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Abstract

The impact of payment for environmental services (PES) on poverty varies. Generally, PES is good for landowners and may negatively affect consumers if food demand is inelastic. Impacts also depend on the correlation between poverty and environmental amenities. If the richer farmers also provide the best environmental services (ES), then the poor farmers may lose. If there is negative correlation between ES and productivity, then the poorer landowners may gain from ES. The distribution of land matters. If smallholders depend on earnings from work on larger farms, then PES may affect them negatively. Program specifications also matter. Working land programs may have better distributional effects then PES for land diversion.

Key Words: Payments for environmental services, poverty, conservation, land use change, market-based mechanisms.

JEL: Q0, Q15, Q24, O13.

When are payments for environmental services beneficial to the poor?

1. Introduction

Coase's (1960) insight that property rights considerations should play a role in managing externality problems provides the intellectual foundation for programs to pay agricultural producers to reduce negative externalities or provide positive ones. These programs include public sector payments such as the Conservation Reserve Program in the United States, agri-environmental payments in Europe, and the Global Environmental Facility in developing countries. They also include payments by nongovernmental organizations such as the Nature Conservancy or Conservation International for development rights and conservation activities and, in a growing number of cases, payments from the private sector. Since modification of agricultural production choices in developing countries can provide positive environmental externalities to people in developed countries, payment for environmental services (PES) has become an important topic in the context of economic development and poverty reduction. Many who are concerned with environmental sustainability are also concerned with poverty reduction, and the close links between the two objectives are resulting in intensified efforts to develop PES programs that aim to achieve both environmental and poverty alleviation objectives.

Tinbergen's (1956) classic research on policy design emphasized the difficulty of attaining more than one objective with any single policy tool, and his analysis suggests that the effort to obtain both environmental quality and equity objectives with PES may

be problematic. This paper aims to develop a conceptual framework to analyze the conditions under which PES policies can serve to reduce poverty and give insight into ways PES programs can be targeted to obtain poverty reduction benefits. The paper is based on the literature that recognizes heterogeneity among economic agents and locations in terms of both agricultural productivity and environmental quality and the implication of correlations between them (Wu *et al*., 2001). Our approach is aimed to investigate how correlations (or lack of them) affect the design of strategies utilizing the same tools for attaining multiple objectives. Specifically, we attempt to identify how the pursuit of environmental goals can be used to improve the lot of the poor in the developing world.

Our analysis considers two broad categories of PES programs, distinguishing between programs where lands are diverted from agricultural production to other land uses, and those where lands remain in agriculture but production activities are modified to achieve environmental objectives. We first develop a model to address the distributional effects of land diversion PES programs, starting with an analysis of micro-behavior in order to obtain aggregate supply and demand. We use the results to investigate the impact of this program on three categories of the poor—urban poor, landless, and poor landowners. We then analyze the impact of a working land program, and end with the conclusions and extension of the analysis.

2. The model

An agricultural good is produced with land, labor, and a variable input (e.g., chemicals) by heterogeneous producers. Heterogeneity may be caused by differences in farm size or productivity. Production of the good results in environmental externalities.

Environmental services (ES) are defined as either a reduction in negative externalities or provision of positive ones. In this first model, we assume that ES are generated by taking land out of agricultural production and diverting it to other uses. There are several groups affected by the program—rural landowners, rural landless, urban consumers, and beneficiaries of ES (who may fall in any of the previous categories as well). A region consists of N_0, landless households, and N_1, landowning households. We separate the consumption and production activities of these households in our model, since the greater realism of integrated models as in Singh *et al.* (1986) leads to extra complexity that detracts from our focus on the effects of introducing PES programs. Expanding the analysis to consider nonseparable household models will be important to understanding program impacts where there are a number of other serious market failures, and thus remains important future work.

We assume that households are of equal size and producers are profit maximizers. Let n be an indicator of the households, which assumes a value from 0 to N_1. All landless households are assigned $n = 0$, since we treat them as homogenous agents; landowners are assigned n, which assumes values that vary from 1 to N_1. The landowners vary in their farm size and land productivity. Let L_n denote the land area of landowner n. Without loss of generality, the n's are established to reflect income, so that landowners with lower n are poorer (have less income) before PES is introduced. We also assume that each producer has one unit of time.

We assume that the agricultural production function has constant returns to scale. Output is produced with land and labor, giving the production function per acre of the nth producer as:

$$y_n = \alpha_n f(x_n)\,, \tag{1}$$

where y_n is output per acre of landowner n, α_n is a multiplicative production coefficient capturing land productivity, and x_n is labor per acre in agricultural production of owner n. The production function is assumed to be concave so that $f'(x) = \frac{\partial f(x)}{\partial x} \geq 0, f''(x) \leq 0$.

We will assume that producers are competitive and are price takers, and there are perfect markets for labor and the agricultural output. During the period of the analysis, landownership is taken as given. Let the prices of output and labor be denoted by p and w, respectively. The prices of output and labor are determined endogenously within the system.

We assume that consumers in the economy derive utility from the agricultural product and all other goods. We will assume that all households have the same utility function, since the emphasis of the paper is production-related choices, but they vary in income. Let Q denote the amount of the agricultural good consumed by a household, let E be expenditure on other goods, and let I denote the household's annual income. The utility function, $u(Q,E)$, is assumed to be measured in monetary units and be additive, and the budget constrained is assumed to be binding. Additionally, we allow for consumers to also benefit directly from the production of the ES, W^{EP}, which they do not pay for (and the production of which is taken as given). Thus, the utility function can be rewritten as a function of consumption, income, and the output price,

$$u(Q, E, W^{EP}) = h(Q) + I + W^{EP} - pQ\ , \tag{2}$$

where $h(Q)$ is the utility from consumption of the agricultural product. We assume that the agricultural commodity is essential, so its initial marginal utility is infinite, but this marginal utility is declining ($h' > 0, h'' < 0$, and $h'(0) \to \infty$).

3. ES from land diversion

In this section we will consider an ES program that is a land diversion program. This program will pay producers to convert land from agricultural to other land uses such as forests or other types of native ecosystems. The land-use change may generate several types of ES and may lead to return of native plants, provide pasture for wildlife, may prevent erosion or air pollution, etc. We will assume that each unit of land generates a fixed amount of environmental benefits, but these benefits vary across locations. The environmental benefit per unit of land of the *n*th landowner is b_n . At this stage we assume that the price paid per environmental benefit is constant and denoted by *v*.

