. Hence, cultivation in the lowlands does not seem to diminish cultivation in the uplands. This means that the labor constraint of most farmers in the area is, due to the very high land constraints, not high.

Revenue Distribution Between Farm Households

From table 2 below it can be seen that, based on the discretionary income, total revenues per farm household type in the base run are very unevenly distributed between different farm types. In the base run scenario, the farm household groups “Water and Land Scarce” and “Water Scarce, Land Rich” live below the one USD per day poverty line and are therefore identified as the two poorest farm household groups.

Table 2: Simulated total revenues per farm household type

	Water and Land Scarce	Water Scarce, Land Rich	Off-Farm Work	Terrace and Uplanders	Terrace and Perennials	Paddy Rich
Ranking in revenue per head ^{a)}	1	2	3	6	5	4
Total Revenue (incl. home consumption) (USD/head/day)	0.49	0.79	1	2.77	1.15	1.13
<i>1USD = 19000 VND</i>						

^{a)} Where 1 represents the poorest farm household and 6 the richest farm household

7. Alternative scenarios

Introduction

In the different simulations, where some sloping land is set aside for re-forestation projects in order to restore the watershed function, land available for upland farming is reduced. In parallel, we assumed that water access for irrigation was improved in the lower part of the catchment. Different alternative scenarios on how land could be set aside (from whom and what share of land set-aside for each farm type) and how the additional available water would be shared were developed. In terms of additional water allocation, we made a distinction between water availability during only the summer or during the spring and summer season and whether this additional availability would occur on terrace or paddy land. With these different simulations, we aim to provide more insight in the trade-offs involved in the resource use between different parts of the catchment for different groups of farmers. In order to restore the watershed functions, land available for upland farming is reduced, which means that the 'sloping' area for each modeled farm is scaled down.

Reforestation and watershed improvement

There are two reasons behind making more water available: Firstly, although still under scientific debate, an increased area of forest in the upper compartment of the catchment has the potential to change the water flows which would make more water available for irrigation in the lower compartments. There is however quite some scientific debate on the direct relationship between reforestation and watershed improvement. Forest restoration upstream may have a net positive or negative impact on water provision in both better water quality and greater quantity downstream (Koysoy *et al.* 2006). There are even opposite PES schemes investigated in South Africa that levied a charge on commercial forestation areas, aimed at giving a compensation for the capture of water by new trees (Katilla and Puustjarvi, 2004). This would imply a tradeoff between the improvement of water availability and biodiversity protection. There is however more consensus on the relationship between forest cover and water quality. It is namely generally approved that a reforestation will lead to less erosion, lower sedimentation rates and more nutrient and chemical outflows as leaching rises (Ayward, 2005).

Secondly, some new infrastructure works can be built that increase the amount of water available for the community. Namely, there is more water available in the study area than is currently used; the main constraint is that farmers cannot fetch the water. Irrigation infrastructures can overcome this problem. These infrastructures could be interpreted as a compensation for the land set-aside in order to restore watershed ecosystem functions and as an incentive from policies for farmers to do so. Depending on the watershed configuration and institutions, different scenarios of water increasing availability can be thought of.

Different scenarios explained

In order to fully measure the trade-offs, we modeled a hypothetical village of 112 households, in which the six types of households are in strict proportion to the data gathered in the typology. We simulated that 10 hectare or 8% of sloping land is to be set aside for forest re-growth, based on the assumption that this would be the maximum amount of sloping land that farm households would be able to set aside. In table 3 three mechanisms to set-aside this 10 ha of land among different types of farm households are calculated: first by converting 8% of each household's sloping land; secondly, by converting 870 m² of sloping land from each farm household; lastly, by setting-aside 1650 m² of sloping land only from farm households belonging to the two richest types. With these three different set-aside schemes, we aim to measure the losses in terms of revenues and food self-sufficiency that different types of farm households have to overcome and what the impacts in terms of revenue of these losses would be for the village as a whole.

At the same time, we analyzed the benefits of additional water access for different types of households and the village as a whole caused by the set-aside of land by investigating four exclusive scenarios based on how much water can be made available and how this is used. In the first scenario, we did not built new terraces, but assumed that the 10 ha of sloping land that is set aside will make additional water in 2 hectare of lowland available, which is allocated by converting 12% of each farm household's existing endowment in paddy/terrace land with only summer irrigation to spring and summer irrigation.

In the following three scenario's, we increase the amount of terraces with water available during the summer. In the first scenario, we allocated 180m² of terrace land with summer irrigation to each household. Secondly, we allocated 150m² of terrace land with spring and summer irrigation to each household. The difference in size between these two scenarios follows from the reasoning that it is more difficult to fetch water during the spring season than during the summer season. Lastly, we assigned 300m² of terraces with spring and summer irrigation to the households belonging to the two poorest types. We assumed a direct relationship between reforestation and watershed improvement under the scenarios where the set-aside of upland is compensated by terrace land. These scenarios are represented in table 3 below.

Table 3: Different trade-off scenarios

	Water and Land Scarce	Water Scarce, Land Rich	Off-Farm Work	Terrace and Perennials	Terrace and Uplanders	Paddy Rich	Total (ha)
No. Farmers	37	16	7	16	14	22	
Sloping area (m2)	6500	14000	7800	8000	16000	15000	122
Set aside of sloping land (m²)							
Equal proportion (8% each)	520	1120	624	640	1280	1200	10
Equal area	866	866	866	866	866	866	10
Equal area (richest)	0	0	1645	1645	1645	1645	10
Additional water in the lowland (m²)							
Convert 12% of terraces ^{a)}	24	60		252	360		1.1
Convert 12% of paddy ^{a)}			180			360	0.9
Total Converted							2
Add equal area terraces ^{b)}	180	180	180	180	180	180	2
Add equal area paddy ^{c)}	150	150	150	150	150	150	1.6
Add equal area terraces ^{c)}	300	300	0	0	0	0	1.6

^{a)} Convert summer irrigation to spring and summer irrigation

^{b)} Add area with summer irrigation

^{c)} Add area with spring and summer irrigation

The three types of sloping land set-aside, and four types of allocation of the newly developed irrigable land lead us to 12 alternative scenarios as represented in table 4. We used exclusive scenario's that analyzed the impact of different water improvement schemes, where some of them are based on a natural improvement in water availability and some are not.

Table 4: Overview of 12 alternative scenarios

Additional water in lowlands	Set aside 8% from all	Set aside 870 m2 from all	Set Aside 1650 m2 from rich
Convert 12% paddy/terraces ^{a)}	S01	S05	S09
Add 180m2 to all ^{b)}	S02	S06	S10
Add 150m2 to all ^{c)}	S03	S07	S11
Add 300m2 to poorest ^{c)}	S04	S08	S12

^{a)} Convert summer irrigation to spring and summer irrigation

^{b)} Add area with summer irrigation

^{c)} Add area with spring and summer irrigation

The following chapter will first examine the change in discretionary income due to different land set-aside schemes if no compensation would be given and thereafter the impacts on the different land set-aside and water addition schemes on the discretionary income from an individual, farm household and village perspective. From this, we will draw implications for the possible effects of wealth distribution on different types of farm households and the village as a whole.

8. Land set-aside and more water in the bottom valleys

Impact of Land Set-Aside on Revenues

Table 5 below shows that if farmers would be forced to set-aside upland areas without receiving compensation of any kind, this would obviously have a negative impact on the discretionary income of all farm household types involved; however, in a very diversified way. The poorest household group, *Water and Land Scarce* would be by far affected worst. With almost no irrigated lowland available and a very low endowment in sloping land, an equal area set aside would lead to a 20% total revenue loss for this type of farm household. While this is by far the largest influence, there is a need for every farm household to be compensated for their loss.

Table 5: Change in discretionary income due to different land set-aside schemes without compensation in 1000 VND

	Water and Land Scarce	Water Scarce, Land Rich	Off- Farm Work	Terraces and Uplanders	Terraces and Perennials	Paddy Rich	Village Total
8% land set-aside	-1337 (-9.9%)	-666 (-2.4%)	-596 (-1.2%)	-832 (-1.7%)	-611 (-1.2%)	-945 (-2.0%)	-106511 (-4.5%)
870 m2 land set- aside	-2711 (-20.1%)	-504 (-1.9%)	-830 (-1.7%)	-565 (-1.2%)	-830 (-1.6%)	-684 (-1.4%)	-150419 (-7.7%)
1650 m2 land set- aside	-	-	-1576 (-3.2%)	-1117 (-2.3%)	-1734 (-3.4%)	-1299 (-2.7%)	-82992 (-2.9%)

Impact of the different scenarios

Table 6 below shows the percentage change of each of the trade-off schemes on the discretionary income of the individual farmer (weighting the impact on households by the number of persons in the household), the different types of farm households and the village as a whole (weighted sum of the impact on each household type). As can be seen from the table, the trade-off schemes have a small impact on average total village revenues, ranging between a negative relative change of 3.3% and a positive relative change of 8.6%. The reason for these small changes is thus not because farm-household objectives are almost unaffected by a land set-aside, but because water addition schemes seem to be a good strategy to compensate farmers from revenue loss incurred by land set-aside. As was represented in table 5, poor households seem to be affected worst by a possible land set-aside; with the lowest amount of land endowments, a change in land allocation is likely to have the highest impact on this type of farm households. However, with one of the objectives being food self-sufficiency and a preference for rice, these food self-insufficient households are also the most benefited by a lowland compensation. Therefore, positive and negative impacts will change most for this type of households, ranging between a negative impact of 8.5% and a positive impact of 27.5%.

The only losses in discretionary income for the village as a whole can be found under scenario S01 (8% land set-aside combined with irrigated lowland conversion) and S05 (870m² land set-aside combined with irrigated lowland conversion). Here, additional production in irrigable land does not compensate for the loss of land in the sloping compartment. The reason for this is that the compensation schemes in the form of 12 percent converted irrigated lowland are not beneficial to the poorest household groups, *Water and Land Scarce* and *Water Scarce, Land Rich*, since they have a very low possession in irrigated lowland. As can be derived from table 3, the poorest group of farm households composes 33% of the households in the village and the two poorest groups together close to 50%. Hence, a positive change in the discretionary income of these two groups will put a relatively high weight on the likelihood for a positive

village discretionary income change. This shows that insufficient compensation for the set-aside of land of these household types can have some dramatic effects in terms of discretionary income. The largest positive changes in discretionary income for the two poorest groups of farmers can be found under S04, S08 and S12, where new terraces are only appointed to the two poorest types of farm households. An increase in irrigated lowland for these types of households is likely to have a major impact on the rice self-sufficiency among these groups of farmers.

Individual financial rewards for setting aside some sloping land are not likely to be viable for the poorest groups of farm households because of their goal of food self-sufficiency combined with the market failures that the households face. These results are complementary to earlier simulations made on poor farmers with very low access to markets (Jourdain, 2009). The analysis leads us to conclude that the allocation of new irrigable land could potentially be attractive from a social and private point of view, because poor farm households will relatively benefit more from the construction of new terrace land. Therefore, the most attractive scenario's for the majority of the village are those that lead to a large increase of farm revenue for the poorest households, and a small decrease for the richest households, such as S02, S03, S04, S08, S10, S11 and S12. In all of these scenarios, poor farmers do not have to set-aside a large amount of upland (8% or only set-aside of land for the rich households) but do get compensated by the construction of new terrace land.

Conclusion and discussion

The analysis of the twelve alternative scenarios leads us to conclude that a reduction of cropped area, associated with small increases in irrigable land in the lower compartment, has some potential beneficial effects in terms of distribution of revenues among households of a community, without having a major impact on the aggregate village revenues. In certain scenarios, this can lead to an improvement in the revenues of poor farmers, while not affecting much of the revenues of better endowed farmers. Coordination at the village or commune level and a deliberative choice to help the poorly endowed households is however essential in order to achieve a distribution that has the support of and is beneficial to most of the households in the village and the poorly endowed households in particular. This is especially of large importance in the light of the re-allocation of land after the transition from the collective to the market system, which showed that a very uneven distribution of land could emerge from village decisions.

This type of scheme, where sloping land is set-aside and small quantities of irrigable land are being distributed seems to work well for the farmers in the upland of Vietnam. Namely, because of the market failures and the combined objective of maximization their discretionary income and food self-sufficiency, households have the preference for, and no other option than, intensifying in cropping activities if they want to increase their objectives. However, the constraints that the farm households face have to allow them to do so and as identified in the base run, the most stringent one is the constraint in land endowments. Hence, compensating farmers by loosening the most stringent constraint that they face, will most likely attribute to an increase in their discretionary income and a higher rice production. However, as is clear from the analysis on the different scenarios, the cut-off point between setting aside upland area and additional irrigation water is highly dependent on the farm household type. So far, we have examined the effects of imposing different ratios of setting aside upland area for more irrigation water. However, if we want to find base for the implementation of these kind of scenarios, farmers have to be willing to voluntarily set-aside sloping land. Therefore, we will analyze the cut-off points between setting aside sloping land and making more irrigation water available in the lowland compartments for each farm household type in the next sections. We will do so with the help of the theory of Payment for Environmental Services (PES) that is explained in the following chapter.

