The Costs and Benefits of REDD:

Local Livelihoods and Leakage

George A. Dyer†

Abstract. Successful initiatives to reduce carbon emissions from deforestation and forest degradation (REDD) must improve local livelihoods while minimizing emissions leakage. We use an agent-based, general-equilibrium model of a developing area to analyze the links between REDD's impacts on livelihoods and leakage in the context of a voluntary Payments for Environmental Services program. The sign and magnitude of program outcomes are driven by non-market demands and market exchanges among heterogeneous agents in a particular market context. Results suggest ways to minimize leakage, but achieving a positive impact on local livelihoods might require compensating rural agents for potentially widespread losses.

Key words: Reducing Emissions for Deforestation and Degradation, Payments for Environmental Services, agent-based models, general equilibrium, Mexico.

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† The Macaulay Land Use Research Institute, Craigiebuckler, Aberdeen AB15 8QH UK. Tel: (0) 1224 395383; e-mail: georgie.dyer@gmail.com

Introduction

Forests and other natural ecosystems provide valuable benefits known generically as environmental services (World Resources Institute, 2000). Services such as the conservation of biodiversity and carbon sequestration are public goods; others, such as the preservation of scenic beauty and various water services, generate positive externalities. Common to most of them is an increasingly short supply that is essentially land-based (World Resources Institute, 2000). Landowners typically receive no compensation for environmental services, so they tend to transform land into other uses, generating a net loss for society. Payments for Environmental Services (PES) have been used effectively to increase the supply of environmental services (Grieg-Gran et al., 2005; Jack et al., 2008; Pagiola, et al., 2005; Wunder, 2007).[1] There is a growing interest in using PES to reduce emissions from deforestation and forest degradation (REDD) within the Clean Development Mechanism (CDM).[2] Although PES has played a role in emissions reduction initiatives in the past, its use within the CDM has been limited. Avoided-deforestation projects could extend this use significantly, but these are not yet eligible under the CDM. Afforestation and reforestation projects already are eligible, yet several contentious issues persist regarding the 'leakage', 'additionality', and 'permanence' of emissions reduction through these means. Analysts believe that REDD could be harnessed simultaneously to promote rural development and alleviate poverty. In fact, projects eligible under the CDM must demonstrate having a positive impact on local livelihoods. Constraints on land use through REDD, nevertheless, are bound to curtail local economic opportunities. REDD's success could depend on anticipating the full range of implications for stakeholders (Ghazoul et al., 2010). Adequate compensation for potential losses, an equitable distribution of costs and benefits, and the availability of economic alternatives would make REDD more acceptable to local communities and their governments.

In this paper we use an agent based, general equilibrium model to identify the local costs and benefits of REDD and their distribution among stakeholders. The model is used to simulate the implementation of a stock-enhancement program based on PES in a developing area. Since participation in PES is largely voluntary, it is often presumed that participants could not be better off without a program. But programs can have indirect consequences that might alter the balance of costs and benefits for both participants and non-participants (Bulte et al., 2008; Pagiola et al., 2005). These consequences can also be the source of unanticipated changes in carbon emissions outside a project's accounting boundary, i.e., the source of leakage. This paper's premise is that REDD's potential impacts on both local livelihoods and leakage depend critically on the same market linkages. Linkages arising from a restriction of land use and forest-extraction activities can represent costs, e.g., loss of employment and foregone tax revenue. Other linkages can generate benefits, such as those associated with the injection of cash into the local economy. These same linkages can have repercussions on emissions leakage, which also can be positive or negative (IPCC, 2000; Schwarze et al., 2002). At the same time, although clearly linked, there is no linear correspondence between REDD's livelihood impacts and leakage.

PES repercussions could depend on the context in which a program is implemented as much as on its design (Bulte et al., 2008). The challenges of quantifying complex market linkages that are highly dependent on context can seem formidable (Ghazoul et al., 2010). Yet, the ability of REDD initiatives to promote economic growth while minimizing leakage could depend on understanding these linkages. Case studies can yield valuable insights, but systematizing case-study findings can be extremely challenging (Jack et al., 2008; Pagiola et al., 2005). Simulations, on the other hand, can help us identify REDD's potential impacts on local livelihoods and program leakage simultaneously and across variable contexts while shedding light on the complex linkages involved. The following section describes the model, data and simulations on which the paper is based. The third section describes responses to the simulated PES program, focusing on the market linkages involved. The last two sections discuss the distribution of costs and benefits and the implications for program leakage, respectively.

Model, Data and Simulation Scenarios

Our modeling framework integrates 49 individual farm-household models into a general equilibrium model of a village economy.[3] Consumption preferences and production technologies are of the same general form for all households, but they are parameterized distinctly so that production and consumption decisions reflect each household's preferences and technology. Given that households are heterogeneous producers and consumers, they interact with each other in local markets. This sets the model apart from conventional CGE models in which production is undertaken by a representative agent and consumption is aggregated into household types. It also represents the heterogeneous rural economy of developing areas more realistically. In many of these areas, commercial producers of staple foods coexist with subsistence farmers that produce a composite agricultural good that often includes the same tradable staples produced by commercial farmers as well as associated non-tradable goods or services (Smale, 2005). Subsistence agriculture thus is guided by endogenous shadow prices that can be considerably higher than the market price of its tradable output (Arslan & Taylor, 2009; Smale, 2005).

Each household in the model faces the following optimization problem:

$$\underset{A,Z,C,\underline{L},\underline{D}}{Max} \quad U(A,\underline{C},Z;\underline{\beta})$$

$$Subject\ to:$$

$$(1) \quad Y = \sum_{i=1}^{I} p_i C_i = p_A(Q_A - A) - wL_A - rD_A + \sum_{i=1}^{m} p_i Q_i - w\left[\sum_{i=1}^{m} L_i - \overline{F}\right] - r\left[\sum_{i=1}^{m} D_i - \overline{D}\right] + \overline{Y}$$

$$(2) \quad Q_A = Q_A(L_A, D_A; k_A, \gamma_A); \quad Q_i = Q_i(L_i, D_i; k_i, \gamma_i) \quad i = 1,\ldots,m$$