When PES is not available, each landowner has to determine the amount of labor per unit of land they use and whether to farm the land. The optimal labor is determined solving

$$\underset{x_n}{\text{Max}}\ P\alpha_n f(x_n) - wx_n \tag{3}$$

subject to $p\alpha_n f(x_n) - wx_n \geq 0$. At the optimal solution $x_n^*(p,w)$, the marginal condition equating the value of the marginal product of labor is equal to the price of labor

$$P\alpha_n f'(x_n^*) - w = 0 \ , \tag{4}$$

where $f'(x_n) = \dfrac{\partial f(x_n)}{\partial x}$ is marginal productivity of labor per acre. We assume that the production function *f* is concave, and thus an optimal solution exists for the farmer

problem. We also assume that all land is utilized and that all labor (both that of landowners and landless households) is employed. The agricultural rent of the land of owner *n* is

$$r_n(p,w) = p\alpha_n f(x_n^*) - wx_n^*. \tag{5}$$

Once the ES program is introduced, the farmers have another choice—to divert land to uses that generate environmental amenities. The per acre benefit for the *n*th landowner from enrollment in the ES program is vb_n. Let $\delta_n(p,w,v)$ be an indicator function, which assumes the value one when the *n*th landowner is enrolled in the ES program and is equal to zero otherwise. The value of the indicator is determined according to

$$\delta_n(p,w,v) = \begin{matrix} 1 & \text{if } vb_n > p\alpha_n f(x_n^*) - wx_n^* \\ 0 & \text{if } vb_n \le p\alpha_n f(x_n^*) - wx_n^* \end{matrix}. \tag{6}$$

The landowner joins the ES program if it generates more income than the agricultural rent. Landowners are divided into groups of participants and nonparticipants in the ES program. The participants are the ones who belong to the S_P set, and nonparticipants belong to S_N, where

$$\begin{aligned} S_P(p,w,v) &= \{n \text{ with } \delta_n(p,w,v) = 1\} \text{ and} \\ S_N(p,w,v) &= \{n \text{ with } \delta_n(p,w,v) = 0\}. \end{aligned} \tag{7}$$

The microlevel choices form the basis for the aggregate supply of output and ES, as well as the aggregate demand for labor. Aggregate agricultural output is denoted by *Y,* and aggregate output supply is

$$Y^S(p,w,v) = \sum_{n \in S_N(p,w,v)} L_n \alpha_n f(x_n^*(p,w)). \tag{8}$$

Aggregate labor demand is

$$X^D(p,w,v) = \sum_{n \in S_N(p,w,v)} L_n x_n^*(p,w)\,. \tag{9}$$

The aggregate level of ES is denoted by *B,* and the supply of the ES, $B^S(p,w,v)$, is

$$B^S(p,w,v) = \sum_{n \in S_P(p,w,v)} L_n b_n\,. \tag{10}$$

The aggregate demand for agricultural output is denoted by $Y^D(p)$ and is negatively sloped. The supply of labor N^S is the sum of the labor of the landless and landowners ($N^S = N_0 + N_1$). Using these definitions, the equilibrium prices of output and labor given the price of the ES are derived from the solution of

$$\sum_{n \in S_N(p,w,v)} L_n \alpha_n f(x_n^*(p,w)) = Y^D(p) \quad \text{Output market equilibrium} \tag{11}$$

$$\sum_{n \in S_N(p,w,v)} L_n x_n^*(p,w) = N_0 + N_1 \quad \text{Labor market equilibrium.} \tag{12}$$

Once the optimal *p* and *w* are determined, the land, labor, and land-use allocations can be derived, and then using equation (10) the aggregate level of ES provision can be computed. Resource allocation before the introduction of an ES program is used as a benchmark for the distributional analysis. Let Y_0, p_0, and w_0 denote the initial levels of output, output prices, and labor prices, respectively, corresponding to $v = 0$. The equilibrium levels of these variables for a positive *v* are denoted by Y_V, p_V, and w_V. The non-negativity constraint on rent ($p\alpha_n f(x_n) - wx_n \geq 0$) results in idling of land and low output supply when the output price is sufficiently low. No output will be provided when output price is below

$$\underline{p}(w_0, 0) = \operatorname*{Max}_p \left\{ p\alpha_n f(x_n) - wx_n \leq 0 \;\; n = 1, N \right\}. \tag{13}$$

When all land and labor are optimally utilized in agricultural production, aggregate output is $Y_0 = \overline{Y}$. Since we assume that all land and labor are employed initially, the equilibrium outcome, Y_0, p_0, occurs at the inelastic segment of the curve. The output supply curve holding labor wage constant but with positive *v* is designated as $Y^S(p, w_0, v)$. This curve is above $Y^S(p, w_0, 0)$ since the introduction of PES will lead landowners to divert land, thus reducing agricultural supplies. However, at the new equilibrium, the wage rate will also change to w_v. If $w_v < w_0$, meaning that the wage rate declines due to the introduction of the PES, this wage effect will indirectly enhance supply of the agricultural output, as captured by the supply curve $Y^S(p, w_v, v)$ corresponding to the case where $w_v < w_0$.

There will be no agricultural output supplied if, for all lands, the rent from farming is smaller than the PES, e.g., when output price is smaller or equal to

$$\underset{\sim}{p}(w_v, b) = \underset{p}{\text{Max}} \left\{ p\alpha_n f(x_n) - wx_n - vb_n \le 0 \;\; n = 1, N \right\}. \tag{14}$$

On the other hand, when output price is sufficiently high, it is worthwhile keeping all lands in agricultural production, and the supply curve is constant at $\overline{Y}$. The lowest price that leads to full production is

$$\overline{p}(w_v, b) = \underset{p}{\text{Min}} \left\{ p\alpha_n f(x_n^*) - wx_n - vb_n \ge 0 \;\; n = 1, N \right\}. \tag{15}$$

Equations (14) and (15) show the output price range for which only part of the land is diverted to ES, which is clearly dependent on the payment for a unit of ES, *v*. A higher *v* increases the lower bound on output prices, $\underset{\sim}{p}(w_v, b)$, that still result in positive production. However, a higher *v* will also increase $\overline{p}(w_v, b)$, the upper bound output

price that results in full production, and thus no reallocation of land to ES. That suggests that if *v* is sufficiently small, it will have no impact on production; and if it is sufficiently large, it can lead to the elimination of production. Figure 1 depicts a more likely middle case, where a program that pays *v* causes partial diversion of land to ES. In this likely case, introduction of ES will reduce agricultural output along with land allocated to agriculture, but will also lead to an increase in output price, e.g., with moderate ES payments, $Y_v < Y_0$ and $p_v \geq p_0$. Since, by our assumption, initial output is the maximum that can be produced with available land and labor, the ES program must reduce output if it has any impact at all.

However, if demand is not infinitely elastic, the impact on labor wage is ambiguous. For every output and ES price level, there is a threshold wage rate separating higher wage rates with zero demand and lower rates with positive demand for labor. This function is

$$\overline{w}(p,v) = \underset{w}{\text{Min}} \left\{ p\alpha_n f(x_n^*) - wx_n - vb_n \leq 0 \;\; n = 1, N \right\}. \tag{16}$$

Given *p*, higher *v* will reduce the range of wages exhibiting positive demand for labor and thus reduce this threshold wage, so that $\overline{w}(p,v_1) < \overline{w}(p,v_2)$ if $v_1 > v_2$. However, an increase in output price has the opposite effect on the threshold wage, so that $\overline{w}(p_1,v) > \overline{w}(p_2,v)$, if $p_1 > p_2$. Since higher *v* results in higher *p,* the overall impact of introducing PES on threshold wages and demand for labor in general is ambiguous.