Table 6: Percentage change in discretionary income due to different land set-aside and compensation schemes

Total Revenue Change Per Farm Household Group (%)	S01	S02	S03	S04	S05	S06	S07	S08	S09	S10	S11	S12
Water and Land Scarce	-1.96	12.51	15.94	24.12	-8.45	10.05	13.48	21.65	4.49	16.19	19.41	27.52
Water Scarce, Land Rich	-1.63	0.1	1.53	5.19	-1.11	0.63	2.06	5.72	0.73	2.36	3.81	7.38
Off-Farm Work	-0.78	-0.41	-0.18	-1.22	-1.26	-0.89	-0.66	-1.7	-2.79	-2.42	-2.19	-3.23
Terraces and Uplanders	-0.88	-1.15	-0.89	-1.74	-0.32	-0.59	-0.33	-1.18	-1.47	-1.69	-1.44	-2.33
Terraces and Perennials	-0.6	-0.48	-0.23	-1.2	-1.03	-0.91	-0.66	-1.63	-2.83	-2.64	-2.41	-3.41
Paddy Rich	-1.13	-1.35	-1.09	-1.99	-0.58	-0.79	-0.54	-1.44	-1.87	-2.09	-1.84	-2.74
Total Revenue Changes For the Village (%)												
Village	-1.35	3.68	5.12	7.85	-3.33	3	4.46	7.2	0.46	4.54	5.93	8.63
Average Revenue Changes Per Head (%)	-6.77	13.64	19.86	30.02	-14.61	10.93	17.36	27.51	-1.31	15.27	21.41	31.35

9. Defining Payment for Environmental Services Schemes

Introduction

In this chapter, we will analyze the Theory of Payments for Environmental Services (PES) and apply it to our case. The aim of the PES-like scheme that we try to develop here, is to find base for farmers to voluntarily set-aside their sloping land instead of imposing schemes as we did in the chapter before.

Theoretical Framework

Although Payments for Environmental Services (PES) is a fairly new concept, the theoretical foundations have been set decades ago by Coase (1960). Coase's theorem states that in markets where transaction costs do not occur, efficiency gains due to the internalization of environmental externalities will lead to efficient outcomes whatever the direction of the payment and the initial endowment of property rights may be. Hence, according to Coase the polluter does not always have to pay for the inconvenience caused by him. Therefore, the polluter pays principle, where the economic agents who cause damage to the natural environment are the ones who have to pay for it, would according to Coase's theorem not be a condition to achieve a Pareto better situation in a PES application (Kosoy *et al.* 2006). Classical in understanding Coase's way of thinking is the example of the steam engine; if a steam engine is causing harm to the cereal fields next to the railway, then less steam engines should be on the railway as long as the marginal harm done to the production of cereal is greater than the marginal revenues from the steam engine. According to Coase, this does not mean that the railway company is responsible for all harm done to cereal production. Payments from the railway company are likely to lead the cereal farmers to produce more cereal, because for every kilo of cereal produced they will get the full market price. This could mean the bankruptcy of the railway company and will definitely not secure an optimal allocation. According to Coase, as long as property rights are clearly established, polluters and those who are damaged by their actions will enter a negotiation that leads to financial compensation that guarantees a Pareto optimal situation. This is however under the precondition that negotiations can take place without costs. However, in real life situations, transaction costs of these negotiations are likely to run high, which will make property rights important in the negotiations and will not lead to a Pareto optimal situation anymore (Dietz *et al.*, 2004).

PES is based on the principles behind the internalization of environmental externalities of Coase. Wunder (2005) defines PES as *"a voluntary transaction where a well-defined environmental service (ES) or a land use likely to secure that service is being 'bought' by a (minimum one) service buyer from a (minimum one) service provider if and only if the service provider secures service provision (conditionality)"*. This definition entails the five criteria of Wunder (2005) for a PES-scheme: 1. a voluntary transaction, 2. a well-defined environmental service, 3. bought by a (minimum one) ES buyer, 4. bought from a (minimum one) ES provider, 5. conditionality is secured. The 'environmental services' mentioned in this definition are the positive externalities that natural or human-managed ecosystems entail and which are normally not taken into account in individual economic decision-making (Kosoy *et al.* 2006). Programs according to these criteria have been applied increasingly in both developed and developing countries as one of the solutions to combat losing or reducing valuable environmental services in ecosystems. These PES programs can be seen as contributing in a new way to the supply side in directly 'buying conservation' (Wunder *et al.*, 2008).

Goals of PES-schemes

The core idea behind PES is that people with access to land in certain local areas adopt practices that guarantee the conservation or restoration of ecosystems, for which they get direct contractual and

conditional payments from external ES beneficiaries in return (Wunder, 2005). Based on their studies of payments for water-related environmental services in Central America, Kosoy *et al.* (2006) found that the opportunity costs of forest conservation are generally larger than the payments received.

An often mentioned second goal of PES-schemes is poverty reduction and welfare equalization. However, there may be quite some reasons that could lead a potential poverty reducing PES scheme to result in a welfare reducing strategy, as described by Wunder (2005). Unsecure property rights may for example lead powerful groups to drive poor households away because previously marginalized land now got a higher value. Moreover, PES schemes are likely to have a positive impact on those who participate, but a negative impact on those who are unable to participate or on the poor consumers. It has also been shown that PES can have a negative impact on farmers with small land endowments and a heavy focus towards agriculture. Furthermore, poverty reduction will not be met if the PES schemes do not cover the opportunity costs of the land-use adjustments. Lastly, there are quite some reasons for the exclusion of targeted producers for reasons as land tenure, lack of endowments or access to credit.

PES-schemes in Vietnam

The practical implementation of PES schemes has only started recently, but there are quite a lot of PES-like schemes already implemented. PES-like schemes are those schemes that share some main characteristics of the PES program but do not fulfill all five criteria. In Northern Vietnam, there are currently no PES schemes implemented in the upper catchments, while there are quite some PES-like projects implemented in Central and South Vietnam. However, the Vietnamese government has recently shown interest in applying PES schemes in Northern Vietnam, which is characterized by the establishment of the Fund for the Protection and Development of Forestry that organizes payment fees by downstream users of watershed services to finance forestry projects in the upper-catchments (Jourdain *et al.*, 2009). In line with this fund, the Vietnamese Ministry of Agriculture and Rural Development (MARD) conducted a pilot policy for Payment for Forest Environmental Services in two provinces in Northern Vietnam. The main aim of this project was to “*stabilize the livelihoods of forest dependent local people in the above watersheds*”, with the specific target group of the over 100.000 people that had to resettle for the hydro-power plant in Son La province. In order to meet this aim, the fund focused on improving watershed services from a forest sector perspective. Under the program, inhabitants with ownership or traditional access to the land get paid for providing forest protection that will in turn help environmental and eco-system protection. This program found its base in the same problem as faced in our study area; the negative environmental impacts created by upland agriculture. Inhabitants setting aside forest land will receive an annual payment of 300,000 VND (around 15.40 USD) per ha/year. The program does however recognize that this would by far not be enough to compensate the opportunity costs of for example not being able to cultivate maize on these slopes; which is estimated at 24 million VND (around 1233 USD) per hectare (Government of Vietnam, 2008).

Application to the study area

The Fund for the protection and Development of Forestry thus aims at providing monetary incentives for farmers to set-aside their farm land for reforestation in order to improve watershed functions, reforestation and eventually overall biodiversity (Government of Vietnam, 2008). As has been pointed out, water is however also a scarce resource for the farmers that possess uplands in our study site. Moreover, reforestation alone is not likely to guarantee watershed improvement. Therefore, we introduce a PES-like program that accommodates collective water infrastructures as payment for setting aside upland for forest restoration by farmers. As mentioned in the study area, the farmers do not construct new terraces because they are not able to fetch the water. An improvement in water infrastructures would lead farmers to get better access to the water and overcome their loss of uplands by getting more lowland area

available. In this way, the opportunity costs of setting aside upland can be compensated by more cultivation in the lowlands. Instead of developing different set-aside schemes to find out which one would fit best into the context of our study area as we did in the first part, we now want to assess for what amount of water addition in the lowlands farm households will voluntarily choose to set-aside upland areas according to the two different set-aside schemes of the previous section; (1) 8% of the land of all farm households, (2) 870m² of all households. The third set-aside scheme investigated in the previous section, 1650m² only for the rich households is left out because this scheme would exclude the participation of poor households in the PES-scheme.

Targets

With the help of table 7 below, the main features of the proposed PES-like scheme can be explained. As has been shown in the sections before, especially the two poorest types of farm households have problems meeting their short-term livelihood needs, and therefore use long rotation cycles with short fallow periods on their uplands, an agricultural practice that is unsustainable in the long term. Converting this land to forestry systems will provide a service that would lead to watershed protection, biodiversity conservation and carbon storage (Jourdain *et al.*, 2009). The main goal of our proposed PES-like program, watershed protection in order to adopt land uses that improve reforestation and are likely to limit soil erosion in the uplands and serve a better biodiversity protection are two of the four main types of ES, the others being carbon sequestration and storage and landscape beauty (Wunder, 2005). In this way, the PES-like scheme can serve as an instrument that will in general improve the condition of the ecosystem services in place and more specifically the natural resources forests and water availability, while at the same time raising awareness to the sustainability of ecosystems and contributing to economic development.

In the previous chapter we have shown that overall village impacts on the revenues of the different schemes are not large but that, with coordination at the village or commune level, certain schemes can lead to an improvement of welfare equalization and therefore poverty reduction of the poorest groups of farm households. This means that the second goal of PES schemes, poverty reduction and welfare equalization, has the potential to be met.

Providers, Buyers and Intermediary

In PES-schemes focused on watershed protection, regulation is often enforced by making downstream water users pay upstream farmers for adopting different land use practices (Wunder, 2005). Hence, the PES schemes then focus on creating a conditional benefit transfer between the Uplanders, which are the providers of environmental services in one village, and the downstream beneficiaries in another village (Jourdain *et al.*, 2009). In Van Chan, all inhabitants of the village are farmers and despite in a much differentiated way, have both upland and lowland areas available. Our study area composes those farmers that are the providers of the environmental services, where the potential users of the various PES-like schemes are located in downstream catchments. Together, farmers can generate environmental benefits by facilitating upland-lowland interactions and at the same time improve their livelihoods. The downstream users of the program are the beneficiaries of the environmental service provided by the upstream farmers and will pay a tax for the water that they use. This tax will be transferred via the Fund for Protection and Development of Forestry to the providers of the environmental service, who will be compensated by the construction of irrigation schemes and additional terrace land. Hence, the downstream farmers will finance the construction of additional irrigated lowland and collective infrastructures, which is organized via de Fund for Protection and Development of Forestry.

Table 7: Main characteristics of the PES-like scheme (based on Wunder et al. (2005)).

Case, Country	Targeted	Paid For	Buyer	Provider	Initiator	Spatial scale and current size	Payment Method	Obstacles to implementation
Upland conversion of farm practice into reforestation in village of Van Chan district, Yen Bai province	Watershed and biodiversity protection (possibly poverty reduction)	Fund for the protection and development of forestry (water infrastructure) / inhabitants of downstream catchments (monetary payments)	Inhabitants of downstream catchments via the Fund for the Protection and Development of Forestry	Individual farm households upstream	Govern ment of Vietnam (MARD)	Upland set-Aside: 1. 8% from all 2. 869 m2 from all	1. More water available on existing terrace / paddy land 2. Construction of new terrace land	Reallocation of land Monitoring costs Transaction costs Conditionality enforcement

Payment Method

Currently, farmers in downstream catchments do not pay for the water that they receive. However, their organization of irrigated lowland, with paddy and terrace land managed in blocks of around six families as explained in Chapter 2, does allow payment schemes to be set-up. The proposed PES-like scheme does not only contribute but also adds to the existing PES literature in two ways; Firstly, it provides a unique mix in the analysis of communal and private payments that will give an incentive for farmers to not only provide ES but also cultivate in a more sustainable way. Namely, if farmers would only get additional payments, they are likely to practice even more intensive cultivation on the land that they have. With additional lowland, their consumer demands can be more easily met by production decisions. Secondly, because the reward for the trade-off between forest and better irrigation is partly additional irrigation water from a public scheme, it will not be negotiated with individuals but with communities. Inhabitants of the village together have to decide how to improve and allocate access to water. This type of PES-like scheme would be defined as an area-based PES scheme that stipulates how the areas of land will be converted. Furthermore, the PES-like scheme is use-restricting in the sense that it rewards providers for fully setting aside upland areas (Wunder, 2005). For the payments by converting existing terrace / paddy land, rewards will be defined in a negotiation between the governmental fund and the local communities of farm households. For the payments in the construction of new terrace land, resource flows will happen between individual farm households who individually decide to engage in the PES-like scheme.