$$(3) \quad Z + \overline{F} + X = \overline{T}$$

$$(4) \quad A \leq Q_A$$

where U is a standard, quasi-concave utility function; A represents consumption of the composite agricultural good; $\underline{C} = (C_1, C_2, \ldots, C_I)$ represents consumption of I tradable goods of which the first m goods are produced by the household; Z is leisure, and $\underline{\beta}$ is a vector of the household's preference parameters. Equation 1 is the household's cash-income constraint, where p_i and Q_i are the price and output of good i; Q_A and p_A are agricultural output and prices; w and r are local wage and land rental rates; L_A and D_A are the amount of labor and land used in agriculture; L_i and D_i are labor and land used in the production of good i; $\overline{F}$ and $\overline{D}$ are the household's labor supply and land endowment; and $\overline{Y}$ is net exogenous income from remittances and government transfers. Equation 2 gives the household's technology constraints, where the output of each good is assumed to exhibit constant returns in labor, land, and capital, k (which is fixed), given the household's production technology γ. Equation 3 is the household's time constraint, where X is commuter work outside the locality and $\overline{T}$ its time endowment. An additional constraint, equation 4, restricts consumption of the composite agricultural good to the household's output. This constraint is binding for subsistence households, making their optimization problem not recursive (Dyer et al, 2006). Subsistence households can buy staple foods at a market price, but the price of the composite good is given by the household's endogenous shadow price, $\rho_A^h > p_A$ (de Janvry et al., 1991). Commercial-farm households are defined by a non-binding subsistence constraint. They might produce and consume agricultural non-market goods and services, but their marginal value is nil for these households;[4] so the price of agricultural output, p_A, is equal to the market price for agricultural tradables. Therefore, these households maximize profits, and their optimization problem is recursive. Profit maximization, in turn, implies that demand for land and labor is a function only of the household's capital endowment, its specific technology parameters, market prices, wages and rents. Utility maximization subject to the full-income constraint yields commercial households' consumption demand. Under the assumption of non-joint production and some fixity of capital, subsistence households behave as profit maximizers with respect to non-agricultural goods that they produce. Thus their factor demands in the production of these goods have the same form as those of commercial households. However, their factor demands in agriculture as well as their consumption demands are functions of household preferences.[5]

In a second stage, the individual household models are linked together into a village-wide general equilibrium model. Equations 5 and 6 represent village-wide constraints equating total demand for land and labor minus total endowments to net demand for land, D^v, and labor, L^v, from neighboring villages. Equation 7 equates net demand for food to the village's net surplus, Q^v. Trade balances are fixed in scenarios where land, labor and food markets are closed, yielding endogenous (i.e., village) factor and food prices.

$$(5)\quad \sum_{i=1}^{m}\sum_{h} L_i^h + \sum_{h} L_A^h - \sum_{h} T^h = L^v$$

$$(6)\quad \sum_{i=1}^{m}\sum_{h} D_i^h + \sum_{h} D_A^h - \sum_{h} \overline{D}^h = D^v$$

$$(7)\quad \sum_{h} (Q_A^h - A^h) = Q^v$$

The model was calibrated with a disaggregated social accounting matrix (SAM) and solved using GAMS software. The disaggregated SAM, which keeps an accounting for each household, was constructed from survey data for the 49 households representing slightly over 10% of all households in the village of Zoatecpan, an indigenous community in the heavily deforested Sierra Norte region in central Mexico. According to survey data, 4% of local households produce maize grain for the market, while 94% practice *milpa*, the traditional multi-cropping system based on maize. Households value highly the non-market goods and services provided by this agro-ecosystem, but they derive little utility from the area's cloud forest other than the extraction of lumber (Smale, 2005). Most households own arable land, but endowments vary widely: the average land holding is only 0.4 hectares, while 2% of households own 50% of the land and act as village landlords. Nearly half of all households rent land from the latter or from absentee landowners, i.e., individuals who do not live in the locality but nevertheless own land within its boundaries.

We simulate the introduction of a program whose goal is to enhance local carbon stocks by retiring 10% of all arable land within its geographic boundary. Program participation is voluntary. Each landowner decides whether to engage in the program and how much land to enroll in exchange for a fixed per-area payment, r^{PES}, equal to 110% of market rental rates, i.e., $r^{PES} = (1.1)r$.[6] That is, enrollment entails surplus rents equivalent to 10% of market rents at the time of implementation. This surplus is attractive to all landowners whose opportunity costs are determined by market rents, given the assumption that no transaction or implementation costs are involved; i.e., all costs are incurred by program managers, and forest regrowth occurs naturally. Nevertheless, general equilibrium effects can change the opportunity costs of alternative land uses, which determine landowners' willingness to participate in PES. Subsistence constraints also affect these costs for some landowners in some scenarios. Ten different scenarios are used to represent alternative combinations of program characteristics and exogenous shocks given a particular economic context (Table 1). In order to keep other sources of variation constant, we make a number of simplifying assumptions and focus on participants' willingness to participate in PES without considering their eligibility or ability to participate.[7]

Scenarios A through F consider the program as described above (in the absence of any other exogenous shock). In scenario A, all goods and factor markets are open, their prices fixed and there is full employment. Scenario B assumes that labor markets are closed, helping reveal wage's role in program outcomes. Scenarios C and D assume a close land market while keeping wages fixed, thus revealing the role of rents under full employment and unemployment, respectively. Scenario C assumes that wages are fixed due to a perfectly elastic demand for labor; i.e., households employ their labor fully in an open market. In scenario D, wages are fixed contractually. Scenarios A through D provide the baseline against which we compare more realistic scenarios. Scenario E explores a combination of rent and wage changes simultaneously. Scenario F introduces a closed food market, highlighting the program's effects on local food prices as well as the effect of food scarcity on the program's cost and effectiveness. The combination of a fixed payment per unit area and flexible rents, in scenarios C through F, implies that surplus rents are variable. Scenario G fixes surplus rents at the level observed in E and lets program payments adjust to keep participation constant. Scenario H analyzes the implications of combining the program with an exogenous 10% increase in food prices. Scenario I identifies the cost of restoring participation in H to pre-shock levels. Finally, scenario J analyzes the effect of the price shock in the absence of PES. Comparison of scenarios H and J thus reveals the program's additionality.