It can be shown that introduction of a land-diverting ES program will reduce the wage of the labor force, thus reducing the income of the landless, if it induces a large shift of land out of production and if demand for agricultural output is sufficiently elastic

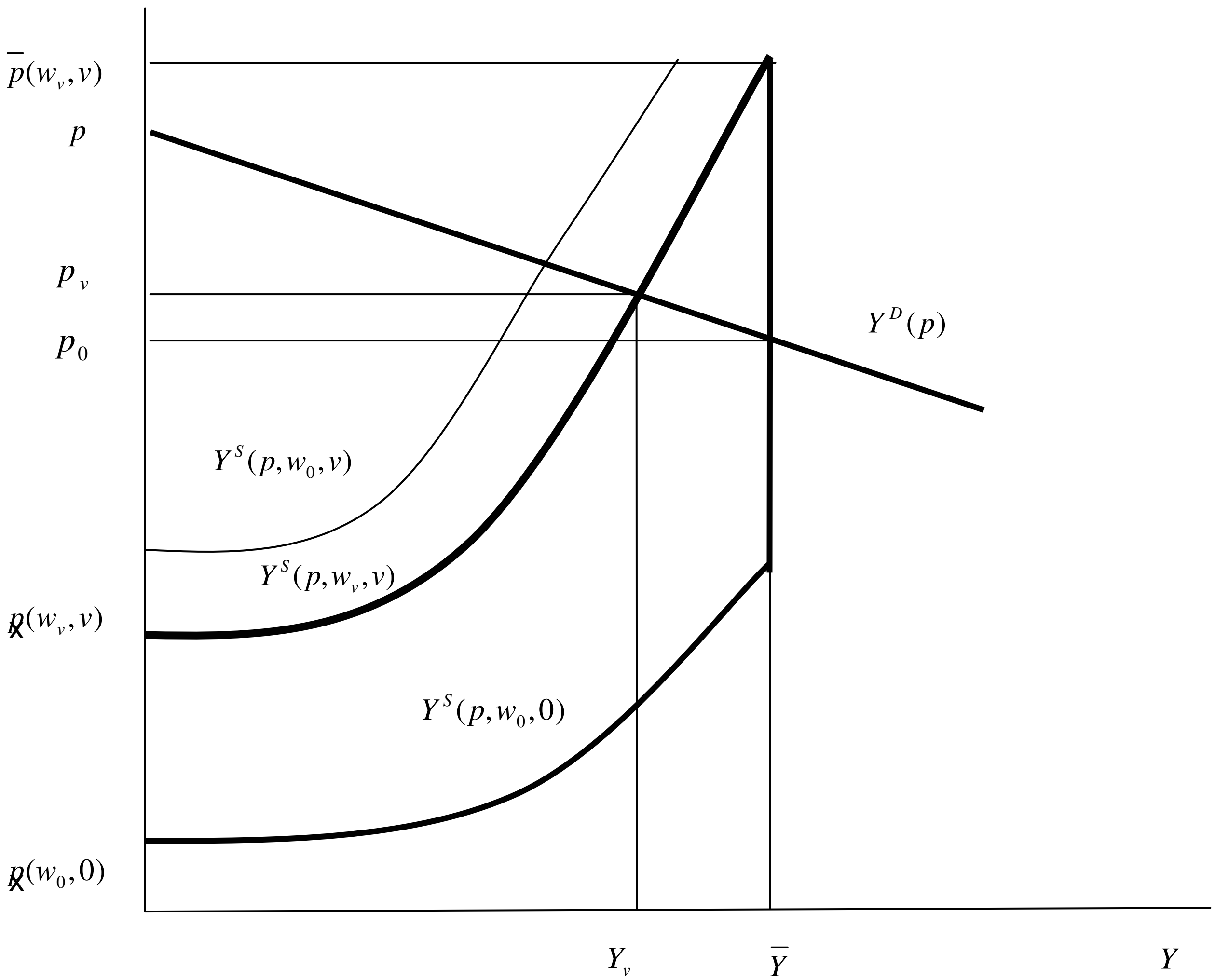

Figure 1. *Equilibrium in the output market*

so that the higher output price induces only a relatively small upward shift in the labor demand curve. However, if the output demand is sufficiently inelastic and labor demand relatively elastic, the introduction of PES will lead to higher wage rates.

1. Intersectoral distribution of impacts and implications for the poor

We next consider the impacts of land set-aside ES programs on the intersectoral distribution of income. We consider three sectors—consumers, farm laborers, and landowners. An analysis of the implications for poverty reduction needs to be made across all sectors, as the poor may be found in each; below we consider each one in turn.

A. The urban poor

The urban poor may be part of two sectors affected by an ES program. They are consumers and may also be direct beneficiaries of amenities created by the ES program. Let ΔW^{C} denote the change in welfare of a household due to the consumption effects of the ES program. From (2), this change can be approximated as:

$$\Delta W^{C} = \left[h'(Q) - p \right] \frac{\partial Q}{\partial p} - \Delta p Q + \Delta W^{EP} = -\Delta p Q + \Delta W^{EP} \leq 0 . \qquad (17)$$

Condition (17) suggests that the ES program may harm consumers. As consumers, the urban poor will lose from the ES program to the extent that they consume the agricultural product and the demand for the product is inelastic. When agriculture is mainly produced for local consumption, the urban poor may be negatively affected by an ES program that reduces the availability of local staples. In cases where agricultural products are globally traded commodities, and price transmission effects from agricultural to urban sectors are limited, the impact of the ES on the poor as consumers

will not be significant. However, the urban poor may also be beneficiaries from ES that prevent externalities, ΔW^{EP}. For instance, the urban poor are often consumers of low-quality water with minimum access to sewage services; they may live in neighborhoods least protected from floods, and they are more likely to be exposed to water or food shortages. ES programs that improve the quality of water and protect against disasters are more likely to benefit this group. On the other hand, this sector is less likely to benefit from ES programs that create environmental amenities that provide positive externalities or semi-public goods. For instance, programs that improve recreational possibilities are likely to yield greater benefits to the wealthy farmers who can take advantage of increased recreational services; programs that preserve endangered species produce large global public benefits but relatively low benefits per person. The net effect depends on the magnitude of the gains from the environmental benefits versus the loss due to increased food prices.

B. The landless poor

We next turn to an assessment of the potential impacts on the landless poor.

Let ΔW^{LL} be the impact of the ES program on the landless poor,

$$\Delta W^{LL} = -\Delta pQ + \Delta w . \tag{18}$$

ES affects the landless by its impact on wage rate and food prices. When the ES program has a weak impact on food prices (demand is elastic), the wage rate is likely to go down, and the impact of land diversion programs on the well-being of the landless will be negative. If the output price effect is positive and the ES program leads to an increase in wage rate, the wage earnings of the landless will increase. However, as equation (19)

suggests, the higher output price will increase the cost of living of the landless, and thus the landless may lose with the introduction of PES programs despite higher earnings. Thus, the landless are more likely to gain from PES programs where the program leads to higher output prices and wage rates, and where consumption of the output is relatively small.