Application to PES-Criteria

We can apply the five criteria of Wunder's (2005) definition to our proposed PES-program in the following way:

1. *Voluntary transaction.* A main prerequisite for a PES scheme is that it is voluntary instead of using a command and control framework. The previous section showed by looking at the revenue impacts for differentiated households and the village as a whole that there is a potential interest to set-aside upland area in return for additional irrigation water. Imposing the quantities for both set-aside and water addition, as we did in the previous section, does however imply a command and control system, a way in which payments in Vietnam have so far mainly been implemented (Wunder, 2005). These command-and-control systems are generally inflexible; they require high transaction, monitoring and enforcement costs. Moreover, they are likely to induce social conflict and non-compliance. Only by knowing that the PES-program will be voluntary, the assumption can be made that farmers that do participate will at least cover their opportunity costs of giving up their environmental damaging activity (Engel *et al.*, 2008). Searching for the cut-off point where different types of farmers will abandon a certain amount of upland area for irrigated lowlands as we will do in the next chapter, will add a voluntary element to the transaction. However, according to our proposed scheme, the farmers still cannot decide on the amount of land they want to set aside.
2. *A well-defined environmental service.* What is bought should be a directly measurable service. The service of setting aside sloping land is directly measurable by the forest area that will be created on this land which will lead to an overall reduction in land degradation and an improvement of the ecosystem functions such as watershed regulation services.
3. *The environmental service is being 'bought' by a (minimum one) ES buyer.* An ES can be either bought by the actual users of the ES or by others acting on behalf of the potential users. Our

PES-like program is operated through the government fund but it are the service users of the ES that pay the annual fee for service provision. This program stands in between a 'user financed' and a 'government financed' program because at least part of the program is directly financed by its users and we aim for collective design decisions between government and service providers on the one hand and government and service users on the other hand (Engel *et al.*, 2008). Hence, the government acts as an intermediary by distributing payments from ES users of downstream catchments to ES providers in upstream catchments. As explained before, farmers get paid by more access to water due to (1) the construction of additional terrace/paddy land from areas where farmers currently cannot fetch the water and (2) the construction of new infrastructure works that are build and will increase the amount of water available for the community. The resource flow goes from the farmers in the downstream catchments (resource to be paid for: more access to water), via the Fund for the Protection and Development of Forestry that act as an intermediate (regulate transfers between service users and service providers, receive upland areas, give access to irrigated lowlands) to the farmers in the upstream areas (resource provided: land set-aside).

4. *The environmental service is 'bought' from a (minimum one) ES provider.* The ES providers are thus the farmers currently cultivating the uplands in a non-sustainable way who adjust their farming practices in order to give space for forest restoration with the function of improving the ecosystems services. They are the landholders that can affect downstream water services in other catchments by adjusting their land-use practices. Here, the resource flow goes from the farmers in the upper catchments (resource set-aside: upland areas), regulated by the Fund for the Protection and Development of Forestry that act as an intermediate, to the farmers in the downstream catchments (resource obtained: additional access to water).
5. *ES is only bought if the ES provider secures ES provision (conditionality).* The mode of payment to the provider of an ES service may be vital for the sustainability of the contract; hence, conditionality is essential. This is the reason why our proposed program is not a PES-program but a PES-like program. The irrigation infrastructures and construction of new terraces do yearly compensate for the set-aside of upland area, but are given once and therefore do not function as an incentive for farmers to provide ES anymore. With only these payments, flexible contracts in which farmers can decide to pull out with for example changing context conditions cannot be granted. We will explain some alternative mechanisms to overcome this conditionality problem that can be thought of. However, none of these seem to suit the local environment or work according to rational economic theory.

Possible ways to Enforce Conditionality

In most PES-programs, environmental services are being paid in cash, but providers of ES have in certain cases also been compensated by technical assistance (TA), agricultural labor, input costs or in-kind compensation such as provision of seedlings in reforestation programs (Wunder *et al.*, 2008). While cash may be the most flexible form of payments to ES providers, it also received the critique from development practioners that cash is not likely to create sustained local welfare (Wunder, 2005). Increased irrigation water is a quite unique payment for PES schemes and because of the infrastructure development that such payment requires, it may be easily confused with Integrated Conservation Development Projects (ICDP's). ICDP's provide alternatives to environmentally damaging activities, but in reality often act as complements instead of substitutes and therefore fail to deliver the desired ES (Engel

et al., 2008). Like the program that we propose, they are also focused on biodiversity conservation and seek to address the social and economic needs of communities who would else threaten biodiversity. It often involves large infrastructure works that are implemented up-front and therefore only induce short-term conditionality (Hughes, Flintan; 2001).

Contingent transfers of infrastructure such as buildings or roads thus have the negative side effect that once established, they do not create an economic incentive for a continuous supply of ES over time (Wunder, 2005). Our proposed program does however differ substantially from these projects in the fact that it aims at both collective (infrastructure works) and private (additional terrace land) payments. This kind of PES-like scheme will act as a substitute for setting aside land and will not be complementary to other payments given. However, that also means that conditionality is not enforced. Possible ways to enforce conditionality in our PES-like scheme include a combination of monetary payments with additional irrigation water and management of additional terrace land in the form of 'lease contracts' regulated by the governmental fund.

Additional irrigation water in combination with monetary payments would not only include a payment that is given once, but also yearly compensation in the form of monetary payments and thus induce a continuous incentive to set aside upland area. However, because the additional irrigation and the monetary payments together are equal to the opportunity costs of setting aside sloping land, the annual monetary payments alone won't be enough to compensate for the opportunity costs that the farmers face every year. Economically, this would still mean that the opportunity costs of setting aside upland are not fully compensated on a yearly basis, which would lead farmers to return to the uplands after payment on additional irrigation is provided. It may be that an improved social capital could bring social control between farm households that will make non-compliance less likely. Furthermore, possible social control is likely to reduce monitoring costs since farm households themselves monitor each other's activities.

Other possible schemes to enforce conditionality are lease contracts for the additional terrace land provided that will exclude farmers from cultivating the terrace land in case of non-compliance. However, the irrigation systems are locally managed and organized by farmers and highly context dependent. Farmers are organized in 'blocks' of around six families in which they collectively manage access to water to their fields and the maintenance of collective irrigation systems (Vidal, 2009). Lease contracts and possible exclusion from cultivating appointed terrace land will therefore overthrow the whole social organization within the villages and is therefore not a possible way to enforce conditionality.

Theoretical Advantages and Disadvantages of the PES-like program

The large advantage of our proposed PES-like program is that partly because all villagers are qualified to participate in the PES-like program and partly because the resource flows are communicated on a community level, there are no villagers who are excluded from participation, but affected by the PES-like scheme. From an efficiency point of view, PES would only pay those farmers who currently pose a threat to the ecosystems for adjusting their farming practices to provide ES (Wunder, 2005). Those who do not pose a threat do not get paid because this would not create any additionality (clearly visible adjustment in practices and net positive difference in biodiversity conservation). This in some way unfair mechanism does not apply to the PES scheme proposed by us. Since all farmers engage in both upland and lowland cultivation, they are all potential ES providers.

A distinction can often be made between those ES that are public goods and those that are not. In our PES program, both are present; the additional access to water that is made available by collective infrastructures is a public good that cannot prevent users from benefiting from the payment provided (non-excludability). The other aspects of the program; allocating additional terrace land, does however happen on an individual basis. Therefore, the resource flow in this latter aspect is on an individual farm household basis and therefore, free-riding does not occur here. For the beneficiaries in downstream catchments, water services are club goods; only the farmers that hold water rights or are located in a well-defined watershed benefit from the ES and thus have to pay taxes (Engel *et al.*, 2008).

Economically speaking, it would be logical behavior that once farmers know that the PES-like scheme will be implemented, they will start to further deplete upland areas in order to gain more compensation. In our case this will not work for two reasons; (1) almost all of the accessible upland areas are currently used, (2) despite the fact that upland areas are not legally appointed to households, ownership of a certain piece of land is a common understanding among inhabitants. Social control among village members is therefore likely to prevent farm households of acquiring new upland just before the start of the PES-like program.

As has been shown in the base scenario, the most intensive cultivators of upland areas are the most vulnerable groups where, due to their cultivation practice, land is usually less productive and more likely to suffer from erosion. Hence, they are the most important providers of environmental services since their farm practices are most harmful for biodiversity. Moreover, because all types of farm households are potential ES-providers and negotiation happens on a community level, the PES has the potential to contribute to a better wealth distribution and thereby poverty alleviation of the poorest types of farm households. The importance of involving the community in the proposed PES system is likely to increase the social capital, i.e. the networks, norms, values and understandings that facilitate cooperation among groups, by improving the internal organization. Lastly, by negotiating collectively over the PES-like schemes, the equilibrium in the inherent conflict between buyers trying to maximize their consumer surplus (setting aside as much upland as possible) and providers maximizing their producer surplus (receiving as much irrigation water as possible) is found.

It is likely that large transaction costs will be involved in our proposed PES-like program. The landholdings of farmers are small and therefore it will involve a large number of contracts to include all interested farm households. Especially the large differentiation in landholdings will make transaction costs run high. One of the fears of PES is that it will decouple conservation from development; it may attract power seeking agents and may erode culturally rooted conservation values (Wunder, 2005). Because all villagers are farmers largely cultivating for self-sufficiency, this first point is not very likely to happen in our case. The proposed PES scheme is however likely to change traditionally and culturally rooted agricultural practices, not only in the uplands but also in the lowlands, as will be explained in the next section. Moreover, the PES scheme is likely to result in different trade-offs for different types of farm-households who are setting aside the same amount of upland area. This may result in negative social influences, which reinforces the importance of community negotiations over the PES program.

Conclusion

This chapter showed with the help of existing theory on Payment for Environmental Services how the PES-like program can be applied to our case. Assuming that the inhabitants of the village are rationally behaving agents with the main objective of maximizing their income and securing food provision, the

GAMS model results in the next chapter will show where the economic gains obtained from the different compensation schemes (additional water allocation in the form of irrigation schemes and new terrace land) are equal to the value of the foregone economic benefits of setting aside sloping land for reforestation. We assume that the farmers will accept all payments that exceed the sum of the opportunity costs that they face, implementation costs they must undertake and transaction costs they bear. Hence, the payments offered to the ES providers must exceed the benefit that they would receive if they would not change their behavior, but must be lower than the value of the benefit to the users of the ES. Assuming that governments pay the costs for the plantation of trees, the opportunity costs of the set-aside of upland remains restricted to the opportunity costs of not being able to use this land. From an efficiency point of view (Wunder, 2005), we would want to compensate the farmers just enough to overcome the opportunity costs of their current farming practice activities.

10. Analysis of PES-like schemes

Introduction

With the help of the GAMS-model, we can find the cut-off point where farmers are indifferent between the proposed PES-like scheme and practice as usual. Any payments above this cut-off point will lead the rationally behaving farmer to decide to engage in the PES-like program. One disadvantage of the linear programming model is the fact that we cannot analyze the optimal amount of land that a specific type of farm household would like to set-aside. Therefore, we developed six scenarios where we examined the cut-off point for each type of farm household for each scenario. The payment scenarios are represented in table 8 below.

Table 8: Overview of the six scenarios of the PES-like program.

	Set aside 8% from all	Set aside 870 m ² from all
Convert paddy/terraces ^{a)}	P01	P04
Add ?? m ² terraces summer irrigation	P02	P05
Add ?? m ² terraces spring and summer irrigation	P03	P06

^{a)} Convert summer irrigation to spring and summer irrigation

Collectively Negotiated PES-like Scheme

P01 and P04 represent the construction of collective water infrastructure works. The idea is that these scenarios will be collectively negotiated between the government and different types of farm households. However, different types of farm households will need different amounts of payments to overcome their opportunity costs of setting aside sloping land. Table 9 below presents an overview for the percentage and amount of terrace / paddy land that needs to be converted per type of farm household. For the farm households that are mostly endowed in terrace land, summer irrigation on terraces has been converted into spring and summer irrigation on terraces. These are the households “*Water and Land Scarce*”, “*Water Scarce, Land Rich*” and “*Terrace and Uplanders*”. Obviously, the other two households “*Off-Farm Work*” and “*Paddy Rich*” are mostly endowed in paddy land. Therefore, we converted a certain amount of paddy land with summer irrigation into paddy land with spring and summer irrigation for these households.

Table 9: Amount and percentage of land to be converted under PES-like scenarios in m²

Payment in irrigated lowland	Water and Land Scarce	Water Scarce, Land Rich	Off-Farm Work	Terrace and Uplanders	Terrace and Perennials	Paddy Rich
P01	18.60%	39.20%	32.90%	24.30%	24.10%	27.60%
P01	37.2	196	493.5	729	506.1	828
Per m ² set-aside ^{a)}	0.07	0.18	0.79	0.57	0.79	0.69
P04	30.85%	30.60%	45.80%	16.50%	24.80%	20.00%
P04	61.7	153	687	495	520.8	600
Per m ² set-aside ^{a)}	0.07	0.18	0.79	0.57	0.60	0.69

^{a)} The m² of irrigated lowland necessary to compensate one m² of upland.

