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OBJECT EVALUATION FOR SUSTAINABLE RURAL DEVELOPMENT  
PLAN SIERRA IN THE DOMINICAN REPUBLIC

DEPARTMENT OF AGRICULTURAL AND  
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DEPARTMENT OF AGRICULTURAL AND RESOURCE ECONOMICS  
DIVISION OF AGRICULTURE AND NATURAL RESOURCES  
UNIVERSITY OF CALIFORNIA AT BERKELEY

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**PROJECT EVALUATION FOR SUSTAINABLE RURAL DEVELOPMENT:  
PLAN SIERRA IN THE DOMINICAN REPUBLIC**

by

Alain de Janvry  
Elisabeth Sadoulet,  
and  
Blas Santos

California Agricultural Experiment Station  
Giannini Foundation of Agricultural Economics

July 1994

**Project Evaluation for Sustainable Rural Development:  
Plan Sierra in the Dominican Republic<sup>1</sup>**

**ALAIN DE JANVRY**

*Department of Agricultural and Resource Economics,  
University of California, Berkeley, California 94720*

**ELISABETH SADOULET**

*Department of Agricultural and Resource Economics,  
University of California, Berkeley, California 94720*

**AND**

**BLAS SANTOS**

*Plan Sierra, Apartado Postal 1152, Santiago de los Caballeros, Dominican Republic*

**Proposed running head: Project Evaluation: Plan Sierra**

**Correspondence should be addressed to:**

**Alain de Janvry, Department of Agricultural and Resource Economics, University of  
California, Berkeley, CA 94720. Tel: 510-642-3348. Fax: 510-643-8911. E-Mail:  
alain@are.berkeley.edu.**

## **ABSTRACT**

A methodology of project appraisal combining the criteria of economic feasibility, acceptability, and sustainability is developed and applied to Plan Sierra, a watershed development project in the Dominican Republic. Feasibility is measured by the change in sustainable income due to the project; acceptability by the change in average annual income for the present generation; and sustainability by the difference between changes in sustainable and average annual incomes. These three criteria may be achieved by schemes of tax and subsidy between project and non-project households and between present and future generations.

## **KEYWORDS**

Sustainability, project evaluation, watershed development

Including in project evaluation the dimensions of environmental impact assessment (EIA) and sustainable development assessment (SDA) not only places new constraints on project design, but also can help create new opportunities by enhancing the resource base for rural development initiatives. Projects with external costs and negative impacts on the welfare of future generations have led to the systematic undervaluation of costs associated with the use of natural capital in the project itself. Internalizing these costs in the project and forcing on the project a sustainability constraint clearly restrict the scope of feasible projects. New opportunities derive from the fact that potential gainers outside the project target population, either in space (externalities) or in time (sustainability), can be taxed of part of the gains which rural development projects may create for them. When transferred to the target households in the project under the form of subsidies, these taxes can help create incentives for households to engage in enterprises which would not otherwise be attractive to them. As a consequence, the scope for socially beneficial rural development may be enhanced.

The challenge in pursuing these possibilities is in the design of an evaluation methodology and in the implementation of rural development initiatives constructed on these principles. This is what we explore in this paper. We first develop a set of theoretical concepts to be used for the environmental appraisal of projects. We then apply them to the evaluation of Plan Sierra, a rural development and watershed management project in the Dominican Republic which seeks to reduce rural poverty, mitigate externalities created by soil erosion, and enhance sustainability. We conclude with recommendations for the successful implementation of such projects.

## **I. THEORETICAL CONCEPTS OF PROJECT EVALUATION FOR SUSTAINABLE DEVELOPMENT**

### **Dimensions of project evaluation**

For projects that make use of natural capital, project evaluation needs to be carried out in three dimensions that require separate accounting exercises:

i) *Economic and financial assessment of projects (EFA)*: This is the traditional component of project appraisal. It is measured by the net present value (NPV) of the stream of benefits and costs--and by the internal rate of return (IRR)--of the project at market prices for the agents in the project. Benefits can include not only the commercial and use values of resources but also their option and existence values for the agents in the project. Financial assessment consists in verifying ability to repay the loan by the borrowing agencies.

ii) *Environmental impact assessment (EIA)*: Focus is on the externalities created by the project, for instance on the non-target populations within the project area or in other regions, and on the internalization of these externalities. For projects that generate positive externalities, for instance reduction of a flow of pollution, pro-active EIA can be used to identify gains that can be taxed and transferred as subsidies to the project households in order to potentially achieve incentive compatibility with project goals.

iii) *Sustainable development assessment (SDA)*: Focus is on intergenerational equity in the incidence of gains from the project. Sustainable development puts a constraint on the way in which the present generation of decision makers uses natural capital so that it does not predetermine future generations, as a consequence of its actions, to a level of welfare that is necessarily lower than that achieved by itself [11]. Since the sustainability constraint is a matter of ethics as opposed to efficiency (which is the case for EFA and EIA), creating acceptability of the sustainability constraint is a key issue for implementation.

These three dimensions of project appraisal can be combined by charging the externality and sustainability taxes to the private accounting of NPV in EFA. If there are price distortions or if the social discount rate is below the market interest rate, these calculations can be done at social prices as well.

## Project-level definition of sustainability

Several approaches have been pursued to implement the concept of sustainability. One is through the ethics of intergenerational welfare where disinterested altruism across generations would imply behavior by the current generation as though there was a zero discount rate and no substitution between the welfare of successive generations. Another is through an intergenerational fund where transfers through tax, capitalization of a fund, and subsidy can compensate future generations for the depletion of natural capital by the current generation and insure a constant flow of welfare [5]. Finally, sustainability can be achieved through non-declining capital stocks, where the stock includes natural, man-made, and human capital [8]. In this paper, we use the concept of an intergenerational fund to establish which recommendations meet the criterion of sustainability and, for those which do not, what is the level of taxation that would need to be imposed on the current generation.