C. Poor landholders

Let ΔW_n^{SF} be the impact from the introduction of the ES program on the well-being of a landowner with land type *n*. Let the optimal labor use per unit of land before the PES be denoted by x_n^0. Even if the farmer does not participate in the program, the change in the output price and wage rate may affect the land rent. The change in the rent per acre is

$$\Delta r_n^{SF} /_{[\delta_n(p,w,v)=0]} = \Delta p \alpha_n f(x_n^0) + \left[p f'(x_n^0) - w \right] \Delta x_n^* - \Delta w x_n^0 , \tag{19}$$

which, once the first-order conditions are considered, becomes

$$\Delta r_n^{SF} /_{[\delta_n(p,w,v)=0]} = \Delta p \alpha_n f(x_n^0) - \Delta w x_n^0 . \tag{20}$$

If a farmer participates in the ES program, the land rent gain is

$$\Delta r_n^{SF} /_{[\delta_n(p,w,v)=1]} = v b_n - p \alpha_n f(x_n^*) + w x_n^* + \Delta r_n^{SF} /_{[\delta_n(p,w,v)=0]} . \tag{21}$$

The gain in rent includes the gain from participating in the program and the gain that occurs if the farmer does not participate, $\Delta r_n^{SF} /_{[\delta_n(p,w,v)=0]}$. The gain from participation includes a change in earnings, $v b_n - p \alpha_n f(x_n^*)$, that may be negative, plus the savings of labor, $w x_n^*$. Conditions (20) and (21) can be combined to give:

$$\Delta r_n^{SF} = \delta_n(p,w,v) \left[v b_n - p \alpha_n f(x_n^*) + w x_n^* \right] + \Delta p \alpha_n f(x_n^0) - \Delta w x_n^0 . \tag{22}$$

Equation (22) suggests that the gain per unit of land includes the direct gain from participation when it occurs, and an indirect gain from an increase in land rent due to changes in w and p. To assess the overall effect of the ES on landowners, we have to multiply the per-land unit effects of equation (22) by the land of the farmer and add the effects of the policy on consumption and labor of the landowning household. After manipulating terms, we get

$$\begin{aligned}\Delta W_n^{SF} = L_n \Big\{ & \delta_n(p,w,v)\left[vb_n - p\alpha_n f(x_n^*) + wx_n^*\right]\Big\} \\ & +\Delta w(1 - x_n^0 L_n) + \Delta p\left[\alpha_n f(x_n^0)L_n - Q\right]\end{aligned}. \qquad (23)$$

Small farms will be affected by the ES program in three ways. First, there is the land rent effect that is likely to be positive. This effect is equal to $\Delta r_n^{SF} L_n$ and reflects gains per acre times the size of land (as seen in equation (22)). Additionally, there is the wage rate effect, which is equal to Δw. The owners of small farms are also farm workers, and thus will be affected by the reduction or increase in the wage rate because of the ES program. Farm households that also participate in the wage labor market —usually smallholders—will gain when the wage rate effect is positive, and lose when it is negative. The third term in equation (23) is the output price effect on consumption, $-\Delta pQ$, which is likely to reduce welfare, as the landowners of small farms are often consumers of the output they produce. The overall effect of the ES program on the welfare of small farms depends on the relative magnitude of the three effects. Table 1 summarizes the potential positive and negative impacts on all three sectors, and presents the conditions under which the poor in each sector is likely to gain.

Table 1: *Impact of land-diverting PES on poverty reduction by economic sector*

Economic sector	*Potential positive impacts*	*Potential negative impacts*	*Conditions for positive impact on poverty reduction*
Urban consumers	Consumption of ES	Increase in food prices where ES have significant impact on supply and demand is inelastic	ES provide benefits to the urban poor (e.g., water or food quality; flood protection) PES has small impact on aggregate food supply, or demand is relatively elastic
Rural landless	Increase in wage rates if PES results in higher labor demand	Increase in food prices Drop in wage rates if PES results in release of labor	Increased wages offset potential negative impacts of higher expenditures on food
Landowners	Increase in land rent from: 1. ES payment 2. Increase in agricultural output prices Increased agricultural wages if household is net seller of labor	Increase in food prices if household is net purchaser Increase in agricultural wage rates if household is net purchaser	1. Price elasticity of demand for agricultural output is inelastic; but the product has a low share in consumption of producer household Household is net seller of labor. or 2. PES has little impact on agricultural output supply and prices of agricultural goods and wages. PES impact is mostly through increased rents to land from PES themselves.

Since landowning households generally constitute an important segment of the rural population, and this group is likely to be the most directly impacted by PES programs, in the following section, we use equation (23) to analyze the distributional impacts of ES on these households when key production parameters vary.

2. Heterogeneity and ES impacts on landholders

Equation (23) suggests that the size of the farm, L_n; the productivity of the land, α_n; and its environmental amenities when land is diverted, b_n, determine the different impacts that ES programs have on rural households. The heterogeneity among households reflected by differences in these key coefficients will result in wide variations in the impacts of PES programs on landowning households. Units with small landownership, low land productivity, and low environmental amenities that do not participate in the ES program will gain little land rent, and the impact of the ES on their well-being will be similar to the impact on the landless. On the other hand, large units with high productivity and/or high environmental amenities that participate in the program will gain from the difference, $vb_n - p\alpha_n f(x_n^*) + wx_n^*$. Large units will also gain relatively more due to the appreciation of output prices, $\Delta p\left[\alpha_n f(x_n^0)L_n - Q\right]$, since L_n is clearly larger but Q is likely to be similar or lower for largeholders versus smallholders. Largeholders—who are more likely hire-in labor—will also gain relatively more when wages decline, captured in the term $\Delta w(1 - x_n^0 L_n)$.

A more detailed analysis of the impacts of ES on landowning households requires assumptions about the properties of L_n, b_n, and α_n. We assume that these parameters are

well-behaved (continuous, differentiable) functions of the variable n, so that $0 \le n \le N_1$[1]. Additionally, we assume that land rents always increase in response to an introduction of the PES program. We consider several scenarios.

A. Heterogeneity in productivity among households with the same size landholding

For the following cases, we assume that $L_n = L$. By our initial assumption, the productivity coefficients are increasing functions of $n, \partial\alpha_n / \partial n > 0$. In this case, we are supposing that poorer households are those characterized by lower productivity lands. We assume that marginal benefits of n are constant for ES, e.g., $b_n = \beta n$, but also consider both positive and negative β's.

A1. *A case of negative correlation between ES and agricultural productivity (* $\beta < 0$ *).*

We define a critical n, n^C. At this critical value

$$vb_n^C = p\alpha_n^C f(x_n^*) - wx_n^*. \tag{24}$$

In this case all households with poorer quality agricultural land, $n < n^C$, will participate in the ES program. Households with better quality land ($n > n^C$) will not participate in the program. Furthermore, the differentiated impact of participation in the ES program among households is derived by differentiation of (23) with respect to n when $\delta_n(p,w,v) = 1$ to yield.

$$\frac{\Delta W_n^{SF} /_{\delta_n(p,w,v)=1}}{\partial n} = L\left\{\left[v\frac{\partial b_n}{\partial n} - (pf(x_n^*) - \Delta pf(x_n^0))\frac{\partial \alpha_n}{\partial n}\right]\right\}^2. \tag{25}$$

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[1] For mathematical convenience, the household indicator is treated as a non-negative continuous variable when we specify properties of key functions and analyze distributional impacts.