As can be seen from the table, different types of farmers are faced with highly differentiated percentages and square meters of conversion necessary to overcome their opportunity costs for every m² of upland that they set aside. The reason for the difference in opportunity costs is linked to the non-separability of the consumer and producer decisions. As explained in the theoretical framework on non-separability, farmers have to adjust consumption and production decisions to each other because of the market failures that they face. As can be found in the mathematical description in the annex, the GAMS model imposes a minimum of food consumption per member of the farm household, of which at least 45% needs to be fulfilled with the consumption of rice. If farmers cannot fulfill their food requirements with the consumption of rice and have to switch to the consumption of maize or cassava, a linear loss component to capture the preference for rice is imposed and will put a strong disutility on rice shortages faced by farmers. The two poorest types of farm households, 'Water and Land Scarce' and 'Water Scarce, Land Rich' are not able to meet their minimum food requirements by the consumption of rice, which leaves them with undesirable rice shortages. This means that their opportunity costs of setting aside upland area in return for more lowland area are very low. Hence, a small improvement in their rice consumption will lead to a relative large improvement of their utility function and therefore these types of farm households are willing to give up a relatively large amount of upland for a relatively small amount of additional irrigation. As can be seen from Figure 7 below, the low opportunity costs of setting aside upland area are largely linked to the fact whether or not self-sufficiency in rice is reached.

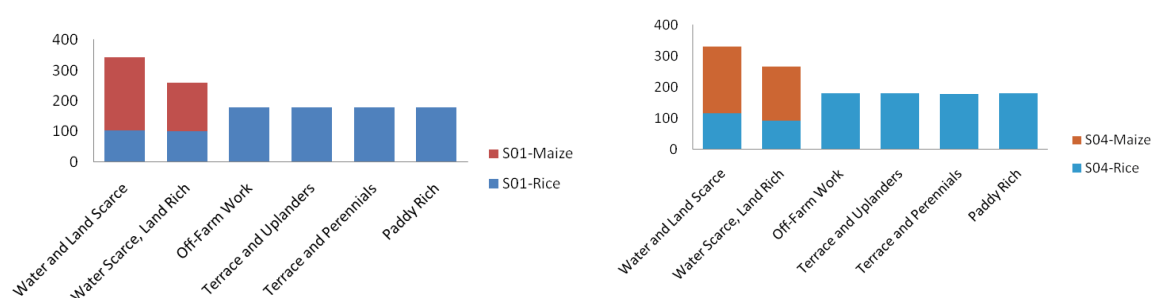


Figure 7: Food consumption under scenario P01 and P04

As can be seen from table 10 below, the smallest total area that needs to be converted with collective infrastructures occurs under scenario P04 with a fixed amount of land-set aside for all farm households that participate. Under the scenario where irrigation schemes will lead to a transformation of lowland irrigation in the summer season to lowland irrigation in the spring and summer season, the providers of ES and the users of the provided ES, together with the government acting as an intermediate, have to collectively decide on the level of upland that has to be set aside in order to receive payments in additional access to water. This because it is not possible to construct irrigation schemes that will regulate the water flow for each individual household, especially because of the local management structure of irrigated lowland in the study area. With a deliberate choice to help the poor farm households, the collective negotiations could lead to an agreement where the poor farm households have to set-aside less sloping land than the rich farm households.

This scheme would be new in the sense that it is collectively regulated; the resource flows do not occur between individual households as is normally the case in PES-schemes, but between villages as a whole, with the governmental fund acting as an intermediary. This way of distribution would allow for a reallocation of land and a better wealth distribution among farm households in the village. However, if the scheme is collectively negotiated, it is likely that there are households who would not be willing to engage in the program, especially the rich households who do not benefit from different set-aside schemes for different types of farm households in favor of the poor households. This would imply a command and control framework for those farm households not willing to cooperate, which is in contrast with the requirement of PES that actions must be voluntarily. Therefore, we will now investigate the individual schemes based on the allocation of additional terrace land.

Table 10: Aggregate payments in of water converted per scenario in m²

	Water and Land Scarce	Water Scarce, Land Rich	Off-Farm Work	Terrace and Perennials	Terrace and Uplanders	Paddy Rich	Total area in m ²
N	37	16	7	14	16	22	
Proportion (%)	33	14	6	13	14	20	
P01	1376.4	3136	3454.5	10206	8097.6	18216	44486.5
P04	2282.9	2448	4809	6930	8332.8	13200	38002.7

PES-like Scheme Between Individual Farm Households

The communal irrigation schemes are different from the other two payment mechanisms where a certain amount of terrace land is allocated to individual farm households. These schemes are captured under the scenarios P02, P03, P05 and P06 in table 11. Also here, the opportunity costs of setting aside upland areas are much differentiated. The poorest household group, *Water and Land Scarce* only requires between 0.03 and 0.11 m² of lowland compensation per m² of upland set-aside, depending on the amount of upland that is set-aside and on whether the compensation given is lowland with only summer irrigation or with spring and summer irrigation. The group *Terrace and Uplanders* are the ones that require the most lowland for every m² of upland that they set-aside if the amount of land to be set-aside is fixed. If the land set-aside is 8% of the total land set-aside per farm household, the group *Off-Farm work* faces the highest opportunity costs per m² of land to be set-aside.

In PES projects that aim for a resource flow between individual farm households, a uniform payment is given on the basis of which farmers could decide whether or not to participate in the program. The amount of payment would be higher than the opportunity costs as represented in table 11, because of all costs next to the loss in cultivation that farmers need to incur (for example changing social practices and working calendars). Under the scenarios with only summer irrigation (P02 and P05) the amount of payment could be set at 0.20 or 0.30, meaning that with 0.20 m² of lowland irrigation for every m² of upland that is set aside only the two poorest groups, *Water and Land Scarce* and *Water Scarce, Land Rich* will choose to engage in the PES-like program. If we would set this higher to 0.30, also the group *Terrace and Perennials* is likely to engage in the program. Under the scenario where compensation is given in the form of spring and summer irrigation (P03 and P06), the payment could be set at 0.10 or 0.20. Under this scenario, 0.10 m² for every m² of lowland would include *Water and Land Scarce* and *Water Scarce, Land Rich* and 0.20 m² would also include the group *Terrace and Uplanders*.

Table 11: PES-like schemes with the construction of additional terraces in m²

Payment in irrigated lowland	Water and Land Scarce	Water Scarce, Land Rich	Off-Farm Work	Terrace and Uplanders	Terrace and Perennials	Paddy Rich
P02	32.5	172.3	272	568	316.6	597
Per m ² set-aside ^{a)}	0.06	0.15	0.44	0.89	0.25	0.50
P03	16.2	89.9	175.2	312	189.5	341
Per m ² set-aside ^{a)}	0.031	0.08	0.28	0.49	0.15	0.28
P05	57.6	130.5	378	376	326.5	426
Per m ² set-aside ^{a)}	0.11	0.12	0.61	0.59	0.26	0.36
P06	29.8	65	244	209	195.7	243
Per m ² set-aside ^{a)}	0.06	0.06	0.39	0.33	0.15	0.20

^{a)} The m² of irrigated lowland necessary to compensate one m² of upland.

Whether payments in terraces with only summer irrigation or terraces with spring and summer irrigation will occur is dependent on the water that can be made available in the village. If the possibility of terraces with spring and summer irrigation is restricted to certain areas within the catchment, it could be decided to combine payments with only summer irrigation and payments with spring and summer irrigation.

The lower opportunity costs for the poorest groups of farm households, induced by the market imperfections and related aim for food self-sufficiency can lead the PES-like schemes to cause a wealth-redistribution among different types of farm households. Namely, the poorest types of farm households, as the most intensive cultivators of the upland areas, will adapt more sustainable practices in the lowlands that more than overcome their opportunity costs. Therefore, they will be better-off in maximizing their objectives after the PES-like program is imposed. The richer farm households on the other hand, face much higher opportunity costs and will thus not engage in the PES-like program. In this way, the PES-like program will induce a *status quo* for the richer farm households, but improve the situation for the

poorest farm households and hence, improve the equalization of wealth among different types of farm households.

Practical discussion on the PES-like schemes

The large advantage of PES-programs is their *quid pro quo* way of handling conservation; only those who provide valuable ES are being compensated. However, it is only truly efficient if the conditions of voluntariness and conditionality are met. Therefore, we will here examine the possible success of our proposed PES-like program and in how far it could be seen as efficient.

Criteria for Success

The success of PES-programs depends on a number of criteria. First of all, potential service providers must enroll in the program. As examined in the previous section, those farmers for whom opportunity costs are more than covered are likely to participate in the PES-like program.

Secondly, providers must comply with the terms of their contract and compliance must be monitored. This compliance could happen through for example site inspections. However, as monitoring in itself will not be enough to ensure compliance, sanctions in case of non-compliance are a necessary mechanism as well. Possible sanctions may be to cut payments for schemes that would combine payments and additional irrigation or to exclude people from cultivating the terraces in case of lease contracts. However, the first mechanism would not be in line with the economic theory of rational behaving agents, when the latter one would overthrow the existing social structure in the study area. Therefore, sanctions to ensure compliance are not covered in our PES-like program.

Thirdly, the induced land-use changes must generate the desired ES. The PES-like program must result in a change in land use compared to what would have happened if the program would not be implemented. Continuous cultivation on the upland will cause increasing soil erosion and pose more pressure on the ecosystem services. However, whether setting aside sloping land will naturally lead to a water improvement in downstream areas is still under scientific debate. Therefore, it is essential to establish a baseline in order to assess this additionality of setting aside sloping land in our PES-like program. The base-run scenarios of this study would already give a clear picture of the 'business-as-usual' counterfactual scenario. It would however also be necessary to assess the *ex-ante* amount and accessibility of irrigation water in both downstream and upstream areas. An important concept within the PES schemes related to additionality is leakage; a program can achieve high additionality in a project area, but this does not help that much if it causes environmental degradation in another area (Wunder; 2005). In our case, almost all upland accessible to the farm households is currently cultivated. Therefore, it will not be likely that farmers will move to cultivate in other areas.

Lastly, the desired ES must be provided on a long term basis. If it would be possible to invent a mechanism to overcome conditionality, it is likely that the PES-like program will secure provision on a long term basis. Namely, in the context of this study, compensating farmers for their set-aside of upland area by lowland area will be much more sustainable in the long term. Bearing the market imperfections in the study area in mind, it would be more difficult for farmers to build a sustainable way of living around monetary payments, especially with an imperfect long-term credit market. With the provision of irrigated lowland, farmers can transfer their practices of cultivation from the uplands to the lowlands and make use of their factor endowments in for example labor. With market failure and an increase in the abundance of

labor under monetary payments, farmers could decide to cultivate the sloping areas that they have left more intensively. This would imply another form of leakage.

Efficiency

According to Kosoy *et al.* (2006), there are two conditions for PES schemes which have to be fulfilled in order to be efficient: Firstly, the compensation to landholders that provide environmental services should be at least equal to the opportunity cost of the promoted land use. In this chapter, we examined the cut-off point where the opportunity costs of setting aside sloping land would be exactly compensated. In the schemes for payment by terrace land, farmers will only accept a certain amount of irrigated lowland for the set-aside of sloping land if it would be beneficial for their objective function of maximizing discretionary income and reaching food self-sufficiency; i.e. at least compensate their opportunity costs. This is however not the case in the communal scheme where farmers collectively have to set-aside land and make water available. This means that some rich farmers face higher opportunity costs for the set-aside of sloping land and are therefore not willing to do so. However, because of the communal way of negotiating, this will lead to a situation where the majority of the farmers (especially the poor) will be much better off against a minority (rich households) who will experience small losses. Secondly, the amount of the payment should be lower than the economic value of the environmental externality. The economic value of the ES provided can only be determined once the PES-like program is in place, given an appropriate baseline.

11. Conclusion and discussion

Conclusion

This thesis explored how farmers in the upper-catchments of Northern Vietnam could relieve the pressure posed on the ecosystem services available by relieving the pressure on cultivating sloping land. Following the existing theory on market imperfections and non-separability, we showed that the market failures that exist in the study area lead farmers to not be able to separate consumption and production decisions anymore. Because of the market imperfections that occur in the labor, land and product markets and because farmers are not able to smoothen income between years, they do not just act as pure profit maximizers. They adopt a second goal next to maximization their discretionary income, namely food self-sufficiency.

This non-separability is a distinct farm household and village characteristic and not a market characteristic, realizing this is especially important in our study area, where land is very unequally distributed among different types of farm households. Therefore, we used a classification of six different types of households based on an existing typology in the farm household model, that we later aggregated to a village level. This model, developed on a GAMS platform, led to the development of optimization models that incorporate essential characteristics of each representative farmer and the environment in which they operate per type of farm household. Including the objectives, resources, possible activities and constraints per type of farm household, the *status quo* of farm household behavior in the villages was examined.