Two concepts of time have been used to introduce the sustainability criterion in project evaluation. The first looks at future time as continuous, that is, without introducing discontinuities from one generation of decision makers to the next [9]. The second, by contrast, breaks future time in lumps of 20 to 25 years that correspond to the succession of decision makers belonging to overlapping generations [11]. This second approach introduces the arbitrariness of having to define the time lapse between generations. It has the advantage of allowing a generation of decision makers within its own time span to manage natural capital free of the sustainability constraint, for as long as these resources are surrendered, at the end of their own generation, in such a shape as to insure sustainability for the next generation of decision makers. This gives current decision makers the flexibility of eventually depleting resources in the short run to subsequently restore them at a sufficient level to achieve sustainability. This clearly requires that a threshold of irreversibility in resource use has not been exceeded, and that whatever investment in restoration of the natural resource stock is necessary to achieve sustainability will be made at the cost of the present generation. In the

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following methodology, we combine the continuous time measurement of annual income with discreet separation of generations to define sustainability in terms of intergenerational equity.

*The sustainability criterion in continuous time*

In continuous time, the concept of sustainability implies that the flow of services derived from the use of natural capital must be constant year after year over an infinite time horizon and that this flow of services is obtained at a constant price (if there is one). Constant quantity and price thus insure intertemporal equity among users, i.e. sustainability. If there is no price involved, sustainability would require a constant yield or a constant level of income achieved in the project. The problem of sustainability originates in the fact that the present generation of decision makers derives an economic rent from the use of natural capital, and that this rent is being eliminated over time by the use which this generation makes of natural capital.

In Figure 1, we analyze the concept of sustainability when it is the income derived from a plot of land that should be maintained over time. Yields fall as soil fertility is being gradually depleted, but there are substitutes to land as a source of income, in particular interest bearing savings accounts. The present value of the stream of annual incomes  $y_t$  as seen from  $t = 0$  and at a discount rate  $r$  is equal to  $NPV(y_t)$ . For any NPV, there always exists a corresponding constant annual income  $\bar{y}$  such that:

$$\bar{y} = rNPV(y_t),$$

which is the sustainability income.<sup>2</sup> To achieve this income, users of the land pay a tax (or save)  $y_t - \bar{y}$  before  $t^*$  and receive a subsidy (or dissave)  $\bar{y} - y_t$  forever after. In Figure 1, the tax levied on the land before  $t^*$  is equal to area A while the subsidy to users of the land after  $t^*$  is equal to area B. At discount rate  $r$ ,  $NPV(A) = NPV(B)$ .<sup>3</sup> If land users always receive the net income  $\bar{y}$ , and the tax collected before  $t^*$  is invested at interest  $r$ , income sustainability has been achieved even though soil fertility is being depleted over time. Intergenerational equity obtains as the resource rent is equally

shared among all generations of land users. If there are high interest earning opportunities, the sustainability income can be held higher, and land can be depleted faster.

*The sustainability criterion in intergenerational time*

The other approach to implementation of the sustainability constraint consists in: (1) Calculating the present value  $NPV_1$  of an intertemporal economic program that uses natural capital as seen by the present generation at time  $t = 0$ . (2) Calculating the present value  $NPV_2$  of the same economic program starting  $t$  years from now, where  $T$  is the time over which a generation remains as the decision maker. (3) Defining the sustainability constraint as the condition that  $NPV_2 \geq NPV_1$ , i.e., that the value of the economic program as seen from the onset of the second generation remains at least equal to that which was available to the first generation.

Figure 2 illustrates these concepts. The annual income achieved by the program follows the irregular decline ABD over time.  $NPV_1 = NPV(\text{area OAD})$  is the net present value of the complete program as seen at time  $t = 0$ .  $NPV_2 = NPV(\text{area TBD})$  is the net present value of the program evaluated at time  $T$ .

The total income received by the first generation is the difference between these two values, both evaluated at  $t = 0$ :

$$Y_1 = NPV(\text{area OABT}) = NPV_1 - e^{-rT} NPV_2.$$

We assume that there is no credit market on which the household can borrow against the terminal value of the assets in year  $T$ , and hence that only the flow of income during these  $T$  years enters in the definition of income.

By comparison, the sustainability income, when sustainability is defined in continuous generational time, is  $\bar{Y}_1 = (1 - e^{-rT})NPV_1$ . In Figure 2, if the first generation's income differs from the sustainability income, when the second generation takes over the sustainability income has been reduced to  $\bar{Y}_2 = (1 - e^{-rT})NPV_2$ .

If  $NPV_1 > NPV_2$ , the resource depletion tax to be paid at time 0 by the first generation to be transferred as a subsidy to the second generation is such that it must compensate the latter for its NPV loss. This tax is thus defined as:

$$NPV_1 = NPV_2 + e^{rT} \text{ tax},$$

where  $r$  is the interest rate at which the tax paid by the present generation can be deposited until time  $T$  when it will be paid as a subsidy to the second generation. By transferring some income from year 0 to year  $T$  through tax, the net present value  $NPV_1$  does not change but the net present value at time  $T$  has increased to  $NPV_2 + e^{rT}$  tax. The tax paid by the first generation is thus:

$$\text{tax} = e^{-rT} (NPV_1 - NPV_2) = \frac{e^{-rT}}{r} (\bar{Y}_1 - \bar{Y}_2).$$

After tax, the level of income  $Y_1$  achieved by the first generation is equal to:

$$Y_1 = NPV_1 - e^{-rT} NPV_2 - \text{tax} = (1 - e^{-rT}) NPV_1.$$

This level of income is the same as the one that would be achieved when the sustainability tax calculated under continuous time has been imposed. It is equal to the net present value of a constant stream of income  $\bar{Y} = r NPV_1$  between 1 and  $T$ , equal to NPV(EFTO) in Figure 2, which is the income received by the first generation:

$$Y_1 = \int_0^T e^{-rt} r NPV_1 dt = (1 - e^{-rT}) NPV_1.$$

The two approaches, continuous and intergenerational time, thus yield the same intergenerational sustainability tax and income.