Equation (25) suggests that when the farms are of equal size and environmental benefits are negatively correlated with productivity, the introduction of the ES program will provide more benefits to poorer households. For example, cases with negative correlation are likely to occur where the poorer farmers are designated to marginal agricultural land (shallow soils or hills) also inhabited by valuable wildlife. In these cases, transition from farming to conservation will benefit the poor households.

A2. *No correlation between environmental benefits and productivity (* $\beta = 0$ *).*

The outcome is the same for the case of negative correlation with the same critical n, n^C defined above. Here, households with less productive land will participate in the ES program and, as suggested by equation (24), will gain relatively greater benefits since the opportunity costs of shifting land out of agriculture are still greater at higher *n*.

Another benefit of the two cases where $\beta \le 0$ is that the least-productive lands are taken out of production, and thus the impact on the prices of output and labor is smaller than if the same area of more productive land were diverted to provide ES. Thus, these cases are also relatively desirable to the urban poor and the landless.

A3. *Positive correlation between ES and productivity (* $\beta > 0$ *) with increasing productivity differences among lands* $(\partial \alpha^2 / \partial n^2 > 0)$.

This is the case where agricultural land productivity is a convex function of *n* and increases with *n* at a greater rate than the ES. This may be the case where lands closer to a body of water provide more valuable environmental benefits, but restricting access to

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[2]To arrive at equation (25), note that $L\left\{\left[(-p+\Delta p)\alpha_n \frac{\partial f(x_n^*)}{\partial x_n^*} + w - -\Delta w\right]\frac{\partial x_n^*}{\partial n}\right\} = 0$.

water has an even larger impact on farm productivity at the margin. In this case, households with $n < n^C$ (where lands provide less valuable ES) are still those that participate in the program, but now those with both greater agricultural productivity and ES benefits continue to farm. Again, the ES program is beneficial to those with the poorer agricultural land quality.

A4. *A case of positive correlation between ES and productivity ($\beta > 0$) with declining productivity differences among lands* $(\partial \alpha^2 / \partial n^2 < 0)$.

This is the case where productivity is a concave function of *n,* and the marginal increase in α is declining with *n*, while the marginal increase in *b* is constant. Equation (23) presents the formula for the critical *n*, n^C. However, in this case the richer households, $n > n^C$, are the ones that participate in the ES program, and the poorer ones continue to farm. From (23), the poorer farm units not enrolled in the program will still benefit if

$$\Delta w(1 - x_n^0 L_n) + \Delta p\left[\alpha_n f(x_n^0) L_n - Q\right] > 0. \tag{26}$$

By differentiation of (26) with respect to *n*, we obtain

$$\frac{\Delta W_n^{SF} /_{\delta_n(p,w,v)=o}}{\partial n} = L \Delta p \frac{\partial \alpha_n}{\partial n} f(x_n^0). \tag{27}$$

Among the poor who do not participate in the ES program, the gain from the program increases with productivity. Thus, whereas all landholders will gain from the program, those with poorer land quality gain relatively less.

When differences among households originate from differences in land productivity but landholdings are similar in size, we have found that those holding poor quality lands (in terms of agricultural productivity) will gain proportionately more than

their high-quality landowning counterparts from the PES program when the correlation between land characteristics that provide ES and those that increase agricultural productivity are negative or zero, and those with poorer land quality in terms of agricultural production will be those who participate in the program. Even if the correlation is positive, but the impact of land quality on agricultural production is increasing at a growing rate, the same results hold. In the case where returns to quality are increasing at a decreasing rate, it will be those with relatively better quality agricultural lands who join the program. Poorer households will still gain (again assuming the land rent gains are positive), but those with the lowest quality land will gain less so that the distributional effects will be regressive. Next, we consider cases with differences in size of landholding.

B. Heterogeneity in productivity when household landholding size varies

For the following cases, we assume that well-to-do households own more land, $\partial L_n / \partial n > 0$. As before, we assume that the marginal benefits of *n* is constant, $b_n = \beta n$, but consider both positive and negative β's.

B1. *A case where richer households have more productive lands,* $\partial \alpha_n / \partial n > 0$, *and there is a nonpositive correlation between ES and productivity (* $\beta \leq 0$ *).*

The critical n value defined in (24), n^C , separates poorer households, $n^C > n$, that participate in the program from the richer ones that do not. A participating household benefits from the ES program if

$$\Delta W_n^{SF} /_{\delta_n(p,w,v)=1} = \left[vb_n - p\alpha_n f(x_n^*) + wx_n^* \right] L_n \\ + \Delta w(1 - x_n^0 L_n) + \Delta p \left[\alpha_n f(x_n^0) L_n - Q \right] > 0 \quad (28)$$

If the program has no impact on the product and output prices, even the smallest household will benefit from it. However, if it leads to an increase in output price and reduction in labor cost, and small landowners cannot generate the gains that will overcome the extra costs due to these price changes, small landowners may lose from the ES program despite their participation in it. To assess the impact of participation on households of different landholdings, we differentiate (28) with respect to *n* to obtain

$$\frac{d\Delta W_n^{SF} /_{\delta_n(p,w,v)=1}}{dn} = L_n \left\{ \left[v \frac{\partial b_n}{\partial n} - (pf(x_n^*) - \Delta pf(x_n^0)) \frac{\partial \alpha_n}{\partial n} \right] \right\} \\ + \left[vb_n - (pf(x_n^*) - \Delta pf(x_n^0))\alpha_n + (wx_n^x - \Delta w * x_n^0) \right] \frac{\partial L_n}{\partial n}. \quad (29)$$

As in equation (25), the first element in the right-hand side of equation (29) is negative and is the direct effect of having per-hectare land quality favoring provision of the ES on the poorer households' well-being. The second element, the marginal effect of larger landholding size on household welfare, depends on the changes in land rent, which are positive for those who enter the program. This effect clearly favors those with larger landholdings. Distributional consequences then depend on whether the direct benefits to smallholders of enrolling land that provides very high ES benefits in the program outweigh the higher land rents per hectare gained by both small and large landholders enrolled in the program. Thus, *if households with larger landholdings are more productive and ES are nonpositively correlated to size, poor households will participate in the program, but the poorest ones may gain less than enrolled units with more land.*

B2. *A case where richer households do not have more productive lands,* $\partial\alpha_n / \partial n \leq 0$*, and there is a positive correlation between ES and productivity (* $\beta \geq 0$ *).*

In this case the richer households, with $n^C < n$, will participate in the ES program. Poorer households, that do not participate, will benefit or lose from the program depending on the sign of

$$\Delta W_n^{SF} /_{\delta_n(p,w,v)=0} = \Delta w(1 - x_n^0 L_n) + \Delta p\left[\alpha_n f(x_n^0) L_n - Q\right]. \tag{30}$$

If the program does not affect prices, it will not have an impact on nonparticipants. When both output prices and wage rates increase, smallholders will lose from the establishment of the ES program if the gains from higher output price and less labor allocated to own production activities are smaller than the sum of the extra consumption costs and lower labor earnings. Differentiation of (30) with respect to *n* yields

$$\frac{\Delta W_n^{SF} /_{\delta_n(p,w,v)=0}}{\partial n} = \left[\Delta p \alpha_n f(x_n^0) - \Delta w x_n^0\right] \frac{\partial L_n}{\partial n}. \tag{31}$$

Households with more land that do not participate in ES programs are likely to benefit more (or lose less) with the introduction of the program, due to higher land rents that increase production profits per hectare.