The base run results showed that currently farmers use all the land that they have available for cultivation. In comparing the base run scenarios with the survey results, we observe some differences in cultivation in the lowland area; the cultivation of soybean-irrigated rice and the upland area; the cultivation of cassava. This because respectively risk considerations and livestock were not adopted in the model. Based on the base run, we can say that in general, the higher the self-insufficiencies in rice from the lowlands that farm households face and the more restrictive the possibilities to engage in off-farm work are, the more likely they are to practice intensive cultivation on the sloping land. This means that especially the poorest groups of farm households practice intensive crop cultivation on the slopes with short rotations and few fallow periods.

We then invented 12 different scenarios for the set-aside of land and improvement of water availability in order to examine the total revenue impacts on the different land set-aside and water addition schemes from an individual, farm household and village perspective. It was showed that the schemes to set-aside upland areas alone could largely reduce revenues for farm households, especially for the poor farmers. The impact of the different scenarios on the average village revenues are small; however, especially the poor farm households seemed to benefit from compensation by additional irrigation. The analysis leads us to conclude that the allocation of new irrigable land could potentially be attractive from a social and private point of view, because poor farm households will relatively benefit more from the construction of new terrace land. However, coordination at the village or commune level and a deliberative choice to help the poorly endowed households is essential in order to achieve a distribution that has the support of and is beneficial to most of the households in the village and the poorly endowed households in particular.

If we want to find base for the implementation of land set-aside and water improvement scenarios, farmers have to be willing to voluntarily set-aside sloping land. Therefore, analyzed for what amount of water addition in the lowlands farm households will voluntarily choose to set-aside upland areas according to (1) 8% of the land of all farm households, (2) 870m² of all households. We assumed that as rational behaving agents, the farmers will accept all payments that exceed the sum of the opportunity costs that they face, implementation costs they must undertake and transaction costs they bear. One disadvantage in searching for this cut-off point with the help of a linear programming model is the fact that we cannot analyze the optimal amount of land that a specific type of farm household would like to set-aside.

This study added to the existing literature on PES by analyzing payment mechanisms for the set-aside of upland areas from two levels. On a communal level, the amount of lowland that needs to be converted if irrigation infrastructures were provided was examined. It was showed that mainly because of the goal of food self-sufficiency, poor farm households face much lower opportunity costs per m² of land to be set-aside in return for additional lowland. Therefore, this way of distribution could allow for a reallocation of land and a better wealth distribution among farm households in the village. However, if the scheme is collectively negotiated, it is likely that there are (rich) households who do not benefit from the program and would therefore not be willing to engage in the program. Therefore, this would still imply a command and control framework for at least some types of farm households, something that we would want to overcome in developing a PES-like program.

Under individual payment schemes with the allocation of additional terrace land, it was showed that the poorest types of farm households face much lower opportunity costs for the set aside of upland areas than the richer types of farm households. If the payment schemes would be set higher than the opportunity costs of the poor farm households but lower than those of the rich farm households, this would only lead the poor farm households to participate. Therefore, these individual schemes could lead to an improvement in the livelihoods of poor farm households while not affecting those of the richer farm households. Hence, this scheme could potentially lead to a welfare equalization.

Discussion

The results presented here indicate both an improvement in the sustainability of cultivation and thereby an improvement in the ecosystem services of the study area. However, there are some limitations to the proposed schemes. Firstly, conditionality is not enforced in the PES-like scheme. If no other mechanism to secure conditionality for the PES-like program will be invented, the program would risk farmers to return to cultivate the upland areas after payments are received. Therefore, it is necessary to find a mechanism that would secure conditionality and transfer the PES-like scheme into a PES-scheme.

Secondly, the PES-like program builds upon the idea that a set-aside of upland by ES providers in upstream catchments will lead to more water available for ES buyers in downstream catchments. There is however quite some scientific debate on the extent to which this is correct. Therefore, further research on the likelihood of a restoration of the watershed functions downstream is necessary. In line with this, it is necessary to determine the baselines of both upland cultivated and water available in the study area, so that additionality could be examined.

Apart from the improvements that could be made in the proposed PES-like schemes, there are also some improvements that could be made in the linear programming model. First of all, all formulas in annex 1 are measured over the seven time periods developed corresponding to the lean and peak seasons in labor on crop cultivation. Also measuring discretionary income over these time periods would however not be necessary and in fact incorrect since it measures the same interest rate on a possible loan over very differentiated time periods.

Secondly, there is room for improvement in examining the discretionary income by including a consumption and/or energetic balance for the farm households. A lack of survey data did however not allow for a full consumption balance. Currently, the requirements for the staple crops maize and cassava in order to compensate one kilogram of rice consumption are overestimated and therefore do not reflect the calorie compensation but a compensation in the preference of consuming rice instead of maize and cassava. The linear weight loss corresponding to a shortage of rice that is included in the utility function punishes the farm households again for not meeting rice requirements. Therefore, it would be best to keep this linear weight loss in the utility function while at the same time implement a consumption and/or energetic balance that is more consistent with reality.

Lastly, one disadvantage of the linear programming model is the fact that the solutions probably did not show the optimal point of land set-aside for farm households. Namely, it calculated the optimal compensation of different kinds of additional access to water given a certain level of land set-aside in the sloping compartment. Therefore, it would be good to estimate the opportunity costs for different amounts of land set-aside for different types of farm households. A dynamic instead of linear programming model would be better suited for this.

Despite these shortcomings, the methodology and results presented here could be of large value in an ex-ante analysis of PES-like programs that provide alternative payments and do not only look at individual resource flows. Moreover, the study could be of large use in coordination and deliberation at the level of local authorities and can contribute to *ex ante* assessments of PES policies targeted at ecosystem restoration by farmers.

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Annex 1: Mathematical Description of the Model

This annex presents the mathematical descriptions of the model used. The farm household model represents an average household for each farm household group as described in the typology. To simplify notations, we omitted the farm type subscripts in the equations below. Table 1.1, 1.2 and 1.3 below give a description of respectively the coefficients, indices and variables used in the model.

EVERYTHING MEASURED PER TYPE OF HOUSEHOLD

CROP PRODUCTION

- Production equation

$$\sum_z \sum_l \sum_i Y_{j,z,l,i,t} X_{z,l,i} \geq 0$$

The sum of the quantities of products that are produced in each period per land use system, per technology used, per agro-ecological zone.

- Balance per product, per time period

$$E_{j,t+1}^{beg} + \sum_z \sum_l \sum_i Y_{j,z,l,i,t} X_{z,l,i} + B_{j,t} - C_{j,t} - S_{j,t} - E_{j,t}^{end} * U_j = 0$$

The initial stock of products of one period plus what the household produces plus what the household buys minus what the household consumes minus what the household sells corresponds to the ending balance of the previous period minus possible storage losses

LABOR ALLOCATION

- Labor balance per time period

$$\sum_z \sum_l \sum_i L_{z,l,i,t} X_{z,l,i} + L_t^{out} \leq L_{f,t}^{fam} + L_t^{in}$$

The labor that is devoted to different cropping activities or off-farm activities. Labor can be sold outside or into the farm.

- Limitation on off-farm opportunities

$$\sum_t L_t^{out} \leq L_{f,t}^{fam} * d_f$$

Off-farm labor opportunities per farm household type depend on the likelihood to find real off-farm opportunities.

CONSUMPTION

- Consumption of rice

$$CJ_t^{Rice} + HJ_t^{Rice} \geq MJ_t^{Rice}$$

Farmers have a preference for the consumption of rice. However, if consumption requirements cannot be met by the consumption of rice, either rice can be purchased on the market or substituted by the consumption of maize and cassava.

- **Minimum consumption of rice**

$$CJ_t^{Rice} \geq MJ_t^{Rice} * 0.45$$

Not all rice can be substituted for maize and cassava; therefore, a minimum of 45% of food requirements has to be met by the consumption of rice.

- **Substitution of rice by maize**

$$CJ_t^{Maize} \geq HJ_t^{Rice} * 2 + HJ_t^{Maize}$$

2 kg of maize necessary to compensate 1 kg of rice

- **Substitution of maize by cassava**

$$CJ_t^{Cassava} \geq HJ_t^{Maize} * 2$$

2 kg of cassava necessary to compensate 1 kg of maize.

Here, we enforced a hierarchy in the preferences for staple crops: (1) rice, (2) maize, (3) cassava without having to develop a full energetic balance (including energy, protein and other nutrient needs) that would describe adequately the consumption function.

LAND CONSTRAINTS

- **Land constraint equation**

$$\sum_z \sum_l \sum_i X_{z,l,i} \leq A_{z,f}$$

The total land use system per technology per zone is limited by the available land per farm household per zone

- **Restriction on use of ginger**

$$J_t^{Gi} \leq 0.05 * A_{z1,f}$$

Ginger is normally only cultivated in the gardens of the farmer and due to the fluctuations in price and market access will remain a side activity to farmers.

OBJECTIVE FUNCTION

- **Discretionary Income:**

$$\begin{aligned} \text{Max } Z = & K_{t+1}^{beg} + \sum_j \sum_t PJ_j X_{z,l,i} + \sum_t W_t^{Hout} L_{f,t}^{fam} * (1 - tr) - \sum_t w_t^{Hin} L_t * (1 + tr) \\ & - \sum_z \sum_l \sum_i \sum_t PI_{z,l,i,t} X_{z,l,i} - \sum_j \sum_t PC_{j,t}^m QC_{j,t}^m - \sum_t R_t = K_t^{end} \end{aligned}$$

The farm household is assumed to maximize its discretionary income (Z). The initial stock of capital plus the earnings from products that are sold and labor that is hired out minus labor that is hired in, inputs for cropping systems that are bought, the costs for food that has to be bought and the interest rate on borrowing. It is possible to borrow, but this has to be repaid at the end of the period. Therefore, each period $t+1$ starts with a positive cash balance. The starting cash flow of one period equalizes the ending of cash flow of the previous period. The crop products produced on-farm are valued at the farm-gate prices, whereas products are valued at the prevailing market prices.

- **Utility Function**

$$\text{Max } U = K_{t+1}^{beg} + \sum_j \sum_t PJ_j X_{z,l,i} + \sum_t W_t^{Hout} L_{f,t}^{fam} * (1 - tr) - \sum_t W_t^{Hin} L_t * (1 + tr) - \sum_z \sum_l \sum_i \sum_t PI_{z,l,i,t} X_{z,l,i} - \sum_c \sum_t PC_{j,t}^m QC_{j,t}^m - \sum_t R_t - N_t * HJ_t^{Rice} = K_t^{end}$$

Discretionary income minus a linear weight loss for a rice shortage.

Table 1.1 Selected coefficients of the model

Coefficients	Description	Unit of measurement
$E_{j,t+1}^{Beg}$	Initial stock of products at the beginning of the first time period	Kg/time period
U_i	Possible storage losses	Kg/time period
L_{zlit}	Labor requirements in each period per land use system per technology per agro-ecological zone	Days/ha
$Y_{l,z,i,t}$	Products produced in each time period per land use system per technology per agro-ecological zone	Kg/ha
$L_{f,t}^{fam}$	Family labor available per farm type per time period	Days/time period
d_f	Limitation to off-farm opportunities per farm household type	Days/year
K_{t+1}^{Beg}	Initial stock of capital	Million VND/period 1
PJ_j	Price per product	Million VND/kg
W_t^{Hout}	Wage of off-farm labor per time period	Million VND/day
tr	Transaction costs	Million VND/day
W_t^{Hin}	Wage of labor hired into the farm per time period	Million VND/day
$PI_{z,l,i,t}$	Price of technology in each period per land use system per technology per agro-ecological zone	Million VND/unit
$PC_{j,t}^m$	Market price of staple consumption good per time period	Million VND/Kg
$A_{z,f}$	Available land per agro-ecological zone per farm household	Ha/zone

Table 1.2 Selected indices of the model

Indices	Description
z	Agro-ecological zone
l	Land-use system
i	Technology (inputs)
j	Products
	J = all products
	$J1$ = staple goods
t	Time Periods
f	Farm Type

Table 1.3 Selected variables of the model

Variables	Description	Unit of measurement
$X_{z,l,i}$	Land use system per technology per zone	Ha/year
$B_{i,t}$	Products bought per time period	Kg/time period
$C_{i,t}$	Products consumed per time period	Kg/time period
$S_{i,t}$	Products sold per time period	Kg/time period
$E_{j,t}^{End}$	Stock of products at the end of the time period	Kg/time period
L_t^{out}	Labor that is hired out per time period	Days/time period
L_t^{in}	Labor that is hired in per time period	Days/time period
L_t	Labor other than family labor used for on-farm work	Days/time period
$QC_{j,t}^m$	Quantity of staple products bought from the market per time period	Kg/time period
R_t	Costs and interest on loans	Million VND/time period
K_t^{end}	Capital at the end of the time period	Million VND/time period
$CJ_t^{Product}$	Consumption of product per time period. Three sub-sets: CJ_t^{Rice} Consumption of rice per time period CJ_t^{Maize} Consumption of maize per time period $CJ_t^{Cassava}$ Consumption of cassava per time period	Kg/time period
$HJ_t^{Product}$	Shortage of product per time period HJ_t^{Rice} Shortage of rice per time period HJ_t^{Maize} Shortage of maize per time period (only if shortage of rice)	Kg/time period
MJ_t^{rice}	Minimum rice needs per time period	Kg/time period
$J_t^{Product}$	Production of Product. Sub-set: J_t^{Gi} Production of ginger	Ha/year
N_t	Linear weight loss for rice shortage	Kg/time period

Annex 2: Data

This annex presents an overview of the most important data incorporated in the linear programming model that is used in this thesis.