#### Appraisal of a project designed to improve sustainability

We address here the issue of a watershed development project where the project households are upstream ( $u$ ) and the externalities are created downstream ( $d$ ). The upstream households are engaged in a set of traditional activities and the project introduces a set of alternative recommended activities. The various impacts of the project are thus the consequences of the changes created by shifts from traditional to recommended activities. Say that, for each traditional and recommended activity, we can assess the following data:

	First generation (1)		Second generation (2)	
	Upstream	Downstream	Upstream	Downstream
Present value	$NPV_1^u$	$NPV_1^d$	$NPV_2^u$	$NPV_2^d$
Average annual income by generation	$y_1^u$	$y_1^d$	$y_2^u$	$y_2^d$
Annual sustainability income	$\bar{y}_1^u = rNPV_1^u$	$\bar{y}_1^d = rNPV_1^d$		

The concepts developed above give us instruments to appraise activities and projects (transitions among activities) according to the following three criteria that need to be jointly satisfied.

i) *Feasibility as an activity or a project*: Feasibility is achieved if net social gains measured by  $NPV_1$  are created by the activity or the transition.

For activities:

Private feasibility:  $NPV_1^u \geq 0$  or  $\bar{y}_1^u \geq 0$ .

For transitions:

Private feasibility:  $\Delta \bar{y}_1^u \geq 0$ .

Social feasibility:  $\Delta \bar{y}_1^u + \Delta \bar{y}_1^d \geq 0$ ,

where  $\Delta$  is the change operator between recommended and traditional activities.

ii) *Acceptability to project households*: Acceptability is achieved if there is incentive compatibility for the adoption of the activity or transition, i.e., if it increases the average annual income of the adopting household over his life span as a decision-maker. Because there is in general no credit market on which the household can borrow against the terminal value of the assets, terminal valuation of the assets does not enter in the calculus of income.

For activities:

Direct acceptability:  $y_1^u \geq 0$ .

For transitions:

Direct acceptability:  $\Delta y_1^u \geq 0$ .

After internalization of downstream externalities:

$$\Delta y_1^u + \Delta y_1^d \geq 0.$$

After internalization of downstream and sustainability gains:

$$\Delta y_1^u + \Delta y_1^d + (\Delta \bar{y}_1^u - \Delta y_1^u) + (\Delta \bar{y}_1^d - \Delta y_1^d) = \Delta \bar{y}_1^u + \Delta \bar{y}_1^d \geq 0.$$

iii) *Sustainability*: Sustainability is achieved if the net social gains from the activity or transition are no smaller for the next generation than they are for the present generation.

For activities:  $NPV_1^u \leq NPV_2^u$  or  $\bar{y}_1^u \leq \bar{y}_2^u$  or  $y_1^u \leq \bar{y}_1^u$ .

For transitions:

$$\text{Direct: } \Delta y_1^u \leq \Delta \bar{y}_1^u$$

$$\text{After internalization of downstream externalities: } \Delta y_1^u + \Delta y_1^d \leq \Delta \bar{y}_1^u + \Delta \bar{y}_1^d.$$

These three criteria of project appraisal can be summarized in Figure 3 where they jointly delineate a triangular area where the three conditions of feasibility, acceptability, and sustainability are satisfied. Use of interregional and intergenerational compensations can be used to attempt to move the upstream income effects into that area, as indicated in by the arrows in Figure 3.

## II. PLAN SIERRA

Plan Sierra was initiated in 1979 with the objective of jointly solving the problems of massive poverty and intense soil erosion in the watersheds of the Dominican Republic above the Cibao valley, the country's most important agricultural area. The Plan itself was motivated by a serious drought in the early 1970s that brought to national consciousness the high levels of malnutrition, poor health, lack of schools and roads, and extensive poverty that prevailed among the region's 110,000 inhabitants. It was also motivated by realization that the program of hydroelectric development started with the Taveras and Bao dams and with a large yet untapped potential (other dams are planned on the Bao and Mao rivers within the area of influence of Plan Sierra) was seriously compromised by rapid sedimentation of the reservoirs. Massive

deforestation had led the Dominican government to close all sawmills in the Sierra in 1967 and to prohibit all cutting of trees, sharply increasing unemployment and poverty. Soil erosion was, however, further intensified by the resulting expansion of slash-and-burn to open food plots (so-called *conucos*), the diffusion of extensive livestock activities on deforested lands, and continued illegal logging.

Plan Sierra is an autonomous civil institution with some 400 employees and a budget initially principally derived from an annual appropriation by the Dominican Congress to the national budget. The Plan focuses on a variety of economic activities including the promotion of ecologically stable *conucos*, reforestation and the sustainable management of existing forests, social forestry schemes, and diffusion of integrated systems of food crops and coffee. Important instruments for this purpose were the organization of grassroots organizations, infrastructure development, experimentation with new technological alternatives for sustainable *conucos*, credit schemes, the subsidized sale of tree seedlings, technical assistance, food-for-work for the adoption of soil conservation techniques, and training programs for community leaders and peasant households. On the social side, the Plan made important advances in the promotion of education with a concern for the ecology of the Sierra and implementation of an effective health program with extensive community participation. The Plan itself was organized with some highly innovative administrative mechanisms including the regional regrouping of technical support in a number of Poles of Development scattered through the region, an intensively participatory internal process of decision making, close consultation with the local grassroots organizations, direct coordination of many of the public services provided to the area, and a frequently revised internal schemes of assignment of responsibilities.

### III. PRIVATE NET BENEFITS OF PLAN SIERRA

Plan Sierra offers households a set of alternatives to the current patterns of land use. Analysis of the private benefits from Plan Sierra thus requires measuring the income gains from transitions from the current to the recommended activities.

## Economic analysis of the traditional cropping sequences

We start with an economic analysis of the private return to the different patterns of land use currently observed in the watershed. These are:

- unmanaged natural forest,
- pasture rented out,
- coffee under tree cover, and
- traditional conuco.

Among these, unmanaged natural forest is not an equilibrium system. Its very low return induces people to convert forests into different cropping systems, starting with slash-and-burn. Hence, for a farmer with access to forest land, three more potential cropping systems are added that give the opportunity cost of natural forests:

- slash-and-burn pasture,
- slash-and-burn conuco, and
- slash-and-burn coffee.