The assumption of fixed wages, rents and prices usually implies that the economy under study is small relative to the land, labor and food market, respectively; i.e., it assumes that these markets extend beyond village boundaries.[8] In the present context, fixed wages, rents and prices can be interpreted also as an assumption on the program's size. A closed land market, for instance, would imply that the program extends over an area large enough to influence rental rates. That is, we can interpret endogenous rents as meaning that neighboring localities experience the same policy shock as the locality under study. In this case, the village becomes a representative locality within the program's area of coverage. Thus, we can identify the consequences of expanding the program by comparing fixed- and flexible-price scenarios. Labor-market specifications can also be interpreted as an assumption on the duration of the program. In this sense, a flexible wage supposes a short-term response where the labor market has not had time to adjust fully. A fixed wage, in contrast, supposes a long-term response where rural out migration has allowed wages to return to normal.

Responses to PES

Participation. Although all local landowners (94% of village households) are eligible to participate in the program, the number wishing to participate and the amount of land that they commit differ markedly across scenarios (Table 2). For instance, every landowner is willing to enroll all of his/her arable land in scenarios A and B; but only one third of households in scenario D commit any land at all. As local enrollment falls short of its target in scenarios C, D and E, to meet their goal, program managers must resort to absentee landowners, who supply up to a fifth of land enrolled in PES across scenarios. In most scenarios, the number of local participants who commit considerable areas is small. Only 2% of local households commits more than 0.5 ha in every scenario. These are village landlords who normally rent land out to other households, so enrollment in PES does not influence their own productive activities.

Baseline scenarios. Participation has widely different effects on the local economy under the range of conditions considered (Table 3). In every scenario, cash transfers increase demand for agricultural non-market goods, which must be satisfied within each farm. This “income effect” linking production and consumption decisions has different implications depending on the local economic context and program design.[9] In most cases, these implications are overshadowed by the program’s more direct effects on production; but they are clearly identifiable when existing markets are open and large. In this context, a design where subsistence farmers were ineligible to participate would result in a fully decoupled program. Commercial farmers would enroll their own land in the program and rent land from others to maintain current output levels. A design with no eligibility constraints, such as the one simulated here, does have an income effect, yet its implications still depend on the local context. Simulation results for scenario A reveal the income effect when existing goods and factor markets are open and large (Table 3). Since both groups face a perfectly elastic supply of land, commercial- and subsistence-farm households alike enroll as much of their own land as program rules allow. Managers face no difficulty in meeting program goals. By construction, the program is not large enough to influence rental rates. That is, although all local landowners are eligible to participate in the program, this is not the case for landowners outside the locality.

Program transfers increase average household income by 0.4%. Given the extent of local participation, income gains promote small but widespread increases in consumption of both market and non-market goods and services. Commercial-farm output remains unchanged despite greater on-farm consumption of maize; but subsistence households must increase output slightly (0.4%) to satisfy consumption given that they produce no surpluses. Since local land is fully employed, expansion of subsistence agriculture ultimately translates into increases in the amount of land rented outside the locality. The same is true of farm labor, which ultimately must come from neighboring localities. Moreover, as local demand for maize increases and village surpluses decline (due to commercial-farm households' greater consumption), a growing food deficit must be satisfied in the open market. Thus, whether they are paid as rents and wages to non-local households or spent on goods produced outside the locality, program transfers in this scenario ultimately leak out of the local economy.

A closed labor market, in scenario B, logically changes this situation. A limited supply of labor first leads to a 0.9% increase in local wages that ultimately curtails demand for labor. Endogenous wages thus constrain the expansion of subsistence agriculture observed in the previous scenario; total output grows two thirds less than in A. However, this leads to no loss of income because wages does not leak out, as in scenario A, but remain in the locality, doubling nominal income gains (Table 3). Although market prices in both scenarios are constant, in scenario B the cost of non-market *milpa* goods and services increases. Thus, real income gains are only 65% larger in B than in A. Widespread participation in PES in both scenarios helps reduce disparities across households, but income gains still differ widely across households, particularly in scenario A, given that they are tied to land ownership. In this scenario, gains range from 3.7% for some landowners to nil for landless households. The range is much smaller in scenario B, where every household experiences at least 0.3% gains, which should be compared to 0.4% average changes directly attributable to program transfers.

When the land market is closed, as in scenario C, the program's most immediate effect is to increase the scarcity of land. Village landlords are not constrained by this change, but most other households become restricted by their own consumption demands. Since every landowner in the market wishes to participate in PES, households cannot substitute rented land for land enrolled in the program. Thus, even though benefits are the same as in previous scenarios, now only 35% of local households decide to enroll any land. Due to the decline in local participation, absentee landowners must contribute nearly one fifth of enrolled land. Nevertheless, the program's impact on the local economy is greater than in previous scenarios (Table 3). The scarcity of land results in a 3.4% increase in local rents, which leads to an 8.6% contraction of agricultural output. Such a marked contraction, the second largest across scenarios, contrasts sharply with the small expansion registered in scenarios A and B, where land markets are open. Subsistence output and consumption drop only slightly despite the higher opportunity costs of land. The brunt of the adjustment in scenario C thus falls on commercial farmers, whose output and market surpluses contract 29 and 54%, respectively. The ensuing deficit in local food supplies leads to a 9.6% increase in open-market purchases.

The contraction of commercial agriculture in scenario C also leads to a 3.7% decrease in demand for labor, but this has no consequences on local income given that working households find full employment outside the locality. Changes in market rents do affect income and reduce the size of surplus rents. Instead of the expected 10%, PES transfers now provide only a 6.4% premium over market rates. Overall, nominal income changes still are markedly different for participants and non-participants, and even among participants. Average gains for participants are nearly the same as in scenario A, but a much larger share of benefits now accrues to landlords, whose gains rise from 0.5 to 4.3% with rent increases. Absentee landlords in particular benefit greatly from both rent increases and participation in PES. In contrast, non participants experience marginal nominal-income losses. Given that only one third of households participate in the program, village income increases only 0.25% in nominal terms, i.e., slightly more than half that in scenario A. Moreover, the cost of subsistence consumption now reduces real gains for the average household.

Scenario D represents the case where the labor market is closed but wages are fixed contractually. In this case, the contraction of local agriculture leads to 1.8% unemployment and wage-income losses, which in turn reduce consumption demands, including demand for *milpa* goods and services (Table 3). Subsistence output thus contracts 1.3%, in contrast to scenario C, where it remains largely unaffected. The contraction of subsistence agriculture also dampens rent increases observed in C. As a result, commercial maize output and surpluses decrease slightly less, while purchases in the open market do not grow as much. The combination of lower rents and income losses has mixed effects on program participation and enrollment: fewer farmers participate than in scenario C, but participants enroll slightly more land in PES. Unemployment reduces nominal income for non-participants and most participants, except landlords.