Table 2.1 Agro-ecological zones

Agro-Ecological Zone	Type of Land
Paddy land with spring and summer irrigation	Irrigated lowland spring and summer
Paddy land with summer irrigation only	Irrigated lowland summer
Terrace land with spring and summer irrigation	Irrigated lowland spring and summer
Terrace land with summer irrigation only	Irrigated lowland summer
Sloping land	Upland
Perennials	Perennials

Table 2.2 Products corresponding to land use systems, technologies and agro-ecological zone

Product	Land Use System	Level of inputs	Agro-Ecological Zone
Cardamom	Cardamom	-	Perennials
Cassava	Cassava	-	Upland
Cinnamon	Cinnamon	-	Perennials
Ginger	Ginger	-	Upland
Maize	Maize spring cycle	High	Upland
Maize	Maize spring cycle	Low	Upland
Maize-Maize	Maize spring and summer cycle	High	Upland
Maize-Maize	Maize spring and summer cycle	Low	Upland
Maize-Peanuts	Maize-peanuts	-	Upland
Peanuts	Peanuts	-	Upland
Irrigated Rice	Irrigated rice summer cycle	Low	Irrigated lowland summer
Irrigated Rice	Irrigated rice summer cycle	Medium	Irrigated lowland summer
Irrigated Rice	Irrigated rice summer cycle	High	Irrigated lowland summer
Irrigated Rice-Irrigated Rice	Irrigated rice spring and summer cycle	Low	Irrigated lowland spring and summer
Irrigated Rice-Irrigated Rice	Irrigated rice spring and summer cycle	Medium	Irrigated lowland spring and summer
Irrigated Rice-Irrigated Rice	Irrigated rice spring and summer cycle	High	Irrigated lowland spring and summer
Soybean	Soybean spring cycle	-	Sloping
Soybean	Soybean summer cycle	-	Sloping
Soybean-Soybean	Soybean spring and summer cycle	-	Sloping
Soybean-Irrigated Rice	Soybean spring-irrigated rice summer cycle	Low	Irrigated lowland summer
Soybean-Irrigated Rice	Soybean spring-irrigated rice summer cycle	Medium	Irrigated lowland summer

Soybean-Irrigated Rice	Soybean spring-irrigated rice summer cycle	High	Irrigated lowland summer
Sweet potato	Sweet potato	-	Sloping
Tea	Tea	-	Perennials
Maize-Cassava	3 years maize – 3 years cassava	-	Sloping
Upland Rice	1 year upland rice – 2 years fallow	-	Sloping
Upland Rice-Maize-Cassava	2 years upland rice – 3 years maize – 2 years cassava – 3 years fallow	-	Sloping
Upland Rice-Cassava	2 years upland rice – 2 years cassava – 2 years fallow	-	Sloping

Table 2.3 Technologies (Inputs) per land use system

Land Use System	Input level	NPK (5-10-3) (Bag 50 Kg)	Nitrogen (Kg)	Pesticides (Package / Bottle)	Herbicides (Package)	Kg hybrid variety seeds
Maize spring cycle	Low	2				30
Maize spring cycle	High	8				30
Maize spring and summer cycle	Low	4				60
Maize spring and summer cycle	High	16				60
Irrigated rice summer cycle	Low			5 ^{a)}		30
Irrigated rice summer cycle	Medium	8	20	5 ^{a)} 5 ^{b)}		30
Irrigated rice summer cycle	High	15	40	10 ^{b)}	3	30
Irrigated rice spring and summer cycle	Low			10 ^{a)}		70
Irrigated rice spring and summer cycle	Medium	20	50	10 ^{a)} 10 ^{b)}		70
Irrigated rice spring and summer cycle	High	40	100	20 ^{b)}	6	70
Soybean-Irrigated Rice	Low			5 ^{a)}		30
Soybean-Irrigated Rice	Medium	8	20	5 ^{a)}		30
Soybean-Irrigated Rice	High	15	40	5 ^{b)}	3	30

^{a)} Package

^{b)} Bottle

Table 2.4 Labor requirements per land use system in days/ha per time period

Land Use System	T1	T2	T3	T4	T5	T6	T7	Total
Cardamom	0	0	0	9	0	9	40	58
Cassava	6	4	95	40	0	35	15	195
Cinnamon	0	0	20	14.3	0	0	14.3	48.6
Ginger	0	0	45	90	30	20	50	235
Maize spring cycle	0	0	75	90	0	20	20	205
Maize spring cycle	0	0	75	90	0	20	20	205
Maize spring and summer cycle	0	0	75	90	0	40	160	365
Maize spring and summer cycle	0	0	75	90	0	40	160	365
Maize-peanuts	0	0	75	90	0	20	195	380
Peanuts	0	0	0	0	0	0	195	195
Irrigated rice summer cycle	0	0	60	50	0	25	0	135
Irrigated rice summer cycle	0	0	0	0	0	60	75	135
Irrigated rice summer cycle	0	0	60	50	0	85	75	270
Irrigated rice spring and summer cycle	0	0	60	73	0	42	0	175
Irrigated rice spring and summer cycle	0	0	10	50	20	0	40	120
Irrigated rice spring and summer cycle	0	0	34	48.5	15	31	61	189.5
Soybean spring cycle	0	0	34	48.5	15	31	61	189.5
Soybean summer cycle	0	0	34	48.5	15	31	61	189.5
Soybean spring and summer cycle	54.5	43.5	28	54	97.5	31	61	369.5
Soybean spring-irrigated rice summer cycle	54.5	43.5	28	54	97.5	31	61	369.5
Soybean spring-irrigated rice summer cycle	54.5	43.5	28	54	97.5	31	61	369.5
Soybean spring-irrigated rice summer cycle	0	40	40	55	97.5	31	61	324.5
Sweet potato	0	40	40	55	97.5	31	61	324.5
Tea	0	40	40	55	97.5	31	61	324.5
3 years maize – 3 years cassava	3	2	80	60	0	37.5	162.5	345
1 year upland rice – 2 years fallow	0	0	0	23.3	0	17	23.3	63.6
2 years upland rice – 3 years maize – 2 years cassava – 3 years fallow	1.2	0.8	38.5	46	0	29.2	62	177.7
2 years upland rice – 2 years cassava – 2 years fallow	2	1.3	31.7	33.6	0	11.7	12.7	93

Table 2.5 Yields per land use system, per technology (inputs), per product per product

Land Use System	Level of inputs	Product	Yield (kg/ha)
Cardamom	-	Cardamom	770
Cassava	-	Cassava	7196
Cinnamon	-	Cinnamon	2132
Ginger	-	Ginger	10000
Maize spring cycle	High	Maize	2400
Maize spring cycle	Low	Maize	2200
Maize spring and summer cycle	High	Maize	4000
Maize spring and summer cycle	Low	Maize	4800
Maize-peanuts	-	Maize	2400
Maize-peanuts	-	Peanuts	850
Peanuts	-	Peanuts	900
Irrigated rice summer cycle	Low	Irrigated rice	3000
Irrigated rice summer cycle	Medium	Irrigated rice	4000
Irrigated rice summer cycle	High	Irrigated rice	5000
Irrigated rice spring and summer cycle	Low	Irrigated rice	6000
Irrigated rice spring and summer cycle	Medium	Irrigated rice	8000
Irrigated rice spring and summer cycle	High	Irrigated rice	10000
Soybean spring cycle	-	Soybean	660
Soybean summer cycle	-	Soybean	660
Soybean spring and summer cycle	-	Soybean	1320
Soybean spring-irrigated rice summer cycle	Low	Soybean	660
Soybean spring-irrigated rice summer cycle	Low	Irrigated rice	3000
Soybean spring-irrigated rice summer cycle	Medium	Soybean	660
Soybean spring-irrigated rice summer cycle	Medium	Irrigated rice	4000
Soybean spring-irrigated rice summer cycle	High	Soybean	660
Soybean spring-irrigated rice summer cycle	High	Irrigated rice	5000
Sweet potato	-	Sweet potato	3500
Tea	-	Tea	3000
3 years maize – 3 years cassava	-	Maize	1200
3 years maize – 3 years cassava	-	Cassava	3996
1 year upland rice – 2 years fallow	-	Upland rice	357
2 years upland rice – 3 years maize – 2 years cassava – 3 years fallow	-	Upland rice	214
2 years upland rice – 3 years maize – 2 years cassava – 3 years fallow	-	Maize	1566
2 years upland rice – 3 years maize – 2 years cassava – 3 years fallow	-	Cassava	1599
2 years upland rice – 2 years cassava – 2 years fallow	-	Upland rice	357
2 years upland rice – 2 years cassava – 2 years fallow	-	Cassava	2665

Table 2.6 Buying and selling price of products

Product	Farm-Gate Price (Million VND)	Market Price (Million VND)
Cardamom	10.75	-
Cassava	1.67	3
Cinnamon	4	-
Ginger	3.3	-
Maize	3.75	-
Peanuts	7.5	-
Irrigated rice	4.5	8
Soybean	8	-
Sweet potato	3.5	-
Tea	5	-
Upland rice	10	15

Table 2.7 Time periods and main activities

Time Period	Dates	Main Activities
T1	1-12-2008 / 15-1-2009	Ploughing irrigated lowland (2 cycles)
T2	16-1-2009 / 20-2-2009	Transplanting (2 cycles)
T3	21-2-2009 / 20-3-2009	Weeding irrigated lowland (2 cycles) and perennials, ploughing upland, harvesting cassava
T4	21-3-2009 / 31-5-2009	Ploughing irrigated lowland (1 cycle), ploughing and seeding upland crops, harvesting cinnamon, harvesting irrigated rice (2 cycles)
T5	1-6-2009 / 20-6-2009	Harvesting upland crops, ploughing and transplanting irrigated lowland (2 cycles)
T6	21-6-2009 / 30-7-2009	Weeding irrigated lowland (1 and 2 cycles), harvesting upland crops, weeding cardamom, harvesting tea
T7	31-7-2009 / 30-11-2009	Harvesting irrigated rice (1 and 2 cycles), harvesting upland crops, harvesting perennials

Annex 3: GAMS-scripts

\$TITLE: FARM HOUSEHOLD MODEL YEN BAI PROVINCE

option limcol = 60;

option limrow = 60;

option lp = bdmfp;

*OPTION LP= GAMSCHK;

```
*-----
* Initial Author:      Esther Boere/Damien Jourdain
* Last Modifications:  Esther Boere
* Last editing:        2010-08-16
* Version:             27
* Project:             CPWF PN11
*-----
```

```
*-----
*IMPORT DATA FROM OUTSIDE
*-----
```

*RUN ONLY WSLs

*To run only when not using the general program TradeGeneral.gms, otherwise make as comment:

\$call gams selWSLS.gms

*READ FROM EXCEL DATA

*Link to text file to import all data from sets and parameters from excel file

\$CALL GDXXRW.EXE @import.txt

*Link to text file to import data on farmers and calibration coefficients from excel file

\$CALL GDXXRW.EXE @importFarmers.txt

*LOAD SPECIFIED ITEMS FROM GDX FILE

*Links the different imported data to each other (e.g. crops and yield per ha)

\$GDXIN data.gdx

```
*-----
*SETS (Imported from Excel)
*-----
```

SETS

zone	gro-ecological zones
time	ime periods
lut	and uses (i.e. cropping systems
crop	rop produced
inputs	nputs used for crop production
lc(lut,crop)	crops of each lut
;	

*To load specified items from GDX file

\$LOAD zone time lut crop inputs lc

SET STAPLE (Crop) Subset of staple crops /cIR, cUR, cCA, cMA/ ;

SET SOYB(LUT) Subset of soybean related cropping systems in the irrigated area /SBIR2L, SBIR2M, SBIR2H, MA1PE/;