With heterogeneity in landholdings, the distributional consequences of the introduction of an ES program are more likely to be regressive than heterogeneity in land quality alone, particularly when the introduction of the program leads to higher land rents per hectare.

The impacts of PES for land diversion programs under heterogeneous land conditions are summarized in figure 2. Thus far, we have discussed the ES program that

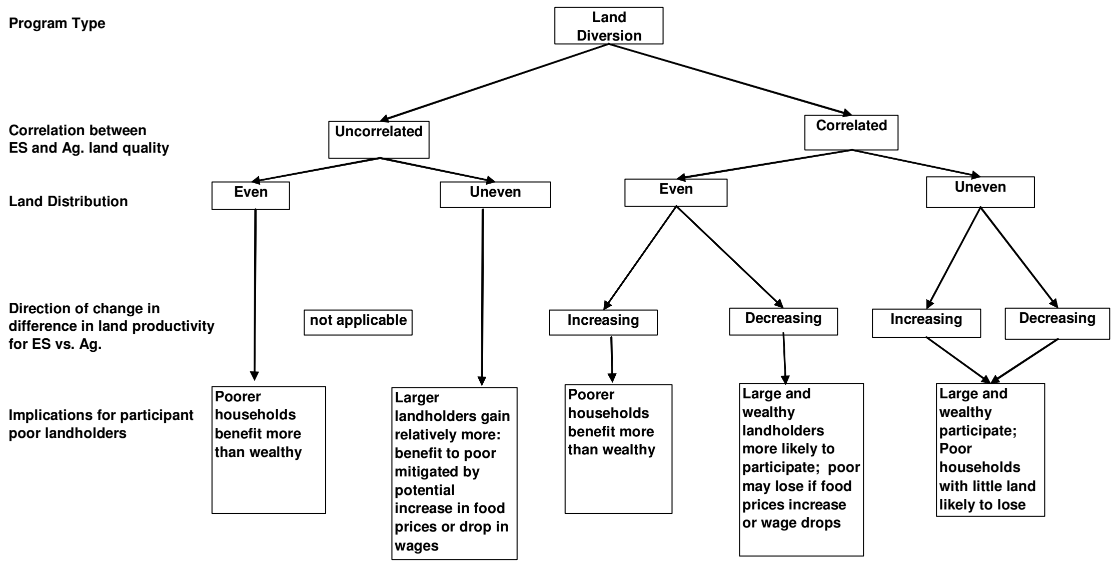

Figure 2
Potential Impacts of PES Programs on Poor Landowners
Under Heterogenous Productivity and Land Distribution Conditions

involves taking land out of production, but what about the impacts of working land (WL) programs?

4. ES Provision from Working Lands and Implications for the Poor

ES programs that require diversion of land from production to ES are easy to model relative to WL programs, which require modification of farming activities, rather than land-use change, to generate environmental amenities. With land diversion programs, there is a separation between agricultural production and the generation of environmental amenities, while in WL programs environmental amenities are generated through the agricultural production process, and there is considerable variation in how these programs could work, making generalized modeling more challenging. For example, some WL programs may aim to sequester carbon in soils by reducing tillage intensity, which in some cases may also involve an increased use in herbicides for weed control. It is plausible to model these activities as reducing output and, in the case of more intensive use of herbicides, increasing operating costs. Other WL programs may aim to reduce pollution by paying for protective efforts (terracing, barriers) that control or slow runoff and erosion. In some cases these activities may increase production costs with limited impact on output. Another WL program may aim to reduce chemical use, and that may lower yields and require a substitution of chemicals with labor. Econometric applications and simulations are especially challenging when modifying the production function to accommodate the specific WL program. Here we will assume that the WL program reduces yield by a certain fraction, γ , and increases the labor requirement by a certain amount per unit of land θ. On the other hand, the program pays b_n per unit of land. This may correspond to WL programs that restrict tillage and pest-control activities to reduce

pollution or to protect wildlife. In this context $\delta_n(p,w,v)$ is equal to one if the *n*th household is participating in the WL program and is equal to zero otherwise. When the *n*th household participates in the WL program, its rent per unit of land is the solution to the optimization problem:

$$r_n^{\delta=1} = \operatorname*{Max}_x \, p\alpha(1-\gamma)f(x-\theta) - wx + vb_n, \tag{32}$$

and let $x_n^{\delta=1}$ be the optimal labor per unit of land if the household participates in the WL program. This consists of labor needed to accommodate the initial production technology and to generate the ES. The optimal level of labor for proper production is $\tilde{x}_n^{\delta=1} = x_n^{\delta=1} - \theta$, and is obtained by the solution to the first-order condition

$$p\alpha_n(1-\gamma)f'(\tilde{x}_n^{\delta=1}) - w = 0\,. \tag{33}$$

The land rent of nonparticipants is $r_n^{\delta=0}$ and is $p\alpha f(x) - w(x)$ for nonnegative *x* values, with optimal $x_n^{\delta=0}$ determined where $p\alpha f'(x_n^{\delta=0}) = w$. The *n*th household will choose to participate in the WL program ($\delta(p.w.v) = 1$, if

$$r_n^{\delta=1} - r_n^{\delta=0} \approx vb_n - \theta w - \gamma p\alpha_n f(\tilde{x}_n^{\delta=1}) > 0\,[3]. \tag{34}$$

Participation is worthwhile if the payment for the ES is greater than the extra labor cost plus the revenue loss associated with the lower output. The aggregate output supply and labor demand can be derived, using the same aggregation procedure we followed for the land diversion program. The introduction of the WL program may result in changes in output price if output demand is not perfectly elastic. A direct comparison of the land diversion programs is not possible, since the overall impact will depend on how many acres enroll for a given payment; however, for any given level of enrollment,

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[3] The term $p\alpha_n(f(x_n^{\delta=0}) - f(\tilde{x}_n^{\delta=1}) - w(x_n^{\delta=0} - \tilde{x}_n^{\delta=1}) \approx \left[p\alpha_n(f'(x_n^{\delta=0}) - w\right]\left[x_n^{\delta=0} - \tilde{x}_n^{\delta=1}\right] = 0$.

agricultural output will be higher under a WL program, and thus prices will increase less. On the other hand, labor wage is more likely to change with participation in the WL program vis-à-vis diversion programs. If θ is sufficiently large, the wage rate increases (Δw), total output decreases ($\Delta Y < 0$), and output price increases ($\Delta p \geq 0$).