Combined scenarios. Scenario E combines some of the assumptions of previous scenarios, and thus reveals a more complex albeit more realistic outcome (Table 3). In this scenario, the reduction in land area leads to a 2.6% decrease in wages, in contrast to scenarios C and D, where fixed wages force farmers to reduce labor use sharply, falling wages now allow them to hire more. As a result, agricultural output contracts only one third of what it did in C and D. Subsistence output is relatively unchanged despite higher increases in rents (7.1%) than in previous scenarios. As before, it is commercial farmers that adjust, but their output and surpluses contract much less (12 and 22%, respectively) than in fixed-wage scenarios. Accordingly, food purchases in the open market increase only 2.8%, compared to the 8 and 9% increases observed under fixed wages. Demand for agricultural land in scenario E is constrained by considerable rent increases and income losses (see below). Therefore, over half of all households decide to enroll land in PES. Local enrollment nearly reaches the program target; only 3% is supplied by absentee landlords. The program also has distinct impacts on income in this scenario. Village incomes decrease more than in any other scenario (i.e., 0.9%); but losses are distributed more evenly due to the combination of wage and rent changes. A large increase in rental rates raises landowners' income but reduces surplus rents to only 2.9% of market rates. Although there is full employment, a significant drop in wages generates more income losses than unemployment in scenario D. A few farmers who hire labor in experience net gains, but the opposite is true of most households. Overall, only 12% of all households experience real income gains. Village landlords experience 1.7% gains, while the average participant experiences a 0.7% loss.

Closing the market for maize in scenario F opens the door to food scarcity, which translates into food-price increases (Table 3). Local maize prices rise 1.3% after PES is implemented, reducing demand for maize but simultaneously limiting the contraction of output to 1.9%, compared to 3.2% in scenario E. Since the market is closed, changes in local supply and demand of maize lead to a 5.4% decrease in sales. That is, commercial growers must still bear the brunt of the adjustment; yet a 4.1% decrease in commercial-farm output is mild compared to the 12 to 29% contraction observed in scenarios C through E. This relative recovery occurs partly at the expense of subsistence agriculture, which now decreases 1.0%. Maize prices also drive local demand for land and labor up relative to scenario E, raising wages only marginally but forcing rents up 14%. These cost increases provide an incentive for subsistence households to decrease their demand for land, which promotes greater enrollment in PES. Program participation is higher than in any other scenario where the land market is closed: 58% of all local households enroll land in the program. The potential supply of land exceeds the program's goal by over 18%. However, since market rents rise above program payments per unit area, participation in PES becomes a liability; i.e., instead of surplus rents, enrollment entails a 3.3% loss relative to the rates that participants could charge in the market. Such increase in the opportunity costs of land would reduce future participation in PES.

In the short term, nevertheless, the endogenous increase in the price of maize paradoxically improves the program's implications on local incomes relative to the open-market scenario. The reason is that wage income does not decline but grows marginally, driving full incomes up 0.4% for the average household (compared to a 0.9% decrease in scenario E). Subsistence households experience relatively small gains (0.3%), but commercial farmers gain as much as village landlords (1.4%). Since participation has no net benefit *ex post*, income gains for program participants and non-participants are very similar. Lowering the opportunity costs of enrolling land, in scenario G, to keep surplus rents at the level observed in scenario E (where the maize market was open), requires increasing program payments to 116.8% of the original rental rates. This increases program costs 68% and redistributes its benefits but has few implications on production (Table 3).

Program additionality. An exogenous 10% increase in food prices has very different implications on program outcomes from those of a price shock induced endogenously by the program. In scenario H, agricultural output increases slightly (0.7%) in response to an exogenous shock despite the reduction in arable land achieved through the program (Table 3). As in scenario F, local maize consumption decreases after prices rise, but commercial farmers now are able to sell their surpluses in the open market. Commercial output and surpluses grow by 11.2 and 24%, respectively, while village purchases in the open market decrease by 9.6%. Given that both land and labor are in limited supply, the expansion of commercial agriculture occurs at the expense of subsistence output, which contracts 3.6%. Since demand for land increases at the same time that its supply decreases, rents rise 21%—far more than in any other scenario.

Demand for farm labor also forces wages up 7.1%. These sharp increases in production costs create clear incentives in favor of program participation. As many households as in scenario F are willing to enroll in PES, but the potential supply of land to the program now surpasses its goal by 19%. Large rent and wage increases also raise nominal village income by 3.8%. Since maize prices are the main factor behind this gain, differences between PES participants and non-participants are minimal. Income gains are distributed more homogeneously than in other scenarios. Commercial farmers experience a 6.8% increase in income; subsistence households enjoy a 3.6% gain, while landlords' income rises 4.5%. Increases in food prices nevertheless represent a considerable loss of purchasing power. Commercial farmers, who produce a surplus, still experience substantial gains. Subsistence households' gains are reduced to 0.9% in real terms because of increases in market prices and, owing to the contraction of output, in the implicit price of *milpa* goods and services. In this case too, the rising opportunity cost of land eliminates surplus rents entirely. Keeping participants in the program, in scenario I, requires payments 24.5% greater than base-case rents, which implies a 145% increase in program costs.

The same price shock would have very different implications in the program's absence. An abundant supply of land in scenario J, where there is no program, constrains cost increases relative to scenarios H and I, allowing maize output to increase 3.8% (Table 3). Output growth can be attributed to commercial farms, whose output and surpluses increase 23 and 46%, respectively. While rents are significantly lower than under the program, the expansion of commercial agriculture raises wages by 10%. As a result, subsistence *milpa* contracts even more than under the program (in scenarios H and I). Along with the foreseeable changes in demand for maize after a price increase, local supply responses result in a 13.1% drop in open-market purchases.

Relative changes in rents and wages redistribute the price shock's costs and benefits. Since wages constitute a larger source of income than rents, the average household now experiences a 5% gain in nominal income. Commercial-farm households again experience the largest nominal increases, but subsistence households also experience significant gains: 8.0 and 4.8%, respectively. Village landlords, the major beneficiaries of a PES program, experience a 5.3% gain—which nevertheless represents a 27% decrease in gains relative to scenario I. Although average real income gains are more modest than nominal gains, they are 92 and 67% greater than in scenarios H and I, respectively, and significantly greater than in any other scenario.