SET SPRICE(LUT) Subset of spring rice cropping systems /IR1IR2L, IR1IR2M, IR1IR2H /;

```

*-----
*PARAMETERS (Imported from Excel)
*-----
PARAMETERS
Labsup(time)          family labour available in each time period (day per person)
Periodsize(time)      nb of days per period
Labreqinv(lut, time)   labour requirements for each land use (days per ha)
Landreq(lut,zone)      land requirements (used for evaluation which lut is feasible where)
Inputamounts(lut,inputs,time) inputs required for each lut during each period
Inputprice(inputs)     input prices (in 000 VND per unit)
Saleprice(crop)        saling price of crop (in 000 VND per kg)
Buyprice (crop)        buying price of crop (in 000 VND per kg)
Yield(lut,crop,time)   yields (in kg per ha)
;

*To load specified items from GDX file
$LOAD labsup periodsize labreqinv landreq inputamounts inputprice saleprice buyprice yield
$GDXIN

*FROM DAMIEN
*Matrix inversion of labor requirement
PARAMETER labreq(time, lut);
labreq(time, lut) = labreqinv(lut,time);

$GDXIN dataFarm.gdx
*Import farmer groups
SET FG  farm types ;

PARAMETERS
hhmembers(fg)         Household members
workforce(fg)          No of persons of working age
budgetavail(fg)        Budget available at the beginning of the simulation
land(zone,fg)          Land available in the different zones
productbeg(crop,fg)    Initial stock of crops
sBUYCOEF(fg)           Max proportion of food crop purchased (calibration coefficient)
sLIMSALAB(fg)          Max percentage of labour sale at a given period (calibration coefficient)
;

$LOAD FG hhmembers workforce budgetavail land productbeg sbuycoef slimsalab
$GDXIN

*-----
*Select the farm type (VERY IMPORTANT!!!)
$include "selectFarm.inc"
*-----

PARAMETERS hhsz, limlab ;
hhsz = SUM(sf, hhmembers(sf));
limlab = SUM(sf, SLIMSALAB(sf));

SCALAR
LABOURPRICE           Price of labour in thousand VND per day /50/

```

;

POSITIVE VARIABLES

vCROP(lut, zone) Area devoted to the particular land use system
vBUYLABOUR(time) Labour to buy per time period
vSALELABOUR(time) Labour to sell per time period
vCASHBEGIN(time) Cash in the first period
vCASHEND(time) Opening of one cash period equalizes ending of previous period
vQPROD(crop,time) Production per crop per time period
vQBEG(crop, time) Initial stock per crop per time period
vCONS(crop,time) Consumption per crop per time period
vBUY(crop,time) Buy per crop per time period
vSALE(crop,time) Sell per crop per time period
vQEND(crop, time) Opening of one crop in one period equalizes ending of previous period
vBORROW(time) Possibility to borrow money in decades
vtotallUT(lut) Total land use
vRICEPROD(time) Rice production (in kg) during period T
vRICECONS(time) Rice consumption (in kg) during period T
vRICESHORT(time) Rice shortage (in kg) during period T
vMAIZESHORT(time) Maize shortage (in kg) during period T

;

FREE VARIABLES

vUT Objective utility maximization including linear weight loss function for rice shortage
*vMB Objective function of income maximization no linear weight loss function

;

*-----
*DECLARATION OF EQUATIONS
*-----

EQUATIONS

* OBJECTIVE FUNCTION

B_OBJECTIVE Maximize the utility function
*B_MARGIN Objective function in VND

* CROP PRODUCTION

B_PROD(crop,time) Production of commodities
B_BEG(SF,crop) Initial stock of the crop
B_BAL(CROP, time) Balance per crop
B_END(crop,time) Transfer from one period to the other per crop
*Include some storage losses between periods (disincentive to store over time)
B_RICEPROD(time) Total production of rice
*Combine upland and lowland
C_MINPROD(sf,crop) No more than X% of food consumed can be bought

*LABOUR ALLOCATION

B_LABOUR(SF,TIME) Labour constraint in working days
C_LABSALELIM(SF, TIME) Constraint on the ability to hire out labour
*Cannot sale more than x percent of the available family labour

*CASH FLOW

B_BUDGETBEG(SF) Budget time period 1

B_BUDGET1(SF,time) Budget constraint in VND not including interest rate
 B_BUDGET2(SF,time) Budget constraint in VND including interest rate
 B_BUDGETEND(time) Budget to pass on to next period

*CONSUMPTION

B_RICECONS(time) Rice consumption
 B_RICEMIN(sf,time) Minimum rice requirements per farm household
 C_RICESHORTMIN A minimum of x% of rice needs fulfilled
 **The farmers cannot only count on substitution for eating
 **A minimum of 45% of the rice needs should be fulfilled by rice (!)
 B_MAIZEMIN(time) Minimum maize requirements caused by a shortage of rice
 B_CASSMIN(time) Minimum cassava requirements caused by a shortage of rice

*LAND CONSTRAINTS

B_LAND(SF,ZONE) Land constraint per zone
 C_GINLIM(SF) Limitation of the area devoted to ginger
 C_SPLIM(SF) Sweet potatoe rotation no more than 20% of the area
 C_NOBUYUR(time) No possibility to buy upland rice
 ;

PARAMETER LZ(lut,zone);
 LZ(lut,zone)\$ (LANDREQ(Lut,Zone)=1) = YES;
 DISPLAY LZ;

*-----

*PARAMETERS FOR SENSITIVITY ANALYSIS

*-----

*Set at their initial values, FROM DAMIEN

PARAMETER sLANDADJUST(zone) Adjustment of the land area for simulation;
 sLANDADJUST(zone) = 0;
 SCALAR sWFADJUST Adjustment of the no of workers;
 sWFadjust = 0;
 SCALAR sHHSIZEadj Adjustment of the no of rice eaters;
 SHHSIZEadj = 0;
 PARAMETER skPRICE(crop) Adjustment of the prices of crops (buying and selling);
 skPRICE(crop) = 1;

SCALAR

LIVINGEXP Living expenses in thousand VND per day /0/
 sWSHORT Weight of rice shortage on the utility function /7/

TCL Transaction costs in the labour market /0.20/
 TCC Transaction costs on the crop markets /0.20/
 sINT Interest rates /1.03/
 vDAYCONSRICE Minimum daily consumption of rice /0.5/
 *vMINDAYCONSRICE Absolute minimum consumption of rice /0.4/;
 ;

*CALCULATE MARGINS

PARAMETER marginsWithLabour(lut);
 marginsWithLabour(lut) = SUM((crop,time), yield(lut, crop, time) * saleprice(crop)* skPRICE(crop))

```

- SUM((inputs,time), inputamounts(lut, inputs, time)*inputprice(inputs))
- SUM(time, LABREQ(time,Lut) * LABOURPRICE *(1+TCL)) ;
*BY ZONE
PARAMETER marg1;
marg1(lut, zone) = marginsWithLabour(lut)$LZ(lut,zone) ;

PARAMETER marginsWithoutLabour(lut);
marginsWithoutLabour(lut) = SUM((crop,time), yield(lut, crop, time) * saleprice(crop) * skPRICE(crop))
- SUM((inputs,time), inputamounts(lut, inputs, time)*inputprice(inputs));
*BY ZONE
PARAMETER marg2;
marg2(lut,zone) = marginsWithoutLabour(lut)$LZ(lut,zone);

*-----
*DECLARATION OF EQUATIONS: B_for balances, C_for constraints
*-----
* OBJECTIVE: MAXIMIZE INCOME (WITHOUT LINEAR WEIGHT LOSS FUNCTION)
*B_MARGIN..          vCASHEND("T6")- SUM(TIME, vBORROW("T6") * 1.2) =E= vMB ;
*B_OBJECTIVE ..      vCASHEND("NOV3")- SUM(DEC, vBORROW(DEC)*1.01) =E= vUT;

* OBJECTIVE: MAXIMIZE UTILITY (CHANGED BECAUSE OF WEIGHT LOSS FUNCTION FOR RICE
SHORTAGE)
B_OBJECTIVE..        vCASHEND("T6")
- vBORROW("T6") * 1.2 =E= vUT ;
*
- Sum(time, vRICESHORT(time))* sWSHORT  =e= vUT;

$ONTEXT
B_OBJECTIVE ..        SUM((crop, TIME), vSALE(crop, TIME)*SALEPRICE(crop))
- SUM((staple, TIME), vBUY(staple, TIME)* BUYPRICE(staple))
- SUM((lut,inputs,TIME), INPUTAMOUNTS(lut, inputs, TIME)
*INPUTCOSTS(inputs)*sum(zone$(LANDREQ(Zone,Lut)=1), vCROP(lut,zone)))
- SUM(TIME, vBUYLABOUR(TIME)*LABOURPRICE*(1+transCost))
+ SUM(TIME, vSALELABOUR(TIME)*LABOURPRICE*(1-transCost))
- SUM(TIME, PERIODSIZE(TIME)*LIVINGEXP*FGHHMEMBERS)
- Sum(time, vborrow(DEC) *1.2)
=E= vMB ;

$OFFTEXT
*-----
*CROP PRODUCTION
*-----
B_PROD(crop,time)..   vQPROD(crop, time)
=L= SUM(lut, YIELD(lut,crop, time)*SUM(zone, vCrop(lut,zone)*LANDREQ(lut,zone))) ;

B_BEG(SF, CROP)..     vQBEG(crop, "T7") =L= PRODUCTBEG(CROP,SF);

B_BAL(CROP, time)..   vQBEG(crop, time) + vQPROD(crop, time)
- vCONS(crop, time) + vBUY(crop,time)
- vSALE(crop, time) =G= vQEND(crop, time);

B_END(crop,time)$(ORD(time)<CARD(time)).. vQBEG(crop,time+1) =L= .99 * vQEND(crop,time) ;

B_RICEPROD(time)..    vQPROD("cUR" , time)+ vQPROD("cIR" , time) =g= vRICEPROD(time);

```

```

C_MINPROD(sf, crop)$staple(crop).. SUM(time, vBUY(crop,time)) =/=
SUM(time, vCONS(crop,time)) * sBUYCOEF(SF);
*-----
*LABOUR ALLOCATION
*-----
B_LABOUR(SF, TIME).. SUM(lut, SUM(zone, vCrop(lut,zone)*LANDREQ(lut,zone)) *
LABREQ(time,Lut))
- vBUYLABOUR(time) + vSALELABOUR(time)
=L= labsup(time) * (workforce(SF) + sWFAadjust) ;

C_LABSALELIM(SF,time).. vSALELABOUR(time) =L= LABSUP(time)*workforce(sf)* sLIMSALAB(SF) ;

*-----
*CASH FLOW
*-----
B_BUDGETBEG(SF).. vCASHBEGIN("T7") =L= BUDGETAVAIL(SF);

B_BUDGET1(SF, TIME)$ (ord(time)=1)..
vCASHBEGIN(time)
- LIVINGEXP*PERIODSIZE(time)*hhmembers(sf)
- SUM(crop, vBUY(crop, time)* SALEPRICE(crop)*skPRICE(crop)* (1+TCC) )
+ SUM(CROP, vSALE(crop, time)*SALEPRICE(CROP)* skPRICE(crop))
+ (vSALELABOUR(time)*LABOURPRICE*(1-TCL))
- (vBUYLABOUR(time)*LABOURPRICE*(1+TCL))
- SUM((lut,inputs), INPUTAMOUNTS(lut, inputs, time)*inputprice(inputs)
*SUM(zone, vCrop(lut,zone)*LANDREQ(lut,zone)))
+ vBORROW(time)
=G= vCASHEND(time) ;

B_BUDGET2(SF, TIME).. vCASHBEGIN(time)
- LIVINGEXP*PERIODSIZE(time)*hhmembers(sf)
- SUM(crop, vBUY(crop, time)* SALEPRICE(crop)*skPRICE(crop)* (1+TCC))
+ SUM(CROP, vSALE(crop, time)*SALEPRICE(CROP)*skPRICE(crop) )
+ (vSALELABOUR(time)*LABOURPRICE*(1-TCL))
- (vBUYLABOUR(time)*LABOURPRICE*(1+TCL))
- SUM((lut,inputs), INPUTAMOUNTS(lut, inputs, time)*inputprice(inputs)
*SUM(zone, vCrop(lut,zone)*LANDREQ(lut,zone)))
- vBORROW(time-1)* sINT + vBORROW(time)
=G= vCASHEND(time) ;

B_BUDGETEND(time)$ (ord(time)<card(time)).. vCASHEND(time) =G= vCASHBEGIN(time+1) ;

*-----
*CONSUMPTION
*-----
*merge upland and lowland rice in terms of consumption
B_RICECONS(time).. vCONS("cUR", time)+ vCONS("cLR", time) =G= vRICECONS(time);

B_RICEMIN(SF,time).. vRICECONS(time) + vRICESHORT(time)
=G= vDAYCONSRICE * PERIODSIZE(time) * (hhmembers(SF) + sHHSIZEadj);