The impact of the WL program on the urban poor presented in equation (18) is $\Delta W^{UP} = -\Delta pQ + \Delta W^{EP}$. When output price is increasing and the environmental benefits of the WL program for the urban poor are small, *the urban poor are likely to lose from the introduction of the WL program.* In this regard the impacts of the WL program are not different than that of the land diversion ES program. The impact of the WL program on the landless in the rural area from equation (19) is $\Delta W^{LL} = -\Delta pQ + \Delta w$. As in the case of the land diversion program, the landless will have to pay more for the products they buy but, unlike the case of land diversion, the earnings of the landless are more likely to increase with the WL program, and thus the *landless may actually gain from the introduction of this program.*

To assess the impact of the WL program on landowners, the change in the land rent due to the introduction of the program can be derived in a manner similar to the derivation of equation (22) in the case of land diversion. The change in rent is

$$\Delta r_n^{SF} = \delta_n(p,w,v)\left[vb_n - \theta w - \gamma p\alpha_n f(\tilde{x}_n^{\delta=1})\right] + \Delta p\alpha_n f(x_n^0) - \Delta w x_n^0. \qquad (35)$$

The change in the welfare of a the *n*th household is thus

$$\Delta W_n^{SF} = L_n\left\{\delta_n(p,w,v)\left[vb_n - \theta w - \gamma p\alpha_n f(\tilde{x}_n^{\delta=1})\right]\right\} \\ + \Delta w(1 - x_n^0 L_n) + \Delta p\left[\alpha_n f(x_n^0)L_n - Q\right]. \qquad (36)$$

The difference between equations (36) and (23)—where equation (23) captures changes in smallholder welfare from the introduction of a land diversion program—is equal to:

$$\Delta W_n^{LandDiv} - \Delta W_n^{WL} = L_n \left\{ \delta_n(p, w, v) \left[\left(1-\gamma\right) p \alpha_n f(x_n^*) - \theta w \right] \right\} \tag{37}$$

when evaluated at the same *p, w* pair. Given our assumption that profits are non-negative for participants in any program, equation (37) is always positive. Under the most realistic scenario, we expect output prices to increase less and wages to increase more under the WL program, reinforcing the likelihood that rents per hectare will be lower under a WL program. Urban consumers and rural landless are likely to be better off than under the land diversion program, but landowners may not benefit as much.

Next, we can follow the discussion in section 3.2 and evaluate the changes in the welfare of landowners when landholdings and land productivity vary across the *n* households. Equation (36) suggests that if b_n is negatively correlated or uncorrelated with α_n, the household with the less productive lands will participate in the WL program. The critical *n* in this case is

$$n_{WL}^{C} \text{ where } vb_n - \theta w - \gamma p \alpha_n f(\tilde{x}_n^{\delta=1}) = 0. \tag{37}$$

In these cases households with less land will gain from the WL program both directly, as their income increases from the payment, and indirectly, if θ is sufficiently large to induce higher labor prices. However, these gains will be reduced to the extent that smallholders are net buyers of agricultural products, since the output price effect of the WL program will negatively affect its well-being.

If both b_n and α_n increase with *n,* but $\partial b_n / \partial n > \partial \alpha_n / \partial n$, households with greater productivity participate in the WL program. The less-productive household that does not participate in the WL program will benefit from it if they do not have much

land, and the labor price effect of the program overcomes the output price effect. Thus, if a WL program pays farmers to not use chemicals, which results in an increase in labor demand, riparian households with high productivity land and even higher relative marginal contributions to ES generation will join the WL program. Less-productive households will not participate but may gain from it because of increased labor demand. In the case of payment for conversion to low tillage or for the use of traditional varieties that reduce land productivity and have little impact on labor demand, nonparticipants in the program will not benefit when the output price effect dominates the labor price effect.

If we relax the assumption of homogenous resources and allow heterogeneity among landowning households, assume that the distribution of land is unimodal and similar in shape, and well-to-do households have an average higher mode of land productivity, we can show:

A. *Negative or no correlation between agricultural land productivity and ES coefficients results in higher participation in the PES by the poorer farmers.* If smaller households have the least land, they may lose despite participation because of the higher consumption costs and lower labor earnings. Alternatively, smallholders gain from the PES if the payment has a stronger effect on agricultural profits vis-à-vis impacts on consumption and wage labor

B. *A positive correlation between productivity and the ES coefficient where marginal ES is convex in productivity and will result in a higher percentage of participation by well-to-do farmers*. If the well-to-do farmers also have more land, they will be the main beneficiaries of the PES program, while poorer farmers may lose as the

production effect has possible gains in income and will be outweighed by losses resulting from higher consumption costs and lower wage earnings.

The results of the analysis of the impact of WL PES programs on the poor under heterogeneous land quality and distribution are shown in figure 3.

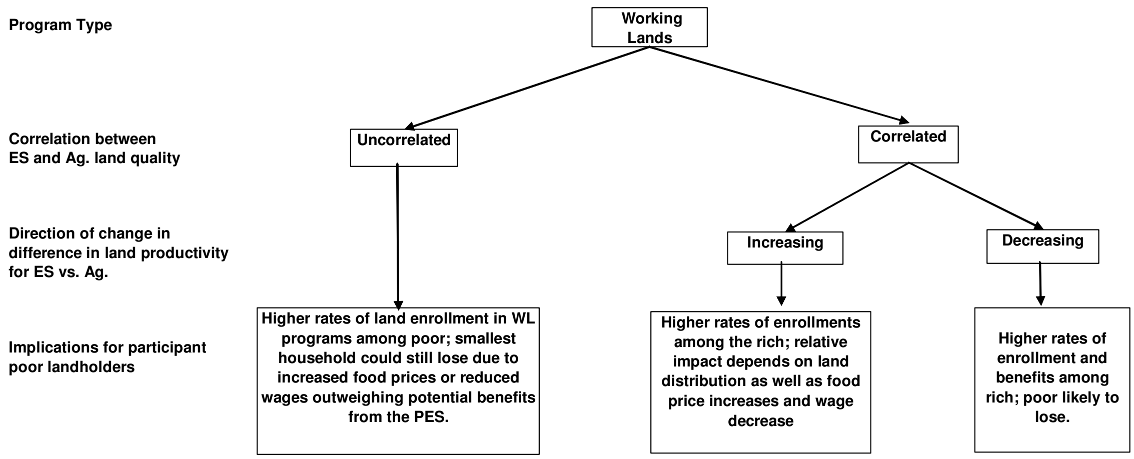

Figure 3
Potential Impacts of PES Programs on Poor Landowners
Under Heterogenous Productivity and Land Distribution Conditions

5. Application to selected countries

Our analysis has indicated a set of factors that are important determinants of the poverty impact of PES programs. They include the price elasticity of food demand, the elasticity of agricultural wages with respect to changes in local labor supply, the distribution of land over wealth, and heterogeneity amongst farmers in land productivity with regard to agricultural and ES production. In this section we apply these concepts to a small set of developing countries to illustrate how the poverty impact of PES programs will vary across different socio-economic conditions. The analysis focuses on the rural poor – both landowners and landless.

One of the important factors across all poverty groups is the potential impact from introducing a PES program on food prices. Higher food prices will clearly hurt the urban and rural landless poor who can be assumed to rely heavily on purchased food. Higher food prices may also hurt small rural landowners, if they are net purchasers of food. For urban consumers, integration into global food markets is an important indicator of the potential food price effect PES programs could have. However, in rural areas where food markets are poorly developed, local supply effects could have a strong effect on food prices, even if the country is integrated into international markets. We therefore note that this is an important issue to consider in assessing PES impacts on poverty that requires a sub-national scale of analysis which is beyond the scope of the present study.