Each of these systems has to be analyzed in a dynamic fashion, as it is characterized by a sequence of land uses, yield levels, and maintenance activities. For example, the traditional conuco system consists in cycles of cultivation and fallow, with yields and lengths of cycles changing as the conuco ages. Similarly, the coffee system has a cycle of growth, maturity, and replacement of the trees. Hence, for each of these systems, the economic value is established from the sequence of annual incomes and expenses which have been calculated over one hundred years.<sup>4</sup> In Table 1 (Section A, Column 1), the net present value of benefits ( $NPV_1^u$ ) of each system is calculated at a 10% discount rate.<sup>5</sup>

Note that, for a farmer with access to a natural forest, the opportunity cost of his land is the highest present value of the different alternatives that are offered to him, i.e., keeping the natural forest, slash-and-burn pasture, slash-and-burn conuco, or slash-and-burn coffee. From the reading of  $NPV_1^u$  for traditional activities in Table 1, we conclude that the maximum profitability is obtained with slash-and-burn conuco,

followed by slash-and-burn coffee wherever it is ecologically possible. The fact that we observe slash-and-burn pastures, however, reflects the existence of other constraints that are not taken into account in a pure profitability calculation at the plot level as done here. A typical situation is that of absentee landlords (usually migrants to New York) who, because it may be difficult to conserve access to one's own land when it has been rented out, prefer to keep their land in direct production with extensive cattle raising supervised by a hired manager. For the farmers whose land is already in pasture, conuco, or coffee, the use of their land is assumed to be optimal for them and the opportunity cost of their land is the net-present value of the activity which they have chosen.

#### Economic analysis of the recommended transitions

Plan Sierra introduced a set of new alternatives for land use which are less erosive than traditional practices. The recommended transitions among sequences of land use are the following:

- from natural forest (and potential slash-and-burn activities) to managed forest,
- from pasture to coffee or planted forest,
- from traditional conuco to coffee or improved conuco.

Evaluation of the private economic worth of each of these transitions is made by comparing the stream of net income generated by the proposed alternative sequence with the stream of net income of the actual sequence. However, for the case of natural forest, the return of a proposed project of managed forest is compared to the opportunity cost of the unmanaged forest, not to the (very low and disequilibrium) return of maintaining this forest.

The improved conuco is the same cropping system traditionally used to produce food for home consumption and sale of the surplus, but it has been improved by introduction of soil conservation practices, use of mulching and composting, with the objective of increasing productivity and eliminating the need for fallow periods, thus offering a land saving technological package. Costs of adoption include soil



conservation practices as well as training in soil conservation and fertility management the first years, technical supervision at least for three years, and credit. Costs and revenues are estimated for one hectare of land.

Comparison of the NPV of the recommended activities with the NPV of the present or potential uses indicates whether each transition is economically feasible or not (Table 1, Section D, Columns 1 and 2). We see that shifting to managed forest for those who have access to natural forest land is feasible, except in comparison to the slash-and-burn conuco option. The slash-and-burn conuco option hence remains a continuing threat to the forest, and special programs need to be designed to prevent its extension. This is an option most frequently chosen by poor households, who either get access to private plots against services rendered to the landowner or squat on common land. For the large landowners themselves, the option of shifting from unmanaged to managed forest is extremely profitable. By law, this option was not available until recently, but Plan Sierra obtained the legal right to re-open forest exploitation in the Sierra under guarantee of its management and supervision.

For those who do not have access to forest land, the coffee option by far dominates any other alternative wherever it is possible. The transition from traditional conuco to improved conuco is also profitable. Reforestation of pastures is, however, not a privately feasible project.

#### **Aggregate economic analysis of the project**

Plan Sierra's future capacity in transforming the region's land use patterns is projected on the basis of its 1980-90 achievements. While the Plan's priorities may be redefined in the future as better information on the private and social worth of alternative transitions becomes available, past activities consisted in converting:

412 ha/year from unmanaged forest to managed forest,

414 ha/year from pasture to planted forest,

412 ha/year from pasture or conuco to coffee,

100 to 124 ha/year from traditional conuco to improved conuco.

This work plan determines the timing of transitions for households in the region. Let us call  $\Delta H_{it}$  the area submitted to transition  $i$  in year  $t$  in response to Plan Sierra interventions. The private economic return from Plan Sierra is the sum of all individual private returns on these transitions. In present value, this gives:

$$NPV_{PS} = \sum_{t=1}^{T_{PS}} \delta^t \sum_i NPV_{it} \Delta H_{it},$$

where  $T_{PS}$  is the projected duration of Plan Sierra,  $NPV_{it}$  is the net present value of an hectare of transition  $i$  in the year  $t$  in which this transition is started,  $\delta$  is the discount factor, and  $\sum_i NPV_{it}$  is thus the net present value of a transition started in year  $t$  evaluated in the first year of Plan Sierra.

The transitions from unmanaged to managed forest have to be assessed against the counterfactual of what would have been done with unmanaged forest in absence of Plan Sierra. We used for this the historical records of deforestation and transition to other activities. Transitions from natural to managed forest were thus disaggregated in probable transitions from the S&B conuco and S&B pasture options as well as from the residual unmanaged forest. The  $NPV_{PS}$  at 10% for the Bao watershed is 11.6 million 1990 RDS (Table 1, Section E) which shows that the highly profitable transitions to improved conuco, coffee, and managed forest largely compensate the cost of reforestation of pastures and the high opportunity cost of transitions from potential slash-and-burn conuco to managed forest. The positive value of the NPV indicates that Plan Sierra is an economically viable project, even without accounting for the external benefits achieved through a decrease in land erosion. This is largely due to the very profitable technological and institutional innovations in conuco and forest management that were introduced by the project.

#### IV. SOCIAL NET BENEFITS OF PLAN SIERRA

##### Erosion from individual plots and Plan Sierra

The Universal Soil Loss Equation (USLE) was adapted to predict erosion corresponding to the different cropping systems and locations. The computed total

potential erosion contribution of each crop in tons/ha/year under average conditions of slope and rainfall is as follows:

Traditional conuco	572.1	Improved conuco	34.7
Pasture	110.7	Unmanaged natural forest	25.1
Fallow	68.7	Planted forest	10.5
Managed natural forest	50.2	National park	8.4
Coffee	40.9		

The traditional conuco is the most erosive of the traditional systems, followed by pasture. Since the area dedicated to conuco has been falling, pasture is, in the aggregate, currently the major contributor to sedimentation. Managed natural forest has a higher erosion rate than planted forest or recommended conuco. The explanation is that most of the remaining natural forests are in lands with a higher propensity to erosion than pasture land, which is the primary land to be planted with forest.