The Distribution of Costs and Benefits

A moderately large PES program could influence local food and factor markets significantly, creating both winners and losers. Scenario E reveals that, in such a context, the program could generate real-term losses for the average household and, somewhat surprisingly, even for program participants. In fact, large landowners could be the only group deriving net gains from PES. The distribution of costs and benefits is highly dependent on the local context, of which ownership of productive assets is an obvious factor (Bulte et al., 2008; Pagiola et al., 2005): higher rents represent benefits for households whose main asset is land, such as landlords, while landless households are bound to suffer losses. A less obvious but equally important determinant of relative gains and losses is the structure of local markets. Simulations help us deconstruct REDD's potential implications on local livelihoods into their respective market and non-market sources.

Scenario A singles out the program's direct contribution to local incomes, consisting of payments to participating landowners. This injection of cash has additional, indirect repercussions on local livelihoods whenever the economy is not entirely open, as it is in scenario A. When local wages retain part of the cash flow within the economy, creating a multiplier effect, as in scenario B, the indirect benefits of PES could be as large as the direct benefits to participants.[10] Although wage increases benefit working households, they also create scarcity that ultimately manifests as a difference between nominal and real income gains, reducing indirect program benefits by more than a third (Table 3). These income estimates (for scenarios A and B) already account for the direct costs of PES, i.e., the opportunity costs of land, which are equal to foregone rents. Opportunity costs are fixed in scenarios A and B, which assume that local landowners can arbitrage in an open land market, paying less for land rented from others than what they receive for their own land in PES. That is, in such circumstances, landowners are able to appropriate all surplus rents created by the program without having to assume the costs. In scenario C, where landowners cannot arbitrage, rental rates rise as participants substitute enrolled land, thus reducing surplus rents appropriable by program participants. This also has indirect repercussions throughout the economy, generating indirect costs and benefits for different groups. On its own, replacing land enrolled in the program raises rents only moderately; local agriculture still contracts, but wage income does not change as long as the labor market is unaffected. Surprisingly, the costs are borne by landowners that decide not to participate in PES due to the limited availability of land. In the study region, surplus rents decrease to less than a third of their original value; but participants still receive full program payments, leaving their nominal gains unaffected. If they do not cultivate rented land (i.e., if arbitrage is not possible), separating returns to land into rents and surplus rents has no consequences on their net income. This is not the case for farmers who rent land from others, such as many non-participants in the model. Thus, the program's costs are imposed on this group, while local and absentee landlords benefit at their expense.

A limited supply of land also raises the implicit price of subsistence consumption, reducing the real value of full-income gains just described. In simulations, these gains are more than halved when land supplies are constrained (i.e., compare real incomes in scenarios A and C; also see below). However, the program continues to generate net benefits to the community as long as it remains small relative to labor markets. Additional costs are incurred when the program is large enough to influence rents and simultaneously generate unemployment or affect wages. (Closing the labor market implied few changes in scenario B, where the supply of land was perfectly elastic; but its implications on local economic activities are much greater in scenario E, where rents are flexible.) Wage changes can multiply program benefits, as discussed above, but also program costs, i.e., the costs of reducing the availability of land. If demand for labor contracts noticeably following program implementation, working households could experience net losses. A combination of rents and wage changes can also intensify the redistribution of income that favors landlords at the expense of tenants. For instance, when we consider the program's impact on the labor market (i.e., comparing scenarios C and E), income losses for non-participants increase significantly; income gains for the average household become losses, and even program participants sustain losses. The weight of wages in household income in the study region means that differences between the average participant and non-participant are minor in the most realistic scenarios, which raises questions on the program's long-term feasibility (see below). Undeniably, wages and unemployment rates could return to normal after program implementation if surplus labor migrates out of rural areas, creating a favorable long-term shift in the balance of costs and benefits for the remaining population. PES could also be a source of employment in the short term. Working-land programs can increase demand for labor to manage forests (Pagiola et al., 2005; Zilberman et al., 2008); but these activities are not free of costs. The added cost of wages must be borne by either landowners or the program.

Comparing scenarios D and E reveals the implications of fixed vs. flexible wages on the distribution of costs and benefits. Sticky wages can constrain nominal income losses for farm workers, but flexible wages ameliorate PES impact on agriculture, curtailing output and real-income losses for other groups.[11] The loss of purchasing power can become crucial when food prices also rise. In the study region, subsistence households could see nominal gains from PES vanish in real terms if the program increases local food prices. Certainly, food prices could rise independently of the program. In our case, however, an exogenous price increase generates real gains because of its positive effect on local wages. Nevertheless, PES would restrict local supply responses to such a shock (i.e., compare scenarios H and J.) While this could force landowners to abandon PES, compensating them for their losses would increase the costs of REDD considerably without a significant contribution to rural livelihoods. Compensation increases landlords' gains from 1.2 to 3.9% in real terms (compare scenarios H and I), but it has few benefits for local households (Table 3).

Since most of PES' costs derive directly from restrictions on land use, it is presumably the structure of land markets which is most important. Participants can reduce the costs of enrolling land in PES by clearing forest areas or cultivating idle lands within their own farms if this is possible. Alternatively, when land markets are present, they can pass along these costs to others. If the market is restricted to the locality, the brunt of the costs is borne by local producers, including participants, in the form of higher rents. Where markets are open, participants can avoid these costs entirely, spreading them imperceptibly across a large area, as long as programs remain local in scope. As the program spreads to neighboring localities, participants lose the ability to arbitrage, and each locality has to bear its own costs. Eventually, if market rents rise sufficiently, program managers are forced to increase payments to sustain enrollment and thus share these costs. The question is: what is the structure of land markets in practice?