We take national-level statistics on agricultural population per hectare of arable land as a crude indicator of the supply conditions in agricultural labor markets for a selected sample of countries. Countries with high ratios are likely to have more excess supply than those with lower rates, although this will be highly conditioned by the

distribution of agricultural land among the population, as well as the type of technology employed in agriculture and the potential for intersectoral and international migration. To capture land distribution over wealth we look at the Gini coefficients on the distribution of landholdings for the same selected set of countries. These statistics are used to develop a categorization of countries, as shown in Table 3. These are countries with: (1) low agricultural population/land densities and even land distribution, (2) low agricultural population/land densities and uneven land distribution. (3) high agricultural population/land densities and even land distribution, and (4) high agricultural population/land densities with uneven distribution. Using information from a study by the FAO, (Dixon and Gulliver 2002) we can generalize about the types of farming systems the poor are likely to be engaged in for each country category, with the caveat that these are only one of several possible types of farming system the poor might engage in, and there is considerable variation within countries and categories. For countries with relatively low agricultural population densities, those with more even land distribution are likely to be characterized by extensive forms of agricultural production, where the poor engage in production systems such as slash and burn agriculture or pastoral systems, and labor may often be a constraint. In low density countries with uneven land distribution, which are primarily found in Latin America, small-holder mixed crop and livestock subsistence systems are prominent among the poor, together with a heavy reliance on wage labor. In countries with high agricultural population densities and equitable land distribution, labor intensive small-holder systems where land, rather than labor is the constraint are frequently found among the poor. In high density

countries with uneven land distribution the poor are more likely to have very small landholdings and be reliant on wage income, or be landless wage laborers.

Table 3. *Country groups by agricultural population density and land distribution*

Distribution of land	*Agricultural population/arable land density*	
	Low (< 3 persons/ha)	High (>3 persons/ha)
Even < .5	(1) Congo Dem. Rep. Indonesia	(3) China Nepal Rwanda Ethiopia
Uneven >.5	(2) Honduras Brazil Paraguay Peru Colombia	(4) Malawi Vietnam Bangladesh India Pakistan

We consider the likely poverty impacts of WL versus land diversion PES programs on rural populations across these four categories of countries. For countries in category (1), land diversion programs that release labor and increase land rents could be very beneficial to the poor, particularly if agricultural and environmental service productivity are uncorrelated or increasing in productivity differences. Working lands programs are unlikely to benefit smallholders, as labor constraints could prevent participation. In category (2) countries, the institution of land-diverting PES programs could improve the returns to land held by the poor, but here the correlation between agricultural and environmental productivity is critical in determining whether poor landholders will benefit. Poor landholders and landless laborers could be hurt if wages fall. Working lands programs may be most beneficial to the rural poor through wage

effects. In category (3) countries, small average size landholdings means poor landholders are unlikely to benefit from land diversion programs. Instead, WL programs are likely to have the highest positive impact for poor landholders though impacts on land rents and the landless through wage effects. For category (4) countries, WL programs which stimulate the demand for agricultural labor and increase in wages may have the greatest impact on the rural poor.

6. Conclusions and implications

We have shown that meeting two objectives—improving environmental quality and reducing poverty—can be challenging. There is a wide array of circumstances where PES can achieve both objectives, but under a different set of plausible situations, trade-offs arise between environmental and distributional objectives. Several considerations determine when the PES will have a positive distributional effect. The first is the difference between production versus consumption and labor effects of ES. Generally speaking, PES is good for landowners as producers because either they directly get ES that are greater than the value of the production that they give up, or they benefit from changes in prices, which increase output price and sometimes reduce labor prices. On the other hand, poor consumers may lose from ES, especially if the products that were replaced by ES have low elasticity of demand. Similarly, particularly when it comes to land diversion programs, laborers may lose as the demand for labor declines. This suggests that when areas supplying ES are well integrated into the global economy, so that prices of labor and output are not affected very much by the ES program, positive effects on the poor are likely. However, if the affected region is isolated, and then the

ES significantly affects prices of output and labor, it may then actually be damaging to the poor.

The analysis suggests the impact of PES depends critically on the spatial correlation of poverty over land quality for ES provision and its alternative (e.g., agricultural production). If the owners of larger farms also have more productive lands and their lands provides the most valuable ES, then the poor who have small parcels of land which may not be productive and may not participate in ES programs can experience significant losses. On the other hand, when there is a negative correlation between land quality for ES and agricultural productivity, and poor landowners are on poor quality agricultural land, then they may gain significantly by switching from agricultural to ES production. Similarly, the distribution of lands matters. If land distribution is unequal and landowners have minimal amounts of lands and much of their income is coming from their labor, then especially when it comes to land diversion program, they may lose a lot from the ES because of labor market effects.

Another feature that will determine the impact of PES is whether it is a land diversion or WL program. The specifications of the exact payments matter, but in general the poor are more likely to benefit from WL programs that increase demand for labor than land diversion payments that reduce labor opportunities.

Our analysis suggests that the assessment of the distributional effects of PES depends on the measurements of poverty used for assessment. If poverty is measured by earnings so that a poor person is defined as someone who earns less than a $1.00 per day, then PES may be viewed as reducing inequality because they may increase the earnings of small farms, but this may understate the negative impact on consumption. Good

measures of poverty impact have to incorporate the implications of both a change in earnings and cost of living. Our analysis also suggests that the distributional effects of ES may differ considering relative or absolute effects on well-being (see Just and Zilberman, 1983). For example, if PES goes mostly to the well-to-do farmers and because of output price effects the smaller farms are also better off, we may have a situation where everyone is better off in absolute terms, but the smaller farms are worse off in relative terms. In this case the Lorenz curve and Gini coefficient will indicate deterioration in income distribution. On the other hand, if the PES is mostly paid to poorer households due to negative correlation between ES and productivity, then, unless the output price effect is very substantial, the PES is likely to improve both relative and absolute income distributions, which will result in better Lorenz curve and Gini coefficients.

The analysis here can and should be expanded. First, we can introduce slippage by allowing every household to have some land that is not utilized under the initial prices, and it may enter production as a result of PES, which will lead to increased output prices. The argument in Wu *et al.* (2001) can hold here, and slippage may actually eliminate some of the environmental gains of the PES. At least in theory one can think about a situation where the PES program may have both negative environmental and distributional effects as a result of slippage. For example, if most of the benefits go to large farms, and they own some of the extra land that go to production as a result of slippage, the damage from this land is larger than the benefits from the land that go out of production due to PES.

Another area where the analysis can be extended is risk aversion. If farmers operate under weather and pest uncertainties, PES can affect both their average income and distribution of income. One advantage of PES is that is provides sure income, and under reasonable conditions smaller farms that are more vulnerable to risk are more likely to participate. On the other hand, the reduction in supply due to the PES may result in increased food insecurity to the urban poor and increase the fluctuation of food prices. Thus, research on the impact of PES on poverty in the context of risk should be valuable.

Finally, the conceptual framework here identifies several key considerations that will determine to what extent ES programs can benefit the poor. The bulk of future research should be empirical and should identify to what extent the various considerations are important in the real world.

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