Total erosion in the watershed is the aggregation of erosion from the plots and erosion from the nonagricultural areas (roads, gullies, etc.) and the national park at the top of the watershed. Computation of aggregate erosion from agricultural land hence requires the estimation of land use distribution.

The observed evolution of the distribution in land use between 1950 and 1980 shows dramatic changes. There has been a strong decline of the forest cover from 58% to 21% of the area, decline in conuco area from 20% to 8%, while pasture land occupation grew from 16% to 46% of the area. Extrapolation of these trends have been estimated and used to project the pattern of land use that would prevail if Plan Sierra did not intervene. Distribution of land use under Plan Sierra is calculated on the basis of the planned intervention of Plan Sierra as reported above. Combining these land use patterns with the erosion corresponding to each land use gives the estimated total erosion without and with Plan Sierra.

Among the array of externalities generated by erosion, we only consider the effect of erosion on siltage of the Bao reservoir and its consequences in reducing

hydroelectrical power generation and water for irrigation in the valley downstream. We assess the "social" value of a change in upstream land use patterns by the value generated by the water storage space saved in the reservoir. This analysis has three components: evaluation of the relationship between soil erosion and sedimentation of the reservoir, determination of the length of useful life of the dam, and estimation of the unit value of water in terms of electricity production and irrigation.

#### Delivery of sedimentation to the reservoir and useful life of a dam

In order to relate soil erosion upstream to sedimentation of the Bao reservoir, we need to estimate the long term sediment delivery ratio (SDR, the proportion of erosion generated in any specific year that will ultimately reach the reservoir) and the fraction of erosion that reaches the reservoir within one year ( $a$ , the short term delivery ratio). Based on comparative data with other reservoirs [10] and on measurements of sediment delivery by Rocheleau [6], we estimated these values at  $\text{SDR} = 50\%$  and  $a = 0.195$ .

If the amount of sediments delivered decreases exponentially at a fixed rate  $r$ , the share of erosion that will have reached the reservoir  $t$  years after its production is  $a(1 - r^t)/(1 - r)$ . The proportion of erosion that will eventually reach the reservoir when  $t \rightarrow \infty$  is  $\text{SDR} = a/(1 - r)$ . This yields a value of  $r = 0.61$ . With these numbers, it takes about 17 years for 50% of the erosion to have reached the reservoir, the maximum that will ever arrive. We have estimated that 50% of the sediments delivered to the reservoir in 1989 came from non-agricultural sources.

To calculate the useful life of the dam based on this sedimentation pattern, let  $A_j$  be the sediments emitted from the upstream region in year  $j$  (in tons). The weight of sediments that will reach the dam in year  $t$  is thus  $A_j a r^{t-j}$ . Consequently, the total volume of sediments reaching the reservoir every year is a function of current erosion and of past erosion history:

$$v_t = \sum_{j=t_0}^t k A_j a r^{t-j},$$

where  $v_t$  is the volume of sediments reaching the reservoir in year  $t$  (in  $m^3$ ),  $k = 1.3$  is the conversion factor from ton to  $m^3$ , and  $t_0$  is the initial year, which should be at least 17 years prior to the beginning of the dam.

The accumulated volume of sediments in the reservoir in year  $t$  is then:

$$V_t = \sum_{t'=1}^t v_{t'} = \sum_{t'=1}^t \sum_{j=t_0}^{t'} k A_j a r^{t'-j}.$$

The useful life of the dam  $T_D$  is the number of years of operation before the reservoir gets filled with sediments. Neglecting the possibility of dredging, on which there is yet no experience in the Dominican Republic, the last year of operation is defined by  $V_{T_D} = V_0$ , where  $V_0$  is the useful volume of the reservoir.

We start from the data on total erosion levels with and without Plan Sierra, converted to  $m^3$ . The time count starts in 1965 which is 17 years before 1982, the year when the dam entered in operation. In year 1, some fraction of the sedimentation produced over each of the past 17 years, and which is still somewhere on the way, reaches the reservoir, in addition to 19.5% of the current erosion. Similarly in every successive year, sediment delivery is computed as the sum of fractions of the erosion over the past 17 years and the current year. Comparing the cumulated sedimentation of the reservoir with the useful volume of the reservoir determines the useful lifetime of the dam. We find that, without Plan Sierra, the Bao dam would last 78 years until 2059. Reduction of sedimentation induced by Plan Sierra intervention increases this life-time until 2082, thus gaining 23 years.

#### The economic value of space in the reservoir

The downstream value of the dam operation in year  $t$  can be written  $p_v (V_0 - V_t)$ , where  $p_v$  is the annual economic value generated by  $1m^3$  of storage space in the reservoir. The economic value of space in the reservoir is determined by the irrigation and electrical power generation capacity which it provides. Note that  $1m^3$  of space in the reservoir is not equivalent to  $1m^3$  of water per year, since each  $m^3$  of space will be filled and emptied several times per year, depending on the patterns of rainfall and

outflow of water from the reservoir. Hence a model of the dam's operation is needed to estimate the annual volume of irrigation water  $w_i$  and the electrical power  $w_e$  generated by one  $m^3$  of reservoir space.<sup>6</sup>

The value of irrigation water,  $p_i$ , is the economic value generated by  $1m^3$  of water in irrigation, in this case for the production of rice. It can be computed from the differential profitability of irrigated and dry land rice. Similarly, the value  $p_e$  of the electrical power generated from the dam operation is based on the cost of producing the same electricity with the alternative source used in the country. In this case, the alternative to hydroelectricity is electricity produced from petroleum. Since both rice and oil are imported,  $p_i$  and  $p_e$  are function of the exchange rate ( $e$ ).