In developing areas, the opportunity costs of land are not a function of land qualities and market prices alone but also of farm-household characteristics. Transaction costs can limit the size of markets from the perspective of individual farmers, who often must walk to their fields. When renting outside their own locality, many farmers restrict to land adjacent to village boundaries. In contrast, absentee farmers regularly use local labor to cultivate the land at a distance, often in various localities simultaneously. Since they also participate in rental markets, they are in an ideal position to arbitrage.[12] Absentee landowners do not experience the indirect costs of retiring arable land from production, given that their participation in the local economy is marginal. They also benefit from economies of scale and rarely are bounded by self-sufficiency constraints. Thus, they could be the first to enroll land in PES as payments rise above market rents. That is, absentee landowners can reap the benefits associated with open land markets while passing the costs to local households facing relatively closed markets. At the same time, local landowners might be better off without a program, but they might realize that once PES is in place, it is in their own interest to participate since enrollment allows them to minimize their losses. As a result, if participation is left to market forces, local communities could sustain losses as long as landlords can draw benefits from PES.

Simulations also suggest that the net costs of PES could be lower in communities relying on local food supplies. Common sense seems to suggest that the direct and indirect costs of retiring land from production should be higher when the supply of food is inelastic (Zilberman et al., 2008). However, the multiplier effect of a closed food market could offset these costs—although not everyone would be entitled to a share of the benefits. It also might seem surprising that participation in PES increases when crop prices rise. Subsistence demands can constrain land use in some situations, but subsistence farmers do not usually benefit from crop-price increases; yet they cannot ignore rising land and labor costs. Thus, they are bound to decrease their consumption demands. Livelihood impacts also seem surprising given that food scarcity clearly benefits surplus farmers at the expense of net buyers. However, farm workers may benefit as much from supply responses as landowners, particularly if the latter commit their land to PES without fully considering the repercussions on the local economy.

Agro-ecosystems can provide substantial non-market goods and services, some of which entail public benefits (Smale, 2005). However, it is their private benefits that could determine landowners' willingness to participate in PES. Few studies have addressed PES' local non-market costs and benefits. Ignoring their importance for local livelihoods can misguide our judgments on the potential acceptability of REDD initiatives. Non-market gains and losses are not a simple function of those observed in the market economy. A contraction of aggregate agricultural output, for instance, does not imply that the value of non-market goods and services decreases, because households value these services distinctly. In our model, the non-market costs of PES—i.e., the loss of *milpa* goods and services—are expressed as the difference between nominal- and real-income gains.[13] In some cases, average income gains decrease between 17 and 24% in real terms when we account for these costs (Table 3). In other cases, non-market benefits increase with PES, reducing income losses up to 23% in real terms.

Implications for Program Leakage

The literature recognizes two types of leakage from REDD initiatives: a) activity displacement or shifting is a direct change in local activities; b) market-effects leakage, also known as demand displacement, is induced vicariously through markets (IPCC, 2000; Schwarze et al., 2002). This classification risks confusing two concepts that should be kept separate. One is the transmission of leakage across space; the other refers to the mechanisms involved. The most immediate response to an initiative is to substitute land enrolled in a program. Participants can satisfy their demand for land themselves (by clearing forest areas under their control) or rent land from other landowners, who in turn might clear their own land. Assuming that forests hold more (less) carbon than cultivated areas, these changes generate positive (negative) leakage. The issue is that while both cases entail a direct response within participating farms, the second case also entails a market exchange with another landowner. Also, in both cases, leakage can occur on either side of the program's geographic boundary. There are other routes through which an initiative can create or diminish land-use pressure. Changes in land, labor or agricultural markets are common causes of land-use change (Angelsen, 2007), so all changes in demand and supply in these markets associated with REDD initiatives are a potential source of leakage. In our analysis, alternative routes involve mostly food and labor markets. While displacement can occur through every route, how much leakage occurs and where ultimately depends on the market linkages involved and the choices available to land-users at the end of the chain.[14] The availability of suitable land within the farm is critical; but assuming that landowners have full access to credit and insurance markets, they will not clear additional land unless its returns increase. When land markets function properly, as in the study region, this requires that rental rates rise. In these circumstances, all leakage is mediated by markets.

When a locality is perfectly integrated into a larger economy through open markets, the potential effects of a PES program on land-use pressure dissipate across a large area with no visible effect on market rents, wages or crop prices. This lack of price changes does not imply the absence of leakage.[15] Although negligible relative to the market's size, demand for land can be significant relative to the program's size. In scenario A, for instance, prices are unaffected, but direct demand for land in the open market (on the part of program participants) exceeds the area retired from production through PES within the locality, the program's geographic boundary. Participants' purchases in an open maize market further raise land-use pressure outside this boundary, while their demand for labor indirectly reduces it. We cannot assess here whether these indirect market effects amount to a net increase or decrease in land-use pressure and leakage. All market effects ultimately manifest as changes in land rents, which are exogenous in scenario A; but compared to direct demand for land, effects transmitted through food and labor markets in this scenario are marginal. That is, rather than decreasing land-use pressure at the regional level, the program ultimately increases it.

There can be no displacement of labor outside program boundaries when labor markets are closed. In scenario B, where labor demand must be satisfied locally, market equilibrium is restored through wage increases. Higher wages can reduce the opportunity costs of local forests (Angelsen, 2007); but their effect on land use spreads thin again across an open land market. Changes in demand for land at a regional level still offset land-use reductions within program boundaries. In the end, all indirect market effects (in scenarios A and B) leak out of program localities via direct demand for land. Whenever this route is closed (as in scenarios C through J), demand for land drives local rents up, increasing the opportunity costs of local forests (Angelsen, 2007). Whether this becomes leakage depends on various factors, but a closed land market does not preclude market displacement into the rest of the region. The program still influences land use vicariously through food and labor markets. Its influence through each of these routes depends, among other factors, on which other routes are open; and total displacement is not the same in each case.

When markets other than land remain open, as in scenario C, land-use pressure within program localities can rise notoriously, but market displacement outside program boundaries also increases (i.e., compared to A). Households may not rent land outside their locality, but they still supply labor or purchase food in open markets, which shifts the potential for leakage out of program localities. If working households are unable to find employment outside their locality (as in scenario D), the ensuing loss of income reduces the pressure on local rents and demand displacement through open food markets. That is, unemployment reduces the potential for leakage both within and outside program localities. More generally, fixed wages stifle local supply responses, increasing the program's impact in the rest of the region. When wages respond to local changes in demand, as in scenario E, the drop in wages caused by PES has an effect similar to unemployment—i.e., it reduces income and thus displacement through food markets—but its effect on local production is very different. In this case, lower labor costs sustain demand for land and output levels, further reducing food purchases in the open market. Since these are the only source of displacement out of the locality (in scenario E), we can conclude that the potential for outside leakage is lower than when wages cannot adjust. Similarly, local displacement is much greater in this flexible-wage economy than in one where wages are fixed (i.e., compare scenarios E, C and D).[16] In sum, flexible wages reduce displacement outside program boundaries but increase it within them. As discussed in a previous section, this trade-off is absent when land markets are open.