```

```

PARAMETER ricemincons;
RICEMINCONS = SUM((sf,time),
    vDAYCONSRICE * PERIODSIZE(time) * (hhmembers(sf) + sHHSIZEadj));

C_RICESHORTMIN.. SUM(time, vRICECONS(time)) =G= ricemincons * 0.4;

B_MAIZEMIN(time).. vCONS("cMA",time) =G= vRICESHORT(time)* 2 + vMAIZESHORT(time) ;
**NEED 2 KG OF MAIZE TO COMPENSATE FOR RICE?

B_CASSMIN(time).. vCONS("cCA", time) =g= vMAIZESHORT(time)*2 ;
**NEED 2KG of CASSAVA TO COMPENSATE FOR 1K MAIZE

*Absolute minimum consumption per day per persons
*B_RICEABSMIN(time).. vRICECONS(time) =g= vMINDAYCONSRICE * PERIODSIZE(time) *
FGHHMEMBERS ;

*-----
*LAND CONSTRAINTS AND CALCULATIONS
*-----
B_LAND(SF,zone).. SUM(lut, vCROP(lut,zone)*LANDREQ(lut,zone)) =l= (LAND(zone,SF) +
sLANDADJUST(zone))/10000;

*Not more than 400m2 of upland area with ginger
C_GINLIM(SF).. vCROP("GI","SLOPING") =L= 400/10000 ;

*Not more than 20% of the upland area with sweet potato
C_SPLIM(SF).. vCROP("SP","SLOPING") =L= (LAND("SLOPING",SF) +
sLANDADJUST("SLOPING"))/(5*10000);

C_NOBUYUR(time).. vBUY("cUR", time) =L= 0;

*QCALCLUT(lut) .. vtotalLUT(lut) =l= SUM(zone, vCrop(lut,zone)*LANDREQ(lut,zone)) ;

*-----

PARAMETER sbuy;
sbuy = SUM(sf, sBUYCOEF(sf));
PARAMETER solCrops(lut);

MODEL FHHYENBAI /ALL/;

SOLVE FHHYENBAI USING LP MAXIMIZING vUT ;
solCrops(lut) = SUM(zone, vCrop.l(lut, zone))*10000;

*-----
*SCENARIO 0 - BASE SCENARIO
*-----
*BASE SCENARIO
PARAMETER landold(zone,fg);
landold(zone,fg) = land(zone, fg);
DISPLAY landold;

```

```

land(zone, fg) = landold(zone, fg);
SOLVE FHHYENBAI USING LP MAXIMIZING vUT;

PARAMETER srSOLV;
srSOLV("S00", SF) = FHHYENBAI.solvestat;
PARAMETER srMODEL;
srMODEL("S00", SF) = FHHYENBAI.modelstat;
PARAMETER srOBJ;
srOBJ("S00", SF) = vUT.l;
PARAMETER srLAND;
srLAND("S00", SF, ZONE) = LAND(zone, sf);
PARAMETER srCROP;
srCROP("S00", SF, lut, zone) = vCrop.l(lut, zone);
PARAMETER srPROD;
srPROD("S00", SF, crop, time) = vQPROD.l(crop, time);
PARAMETER srCASHOBJ;
srCASHOBJ("S00", SF) = vCASHEND.l("T6") - vBORROW.l("T6");
PARAMETER srSALE, srPURC, srCONS;
srSALE("S00", SF, crop, time) = vSALE.l(crop, time);
srPURC("S00", SF, crop, time) = vBUY.l(crop, time);
srCONS("S00", SF, crop, time) = vCONS.l(crop, time);
PARAMETER srBUYLAB, srSALLAB, srCASHBEG, srBORROW;
srBUYLAB("S00", SF, time) = vBUYLABOUR.l(time);
srSALLAB("S00", SF, time) = vSALELABOUR.l(time);
srCASHBEG("S00", SF, time) = vCASHBEGIN.l(time);
srBORROW("S00", SF) = vBORROW.l("T6")*1.2;
PARAMETER srRSHORT, srSALLABCASH, srPURCASH, srCROPSALE, srCASHEND, srLAND;
srRSHORT("S00", SF) = sum(time, vRICESHORT.l(time));
srSALLABCASH("S00", SF) = sum(time, vSALELABOUR.l(time)*LABOURPRICE*(1-TCL));
srPURCASH("S00", SF) = sum((crop, time), vBUY.l(crop, time)* SALEPRICE(crop)*skPRICE(crop) *
(1+TCC));
srCROPSALE("S00", SF) = sum((crop, time), vSALE.l(crop, time)*SALEPRICE(CROP)*skPRICE(crop));
srCASHEND("S00", SF) = vCASHEND.l("T6");
srLAND("S00", SF, ZONE) = LAND(zone, sf);

*EXPORT ALL PARAMETERS TO GDX S0 FILE;
EXECUTE_UNLOAD 'S00.gdx' srSOLV, srMODEL, srOBJ, srLAND, srCROP, srPROD, srCASHOBJ,
srSALE, srPURC, srCONS, srBUYLAB, srSALLAB, srCASHBEG, srBORROW,
srRSHORT, srSALLABCASH, srPURCASH, srCROPSALE, srCASHEND, srLAND;

*BASE SCENARIO
*DISTINGUISH BETWEEN MAJORITY OF TERRACES AND MAJORITY OF PADDY
SET woTer(FG) /OFFW, PARI/;
SET wiTer(FG) /WSLS, WSLR, TERUPL, TERLAB/;
*DISTINGUISH BETWEEN POOR AND NON-POOR
SET poor(FG) /WSLS, WSLR/;
SET nonpoor(FG) /TERLAB, TERUPL, OFFW, PARI/;

*-----
*SCENARIO 1      8% OF LAND SET ASIDE FOR ALL FARM HOUSEHOLDS
*      CONVERT IRRIGATED LOWLAND SUMMER TO SPRING + SUMMER
*-----

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```

*Restore initial value
land(zone,fg) = landold(zone,fg);

*Reduce 8% of sloping land
LAND("SLOPING", FG) = landold("SLOPING", FG) * 0.92;

*convert IRRTER_SU en IRRTER_SP for those who mainly have terrases
land("IRRTER_SU", wiTer) = landold("IRRTER_SU", wiTer)*0.832;
land("IRRTER_SP", wiTer) = landold("IRRTER_SP", wiTer) + landold("IRRTER_SU", wiTer)*0.168;
*convert IRRPAD_SU en IRRPAD_SP for those who mainly have paddy land
land("IRRPAD_SU", woTer) = landold("IRRPAD_SU", woTer)*0.832;
land("IRRPAD_SP", woTer) = landold("IRRPAD_SP", woTer) + landold("IRRPAD_SU", woTer)*0.168;

SOLVE FHHYENBAI USING LP MAXIMIZING vUT;
*EXPORT ALL PARAMETERS TO GDX S01 FILE;
EXECUTE_UNLOAD 'S01.gdx' srSOLV, srMODEL, srOBJ, srLAND, srCROP, srPROD, srCASHOBJ,
srSALE, srPURC, srCONS, srBUYLAB, srSALLAB, srCASHBEG, srBORROW,
srRSHORT, srSALLABCASH, srPURCASH, srCROPSALE, srCASHEND, srLAND;

*-----
*SCENARIO 2    8% OF LAND SET ASIDE FOR ALL FARM HOUSEHOLDS
*    CONSTRUCT NEW TERRACES WITH SUMMER IRRIGATION
*-----
*Restore base scenario of land
land(zone, FG) = landold(zone,FG);

*Reduce sloping of 8%
land("sloping", FG) = landold("sloping", FG) * 0.92;

*Add ?? m2 of IRRTER_SU
land("IRRTER_SU", FG) = landold("IRRTER_SU", FG) + 32.4;

SOLVE FHHYENBAI USING LP MAXIMIZING vUT;
EXECUTE_UNLOAD 'S02.gdx' srSOLV, srMODEL, srOBJ, srLAND, srCROP, srPROD, srCASHOBJ,
srSALE, srPURC, srCONS, srBUYLAB, srSALLAB, srCASHBEG, srBORROW,
srRSHORT, srSALLABCASH, srPURCASH, srCROPSALE, srCASHEND, srLAND;

*-----
*SCENARIO 3    8% OF LAND SET ASIDE FOR ALL FARM HOUSEHOLDS
*    CONSTRUCT NEW TERRACES WITH SPRING AND SUMMER IRRIGATION
*-----
*Restore base scenario of land
land(zone, FG) = landold(zone,FG);

*Reduce sloping of 8%
land("sloping", FG) = landold("sloping", FG) * 0.92;

*Add ?? m2 of IRRTER_SP
land("IRRTER_SP", FG) = landold("IRRTER_SP", FG) + 16.5;

SOLVE FHHYENBAI USING LP MAXIMIZING vUT;
EXECUTE_UNLOAD 'S03.gdx' srSOLV, srMODEL, srOBJ, srLAND, srCROP, srPROD, srCASHOBJ,

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srSALE, srPURC, srCONS, srBUYLAB, srSALLAB, srCASHBEG, srBORROW,
srRSHORT, srSALLABCASH, srPURCASH, srCROPSALE, srCASHEND, srLAND;

*-----
*SCENARIO 4 REDUCE SLOPING LAND WITH 869 M2
* CONVERT IRRIGATED LOWLAND SUMMER TO SPRING + SUMMER
*-----

*Restore base scenario of land
land(zone,fg) = landold(zone,fg);

*reduce sloping of 869 m2 per household
land("sloping", fg) = landold("sloping", fg) - 869;

*convert IRRTER_SU en IRRTER_SP for those who mainly have terrases
land("IRRTER_SU", wiTer) = landold("IRRTER_SU", wiTer)*0.6915;
land("IRRTER_SP", wiTer) = landold("IRRTER_SP", wiTer) + landold("IRRTER_SU", wiTer)*0.3085;
*convert IRRPAD_SU en IRRPAD_SP for those who mainly have paddy land
land("IRRPAD_SU", woTer) = landold("IRRPAD_SU", woTer)*0.6915;
land("IRRPAD_SP", woTer) = landold("IRRPAD_SP", woTer) + landold("IRRPAD_SU", woTer)*0.3085;

SOLVE FHHYENBAI USING LP MAXIMIZING vUT;
EXECUTE_UNLOAD 'S04.gdx' srSOLV, srMODEL, srOBJ, srLAND, srCROP, srPROD, srCASHOBJ,
srSALE, srPURC, srCONS, srBUYLAB, srSALLAB, srCASHBEG, srBORROW,
srRSHORT, srSALLABCASH, srPURCASH, srCROPSALE, srCASHEND, srLAND;

*-----
*SCENARIO 5 REDUCE SLOPING LAND WITH 869 M2
* CONSTRUCT NEW TERRACES WITH SUMMER IRRIGATION
*-----

*Restore base scenario of land
land(zone,FG) = landold(zone,FG);

*reduce sloping of 869 m2 per household
land("SLOPING", FG) = landold("SLOPING", FG) - 869;

*Add ?? m2 of IRRTER_SU
land("IRRTER_SU", FG) = landold("IRRTER_SU", FG) + 57.6;

SOLVE FHHYENBAI USING LP MAXIMIZING vUT;
EXECUTE_UNLOAD 'S05.gdx' srSOLV, srMODEL, srOBJ, srLAND, srCROP, srPROD, srCASHOBJ,
srSALE, srPURC, srCONS, srBUYLAB, srSALLAB, srCASHBEG, srBORROW,
srRSHORT, srSALLABCASH, srPURCASH, srCROPSALE, srCASHEND, srLAND;

*-----
*SCENARIO 6 REDUCE SLOPING LAND WITH 869 M2
* CONSTRUCT NEW TERRACES WITH SPRING AND SUMMER IRRIGATION
*-----

*Restore base scenario of land
land(zone,fg) = landold(zone,fg);

*reduce sloping of 869 m2 per household
land("sloping", fg) = landold("sloping", fg) - 869;

```

*Add ?? m2 of IRRTER_SP
land("IRRTER_SP", FG) = landold("IRRTER_SP", FG) + 29.8;

SOLVE FHHYENBAI USING LP MAXIMIZING vUT;
EXECUTE_UNLOAD 'S06.gdx' srSOLV, srMODEL, srOBJ, srLAND, srCROP, srPROD, srCASHOBJ,
srSALE, srPURC, srCONS, srBUYLAB, srSALLAB, srCASHBEG, srBORROW,
srRSHORT, srSALLABCASH, srPURCASH, srCROPSALE, srCASHEND, srLAND;

*-----
*SCENARIO 7    REDUCE SLOPING LAND 1650 M2 ONLY FOR RICH
*              CONVERT IRRIGATED LOWLAND SUMMER TO SPRING + SUMMER
*-----
*Restore base scenario of land
land(zone,fg) = landold(zone,fg);

*reduce sloping of 1650 m2 per non-poor households
land("sloping", nonpoor) = landold("sloping", nonpoor) - 1650;

*convert IRRTER_SU en IRRTER_SP for those who have terrases mainly
land("IRRTER_SU", wiTer) = landold("IRRTER_SU", wiTer)*0.9;
land("IRRTER_SP", wiTer) = landold("IRRTER_SP", wiTer) + landold("IRRTER_SU", wiTer)*0.1;

*convert IRRPAD_SU en IRRPAD_SP for those who have mainly paddies
land("IRRPAD_SU", woTer) = landold("IRRPAD_SU", woTer)*0.9;
land("IRRPAD_SP", woTer) = landold("IRRPAD_SP", woTer) + landold("IRRPAD_SU", woTer)*0.1;

SOLVE FHHYENBAI USING LP MAXIMIZING vUT;
EXECUTE_UNLOAD 'S07.gdx' srSOLV, srMODEL, srOBJ, srLAND, srCROP, srPROD, srCASHOBJ,
srSALE, srPURC, srCONS, srBUYLAB, srSALLAB, srCASHBEG, srBORROW,
srRSHORT, srSALLABCASH, srPURCASH, srCROPSALE, srCASHEND, srLAND;

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