The economic value of one  $m^3$  of space in the reservoir is:

$$p_v = w_i p_i + w_e p_e = (w_i p_i^S + w_e p_e^S) e \equiv p_v^S e.$$

The opportunity cost of irrigation water ( $w_i p_i^S$ ) was estimated at US\$2.64 per  $1,000m^3$  per year. Using MODSIM, the effect of the deficits of stored water in reducing hydroelectrical power generation was estimated, and the opportunity cost computed based on the cost of producing the same amount of electricity with petroleum. This opportunity cost, ( $w_e p_e^S$ ) was estimated at US\$3.43 per  $1,000m^3$  per year. Thus:  $p_v^S = \text{US\$}0.0061$ . For 1990, when the parallel exchange rate was around 11 to one, the Central Bank recommended to use an equilibrium exchange rate of DR\$10.50. Thus, the social value of a  $m^3$  of reservoir space was estimated for 1990 as  $p_v = \text{DR\$}0.064$  per year.

#### Social value of Plan Sierra

The downstream value of Plan Sierra is estimated as the increase in the net present value of the dam operation brought about by the project:

$$NPV^d = \sum_{t=1}^{T_D} d^t p_v (V_0 - V_t) - \sum_{t=1}^{T_D'} d^t p_v (V_0 - V_t'),$$

where  $T_D$  and  $T_D'$  represent the dam's lifetime with and without Plan Sierra, and  $V_t$  and  $V_t'$  the volumes of sedimentation with and without Plan Sierra. This gives a net present

value of the positive externality induced by Plan Sierra of RDS2.6 million (Table 1, Section C, Column 3).

Turning to the criterion of sustainability, we see that the NPV of the dam is lower for the future generation ( $NPV_2^d$ ) than it is for the present generation ( $NPV_1^d$ ). This is because a dam, without dredging, is not a renewable resource. Larger benefits are captured in the first 20 years of operation when the reservoir has little siltage. By extending the useful life of the dam, the contribution of Plan Sierra is more than four times larger for the future generation, with an NPV of RDS10.96 million, than it is for the current generation (Table 1, Section C, Column 5). This underscores the role of Plan Sierra in improving the sustainability of the dam. As a project for the downstream, Plan Sierra thus clearly passes the test of sustainability.

#### Externality of a single activity and transition

The downstream value of any specific reduction of erosion upstream depends on the life-time  $T_D$  of the dam, which itself depends on the global reduction of erosion. Hence the value of any specific transition depends on the overall magnitude of Plan Sierra interventions. Considering, however, that none of the specific transitions by itself affects the overall lifetime of the project, the NPV of each transition can be written:

$$NPV^d(\text{at } T_D \text{ given}) = \sum_{t=1}^{T_D} d^t p_v (V'_t - V_t).$$

In addition, when the dam's lifetime is kept constant, the contributions of all the different actions contributing to the reduction of erosion are additive. This is because the volume of sedimentation  $V_t$  is the sum of the sediments delivered from the different sources of erosion.

We estimated the  $NPV^d$  for each activity and transition numerically by calculating (1) the erosion with Plan Sierra and (2) the erosion with Plan Sierra minus one hectare of the activity or with one hectare going through one of the prescribed transitions. The  $NPV^d$  is calculated both for the present generation ( $NPV_1^d$  in Table 1, Column 3) and for the next generation starting  $T$  years later ( $NPV_2^d$  in Column 5).

## V. FEASIBILITY, ACCEPTABILITY, AND SUSTAINABILITY OF PLAN SIERRA RECOMMENDATIONS

We now return to the three criteria of environmental appraisal introduced in this paper: feasibility, acceptability, and sustainability. If a project is not feasible after compensation, it simply cannot be performed. For feasible projects, we will look at the possibilities of achieving acceptability and sustainability as follows:<sup>7</sup>

	Acceptability	Sustainability
Upstream	$y_1^u > 0$ Win $y_1^u < 0$ Loss	$\bar{y}_1^u - y_1^u > 0$ Win $\bar{y}_1^u - y_1^u < 0$ Loss
Downstream	$y_1^d > 0$ Win $y_1^d < 0$ Loss	$\bar{y}_1^d - y_1^d > 0$ Win $\bar{y}_1^d - y_1^d < 0$ Loss

In Table 1, annual incomes are calculated in discrete time. Correspondence with the continuous time formulas established above is as follows:

- i) Average annual income of first generation upstream:  $y_1^u = \frac{r}{1 - 1/(1+r)^T} Y_1^u$ ,  
 where  $Y_1^u = NPV_1^u - \frac{1}{(1+r)^T} NPV_2^u$  is the total income of the first generation upstream.

- ii) Sustainability tax or subsidy, i.e. annual transfer to the first generation to reach sustainability income:

$$\bar{y}_1^u - y_1^u = -\frac{r}{1 - 1/(1+r)^T} \text{tax},$$

where  $\text{tax} = \frac{1}{(1+r)^T} (NPV_1^u - NPV_2^u)$ .

Looking first at the traditional activities one at a time, we see that they are all privately profitable upstream for the present generation (acceptability), which is expected since they would otherwise not be practiced (Table 1, Section A, Column 8). Comparing private profitabilities reveals the great attractiveness of S&B conuco over all other alternatives. All the traditional activities create negative externalities



downstream, with S&B conuco the main source of emission on a per hectare basis (Section A, Column 9). This reveals the conflict between private upstream interests that draw households toward slash-and-burn for food and the social downstream interests for whom this is the pattern of land use with the greatest external cost. Notice, however, that the external losses are small compared to private gains, and these externalities could easily be internalized, were it not for the fact that upstream people are poor. We see that the conuco and pastures do not meet the sustainability constraint upstream (Section A, Column 10). By contrast, natural forest and S&B coffee are sustainable, the first because it produces constant yield with no front end costs, the second because the set up costs have been incurred by the first generation, thus benefiting more the second. None of the traditional activities are sustainable in terms of externalities as the costs of these externalities are higher for the second generation than they are for the first (Section A, Column 11). Patterns of wins and losses are thus as follows:

Slash-and-burn coffee		
	Acceptability	Sustainability
Upstream	W	W
Downstream	(L)	(L)

All other traditional activities	
W	(L)
(L)	(L)

where (L) means that the loss can be compensated by taxing wins and by transfers, either between up and downstream or across generations.