When food markets also are closed, as in scenario F, all changes in demand for food must be satisfied through local supplies. That is, in this case, all leakage occurs within program localities. Rents and land-use pressure could rise considerably in the study region if food markets were closed (compare scenarios E and F); but the fact is that food markets often are relatively open (Motamed et al., 2008). A locality linked to a large food market, on the other hand, is vulnerable to exogenous price shocks. Setting land aside through PES limits local supply responses to such shocks, raising rents and land-use pressure significantly. The fraction of rent increases attributable to the program, nevertheless, is smaller than when food markets are closed.[17] Moreover, local farmers also supply more food to the open market, decreasing land-use pressure outside program localities.

A crucial policy issue is where to implement REDD. An obvious consideration, from an efficiency perspective, is the distribution and quality of environmental services. Areas where the total biomass density of natural ecosystems is above average, such as the cloud forests in the study region, are a prime target.[18] An equally important consideration should be the potential for leakage. Leakage out of remote localities with closed markets is bound to be low, but leakage within these localities remains a possibility. In these cases, an efficient strategy might be to target localities where the availability of uncultivated land is low, so that retiring arable land from production might lead to agricultural intensification rather than the expansion of the agricultural frontier. Every alternative's implications on livelihoods must be considered individually. Simulation results suggest that the outcome could be better in an self-sufficient locality than when food markets are open, albeit not entirely positive: a program could result in nominal income gains but still yield real term losses (compare scenarios E and F). The distribution of gains and losses across the population is an additional question to be addressed.

The analysis complicates in localities that are better integrated to the regional economy, since REDD will result in demand displacement into other areas. These areas could be localities immediately outside program boundaries or more distant places. Again, the implications on local livelihoods are not necessarily better in well integrated localities, but the potential for local leakage does decrease. The program's total leakage and overall implications on livelihoods depend additionally on conditions in localities linked to it through markets. Farmers in south and central Mexico, where the study area is located, consume most of their maize output (Dyer, 2008). The area suffers a large food deficit, nevertheless, that is satisfied by grain produced in highly industrialized farms in northwest Mexico and the United States. Since yields are much lower in the study area than in these regions, a REDD initiative might be justified from the perspective of efficiency, but life-cycle emissions leakage still needs to be considered.[19] Achieving a positive impact on local livelihoods nevertheless would require compensating non-participants for their losses.

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[1] PES is defined as a voluntary agreement involving direct payments to landowners for undertaking specific land use practices that are thought to increase provision of a particular environmental service (Wunder, 2007).

[2] The CDM is one of three mechanisms contemplated in the Kyoto Protocol to help industrialized countries meet their emission-reduction targets. Its purpose is to promote partnerships between industrialized and developing countries that allow the latter to contribute to emission reductions while achieving sustainable development.

[3] The household and village models are modified versions of those described in detail in Dyer et al., 2006.

[4] This happens when the cost of harvesting non-market goods is constant, but the marginal utility of consumption decreases with scale.

[5] Cobb-Douglas production functions are calibrated for each household and activity. Exponents in these functions are equal to measured factor shares in value added. Consumption demands are modeled using a linear expenditure system (LES) with no minimum required quantities. The parameters in the demand equations are set equal to measured budget shares for each household and good. These simple functional forms permit estimation of a separate model for each household and lend transparency to the results. Results are generally robust to the specification of functional forms inasmuch as scenarios involve marginal changes in exogenous variables and the model is always estimated at the same point given by survey data. Despite the linearity of individual household responses, aggregate supply and demand responses are highly nonlinear, shaped by households' production and consumption parameters and the endogenous price of the composite agricultural good.

[6] A reasonable payment must lie somewhere between the minimum willingness to accept as compensation for restrictions on land use and the maximum willingness to pay for the environmental services a given land use provides. In practice, payments tend to lie close to the first (Pagiola et al., 2005).

[7] Simulations assume no eligibility requirements other than to set aside any amount of land; i.e., participants pool resources to avoid minimum-area requirements and reduce fixed costs that may otherwise constrain small holders' participation (Grieg-Gran et al., 2005; Pagiola et al., 2005). Also, extraction of lumber is not allowed, which implies that potential benefits associated with an expanding supply of forest products are not explored. As for environmental services, possible sources of heterogeneity are not considered; i.e., soil quality, microclimate and other biophysical attributes are assumed to be homogenous across the landscape. Thus, intrinsic agricultural yields as well as total biomass densities are fixed and uniform, which implies that both land rental rates and environmental benefits per unit area also are uniform. Finally, marginal environmental benefits do not change with the scale of implementation, which is reasonable in the case of carbon sequestration.

[8] Alternatively, these variables could be fixed institutionally, i.e., through price controls, as in scenario D.

[9] If markets were complete, open and large enough to keep prices constant, transfers would be completely decoupled from production decisions. Income gains associated with these transfers would encourage consumption, but a perfectly elastic supply of goods would satisfy local demand fully.

[10] Average nominal-income gains double when comparing scenario B to A. These indirect benefits do not depend on activities directly related to the program, which are not considered in this paper.

[11] The reason is that as agriculture contracts in a sticky-wage economy, the implicit price of non-market goods and services increases, reducing the "purchasing power" of full income.

[12] Apparently, PES has been implemented largely in localities where land markets are not well developed (Pagiola et al., 2005). In the study region, in contrast, almost half of all households rent land. Land rental is common throughout Mexico and markets often extend beyond village boundaries (Dyer, 2008). At least 80% of land rented by Mexican rural households in different regions is satisfied by absentee landlords, except in northeast Mexico, where rural landowners hire out more land than they hire in (Dyer, 2008).

[13] This is true for scenarios A through E, where market prices are constant. Notice that nominal and real income losses are not correlated; e.g., compare income losses in scenarios D and E.

[14] Land-use change (and thus leakage) also depends on a host of other factors beyond the scope of this analysis, including institutional variables and land property issues (Angelsen, 2005).