Recommended activities are privately profitable, except for planted forest. Coffee is the most attractive option where it can be grown. These recommended activities all generate external costs, although much lower than traditional activities, particularly for the conuco where an improved conuco has an  $NPV_1^d$  of RDS-91 compared with RDS-675 for the traditional conuco. The upstream gains from these activities are all

sustainable, both because yields are fairly stable and because many of the set up costs have been incurred by the first generation. The external cost, however, continues to increase, indicating that even recommended activities are not socially sustainable. The payoff matrices are thus as follows:

	Planted forest	
	(L)	W
(L)	(L)	0

	All other recommended activities	
	W	W
(L)	(L)	(L)

Again, compensation for losses is feasible. In the case of planted forest, compensation has to be from future generations to the present generation, which raises interesting institutional questions for implementation that we discuss below.

Looking at the transitions recommended by Plan Sierra, we see that neither a managed forest when the opportunity cost is a S&B conuco, which applies particularly to the smaller farmers and sharecroppers, nor the reforestation of pastures are feasible (their IRR are less than 10%). The patterns of wins and losses are as follows:

• Pasture to planted forest and S&B conuco to managed forest

	L	W
W	W	W

In both cases, wins are inferior to losses (infeasibility), making any scheme of compensations to achieve acceptability impossible. This is particularly serious in the case of natural forest whose opportunity cost is S&B. If there forests are to be protected, other justifications need to be found than the private and external gains calculated here. Since taxation of gains for subsidy schemes is impossible, either prohibition or an influx of external resources are needed.

Most of the recommended transitions—S&B pasture to forest, pasture to coffee, conuco to coffee, and conuco to improved conuco—are four-way wins and thus not

problematic to implement. These projects are feasible, acceptable, and sustainable. However, constraints on adoption of these transitions by households may need to be relaxed, such as sufficient access to credit, insurance, and delivery of technical assistance by Plan Sierra.

Transfers are needed in two other transitions. For the transition from unmanaged to managed forest, small downstream externalities for both generations can easily be compensated, each by the corresponding generation, given the high profitability of the switch to forest management. The transition from S&B coffee to managed forest has a payoff matrix as follows:

S&B coffee to managed forest

	W	(L)
W	W	0

In this case a sustainability tax needs to be imposed on present users to compensate the next generation, a tax which can easily be paid.

Finally, Table 1, Section E gives the environmental appraisal of Plan Sierra's activities in the Bao watershed in terms of the planned schedule of recommended transitions. We see that the project is easily feasible, but that it creates losses for the present generation, and thus lacks acceptability as a project for upstream households. This is because the introduction of new activities year after year creates high start-up costs. External gains captured by the present generation are not sufficient to compensate for these upstream losses. Compensation would thus need come from the future generations to compensate the present generation for initiating activities which are highly sustainable, but not to its own benefit. The payoff matrix for Plan Sierra is thus as follows:

Plan Sierra, Bao watershed	
(L)	W
W	W

It would thus be logical for future generations to subsidize the current generation, in order to induce it to undertake the recommended transitions.

## VI. IMPLICATIONS FOR PROJECT DESIGN

We found that, while diffusion of some activities requires active management through taxes and subsidies if they are to be adopted, most of the recommended practices are privately profitable, generate significant social gains, and both upstream and social gains are easily sustainable over several generations. Watershed management increases the downstream value of the dam. For the first generation, it increases NPV from the dam by 1.4% and for the second generation by 9.3%. Because, short of dredging, a dam is a nonrenewable resource, external gains from watershed management will ultimately disappear as the economic value of the reservoir vanishes, but not before having generated significant gains for the downstream households.

Implementing the recommended transitions when they are not directly feasible, acceptable, and sustainable raises important questions of designing institutional mechanisms to achieve the desired solution. If taxes and subsidies are involved, questions of credibility in the continuity of the tax, and monitoring and enforcement in the use of the subsidy for the intended purpose arise. Specifically, we have met the following four situations:

i) Transitions that are not feasible (S&B conuco to managed forest and pasture to planted forest): For the former, prohibition (as currently "enforced" by the National Forest Service), appeal to cultural values, valuation of other benefits and externalities, and transfers of external resources would be needed to prevent deforestation for the establishment of highly profitable S&B conucos. For the latter, subsidies to reforestation of pastures would need to be supported by external resources. Plan Sierra has done this through establishment of a rotating fund for the reforestation of degraded pastures based on a donation of the Swedish Government. Reforestation is easily monitored and enforced by Plan Sierra's direct involvement in the management and supervision of reforestation projects.

ii) Transfers from downstream to upstream (Plan Sierra): To insure credibility in the continuity of taxation, a specific tax could be levied by law on electricity and irrigation water fees to fund watershed management. A bill for this purpose has been introduced several times in the Dominican Congress, but yet unsuccessfully. In the mean time, the subsidy has been transferred through Plan Sierra's technical assistance funded by the national budget and through easily monitorable food-for-work projects for the adoption of soil conservation techniques and reforestation.

iii) Transfers from the present to the next generation (transition from S&B coffee to managed forest): Non-sustainability comes from exploitation by the present generation of a stock of natural capital under the form of unmanaged forest. A sustainability tax can be imposed on the harvesting of trees to subsidize reforestation. Since Plan Sierra is mandated to supervise these operations and charges for its services, this transfer mechanism is easily implemented and verified.

iv) Transfer from the second to the first generation (planted forest, Plan Sierra): Future generations are not present to engage in this type of deal. Long term soft loans of the type extended by IDB (Inter-American Development Bank) and IFAD (International Fund for Agricultural Development) to poor countries like the Dominican Republic can be seen as fulfilling this function on behalf of the next generation: they permit a forward intergenerational transfer of funds that allows the current generation to engage immediately in sustainable activities. These activities have benefits for the next generation which are larger than the costs of these forward transfers. Most of the cost of these loans (typically 40 years with a 10 years grace period and 2% interest rates) are effectively paid by the second generation.