[15] PES' effect on market signals depends on program size relative to that of the corresponding markets. If markets are sufficiently large, price changes will be negligible, but potential leakage remains a function of absolute changes in demand for land.

[16] This is clear because the increase in local rents subsumes all direct and indirect land-use effects via land and labor markets.

[17] The measure of the program's additionality is given by differences in local rents and food purchases between scenarios H and J.

[18] The average total biomass density of Mexican cloud forests is 149.8 Mg/ha (Cairns et al., 2000).

[19] This third type of leakage, which has not been considered here, is tied to changes in emissions due to activities not directly linked to land use, e.g., transport of grain across localities (Schwarze et al., 2002).

<table>
<tr><td colspan="11">Table 1. Alternative simulation scenarios and implications for model variables.</td></tr>
<tr><td colspan="11"></td></tr>
<tr><td>Scenario</td><td>G</td><td>F</td><td>E</td><td>D</td><td>C</td><td>A</td><td>B</td><td>H</td><td>I</td><td>J</td></tr>
<tr><td colspan="11">Exogenous shocks</td></tr>
<tr><td>Policy shock</td><td>adjusted program</td><td colspan="7">original PES program</td><td>adjusted program</td><td>no program</td></tr>
<tr><td>Market shock</td><td colspan="7">no price increase</td><td colspan="3">food price increase</td></tr>
<tr><td colspan="11">Market structure</td></tr>
<tr><td>Food</td><td colspan="2">closed (local) mkt</td><td colspan="8">open market</td></tr>
<tr><td>Land</td><td colspan="5">closed (local) market</td><td colspan="2">open market</td><td colspan="3">closed (local) market</td></tr>
<tr><td rowspan="2">Labor</td><td colspan="3">closed (local) market</td><td colspan="3">open market</td><td colspan="4">closed (local) market</td></tr>
<tr><td colspan="3">full employment</td><td>unempl</td><td colspan="6">full employment</td></tr>
<tr><td colspan="11">Implications for specific model variables</td></tr>
<tr><td>Payment as a fraction of market rents</td><td>endog</td><td colspan="7">fixed</td><td>endog</td><td>fixed</td></tr>
<tr><td>Rents</td><td colspan="5">endogenous</td><td colspan="2">fixed</td><td colspan="3">endogenous</td></tr>
<tr><td>Program Area</td><td colspan="10">fixed</td></tr>
<tr><td>Food prices / external food supply</td><td colspan="2">endog / fixed</td><td colspan="8">fixed / endogenous</td></tr>
<tr><td>Internal supply of labor</td><td colspan="3">fixed</td><td>endog</td><td colspan="6">fixed</td></tr>
<tr><td>Wages</td><td colspan="3">endogenous</td><td colspan="3">fixed</td><td colspan="4">endogenous</td></tr>
<tr><td>External commuting Labor demand</td><td colspan="4">fixed</td><td colspan="2">endogenous</td><td colspan="4">fixed</td></tr>
<tr><td>Internal migrant labor supply</td><td colspan="10">endogenous</td></tr>
<tr><td>Total supply of land / rents</td><td colspan="5">fixed / endogenous</td><td colspan="2">endog / fixed</td><td colspan="3">fixed / endogenous</td></tr>
</table>

Table 2. Household participation and land enrollment in simulated PES program										
Scenario	G	F	E	D	C	A	B	H	I	J
Program participation										
Participating households[1]	58	58	52	33	35	94	94	58	58	
Participants enrolling > 0.5 ha[2]	4	4	4	6	6	4	4	4	4	4
Land enrollment										
Potential local supply of land[3]	111	111	97	82	81	1000	1000	119	119	
Absentee landowner supply[3]	0	0	3	18	19	0	0	0	0	

1. As a percentage of total village households.
2. As a percentage of total local participants
3. As a percentage of program goals.

Table 3. Percentage effects of program implementation on the local economy										
Scenario	G	F	E	D	C	A	B	H	I	J
Crops										
Price[1]	1.3	1.3						*10*	*10*	*10*
Total output	-1.9	-1.9	-3.2	-9.1	-8.6	0.35	0.13	0.68	0.68	3.8
Subsistence farm output	-0.98	-0.98	0.34	-1.2	-0.26	0.44	0.17	-3.6	-3.6	-3.9
Commercial farm output	-4.1	-4.1	-12	-29	-29	0.00	0.00	11	11	23
Local market output	-5.4	-5.4	-22	-52	-54	-0.12	-0.65	24	24	46
External purchases			2.8	8.2	9.6	0.46	0.78	-9.6	-9.6	-12
Factors										
Wages	0.07	0.07	-2.6				0.9	7.1	7.1	10
Rents	14	14	7.1	2.7	3.4			21	21	13
Surplus rents	2.7	-3.3	2.7	7.1	6.4	10	10	-9.3	2.7	0.00
Internal labor demand				-1.8	-3.7	0.37				
Internal land demand						0.004	0.01			
Nominal income										
All households	0.51	0.39	-0.94	-0.84	0.25	0.43	0.86	3.8	4.0	5.0
Subsistence farmers	0.46	0.34	-0.93	-0.81	0.25	0.42	0.84	3.6	3.8	4.8
Commercial farmers	1.4	1.4	-1.1	-1.3	0.32	0.62	1.3	6.8	6.8	8.0
Program participants	0.58	0.39	-0.89	-0.66	0.47	0.45	0.89	3.8	4.0	
Non-participants	0.39	0.39	-1.01	-0.99	0.09	0.03	0.27	3.9	3.9	
Landlord	3.6	1.4	1.7	3.8	4.3	0.51	0.91	4.5	7.3	5.3
Real income										
All households	0.01	-0.10	-0.72	-0.91	0.19	0.43	0.71	0.93	1.1	1.8
Subsistence farmers	0.00	-0.11	-0.70	-0.87	0.17	0.42	0.69	0.8	0.96	1.7
Commercial farmers	0.20	0.19	-1.1	-1.3	0.32	0.62	1.3	3.2	3.2	4.4
Program participants	0.19	0.00	-0.66	-0.70	0.4	0.45	0.75	0.94	1.2	
Non-participants	-0.24	-0.24	-0.8	-1.1	-0.02	0.03	0.17	0.91	0.91	
Landlord	3.5	1.4	1.7	3.6	4.1	0.51	0.81	1.2	3.9	1.4

1. Exogenous price changes in *italics*.