## FOOTNOTES

<sup>1</sup> We are indebted to Alfredo Jimenez, José Elias Sanchez, Loïc Sadoulet, and Inmaculada Adames for their participation to this research and to Plan Sierra and the International Fund for Agricultural Development for financial assistance.

<sup>2</sup> The NPV of the constant income  $\bar{y}$  is: 
$$\text{NPV}(\bar{y}) = \int_0^{\infty} \bar{y} e^{-rt} dt = \frac{\bar{y}}{r}.$$

<sup>3</sup> 
$$\text{NPV}(\bar{y}) = \int_0^{\infty} \bar{y} e^{-rt} dt = \int_0^{\infty} y_t e^{-rt} dt = \text{NPV}(y_t).$$
 Hence, 
$$\int_0^{\infty} e^{-rt} (\bar{y} - y_t) dt = 0.$$
 At time  $t^*$

where  $y_t = \bar{y}$ , 
$$\text{NPV}(A) = \int_0^{t^*} e^{-rt} (y_t - \bar{y}) dt = \int_0^{t^*} e^{-rt} (\bar{y} - y_t) dt = \text{NPV}(B).$$

<sup>4</sup> Full details on these calculations are given in [7] and [2].

<sup>5</sup> We follow here the tradition of Pearce, Markandya, and Barbier [5] in using consistently the financial interest rate as the discount rate. Prices are adjusted to their shadow equilibrium values and the sustainability condition imposed explicitly as opposed to seeking to account for it through an adjustment of the discount rate. Use of different discount rates would evidently affect the intertemporal structure of each sequence (see [1]). Here, we assume that these sequences have been optimally determined at the 10% discount rate.

<sup>6</sup> Jorge [3] estimated values of  $w_i$  and  $w_e$  with the simulation model MODSIM developed by the University of Colorado, using data from the Valdesia Dam which is adjacent to Bao and has similar characteristics.

<sup>7</sup> We use average annual incomes over a generation instead of total generational incomes because the lengths of crop cycles differ and we do not always reach a completed cycle in year 20. We make generational cutoffs coincide with the end of cycles closest to 20 years.

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Table 1. Feasibility, Acceptability, and Sustainability of Plan Sierra Recommendations

	Types of Evaluations*					Criteria for project appraisal										
	EFA		EIA		SDA		Feasibility			Acceptability			Sustainability			
	Private profitability		Externality		Sustainability (next generation)		Annual sustainable income			Annual income of first generation			Annual transfer to first generation for sustainable income			
	1	2	3	4	5	Private	Externality	Private	Externality	Private	Externality	Private	Externality	Private	Externality	
	NPV <sup>1</sup>		NPV <sup>3</sup>	NPV <sup>2</sup>	NPV <sup>4</sup>	upstream	downstream	upstream	downstream	upstream	downstream	upstream	downstream	upstream	downstream	
A. Traditional Activities (1990 RD\$ per ha)																
S&B conuco	15,033		-675	5,490	-1,823	1,503	-67	1,652	-49	-149	-18					
Established conuco	4,660		-675	2,749	-1,823	466	-67	508	-42	-42	-25					
S&B pasture	3,465		-450	400	-1,023	347	-45	369	-41	-23	-4					
Established pasture	1,520		-261	401	-797	152	-26	172	-17	-20	-9					
Natural forest	2,400		-59	2,399	-181	240	-6	240	-4	0	-2					
S&B coffee	9,183		-314	14,860	-555	918	-31	830	-28	89	-4					
B. Recommended Activities (1990 RD\$ per ha)																
Managed forest	11,696		-118	16,261	-361	1,170	-12	1,090	-8	80	-4					
Planted forest	610		-25	16,604	-76	61	-2	-218	-2	279	-3					
Improved conuco	10,369		-91	23,521	-261	1,037	-9	831	-6	205	-3					
Improved coffee	27,950		-194	52,453	-413	2,795	-19	2,191	-14	604	-5					
C. Bao Dam (1000 RD\$ of 1990)																
Without Plan Sierra			178,301		124,777			17,830		18,765						
With Plan Sierra			180,854		135,736			18,085		18,873						
Value of Plan Sierra			2,553		10,960			255		109						
D. Recommended Transitions (1990 RD\$ per ha)																
	ANPV <sup>1</sup>	IRR	ANPV <sup>3</sup>	ANPV <sup>2</sup>	ANPV <sup>4</sup>	$\Delta y^1$	$\Delta y^3$	$\Delta y^2$	$\Delta y^4$	$\Delta y^1$	$\Delta y^3$	$\Delta y^1 - \Delta y^3$	$\Delta y^3 - \Delta y^2$	$\Delta y^2 - \Delta y^4$	$\Delta y^4 - \Delta y^1$	
For farmers with access to forest land: transition to managed forest starting from																
Unmanaged forest	9,297	469.9%	-59	13,862	-181	930	-6	850	-4	80	-2					
S&B pasture	8,231	65.4%	332	15,861	661	823	33	721	33	103	0					
S&B conuco	-3,337	6.6%	556	10,771	1,462	-334	56	-563	42	229	14					
S&B coffee	2,514	66.8%	196	1,401	193	251	20	260	20	-9	0					
For farmers with no access to forest land																
Pasture to planted forest	-910	9.0%	236	16,203	721	-91	24	-390	15	299	8					
Pasture to coffee	26,430	22.2%	67	52,051	383	2,643	7	2,019	3	624	4					
Conuco to coffee	23,290	19.9%	481	49,704	1,410	2,329	48	1,683	28	646	20					
Conuco to improved conuco	5,709	14.4%	583	20,772	1,562	571	58	323	36	247	23					
E. Plan Sierra project in Bao Watershed (1000 RD\$ of 1990)																
	11,612		2,553	102,943	10,960	1,161	255	-433	109	1,595	147					

\* Types of evaluation: EFA = Economic and Financial Appraisal; EIA = Environmental Impact Appraisal; SDA = Sustainable Development Appraisal.  
All NPVs are calculated at the interest rate  $r = 10\%$ .



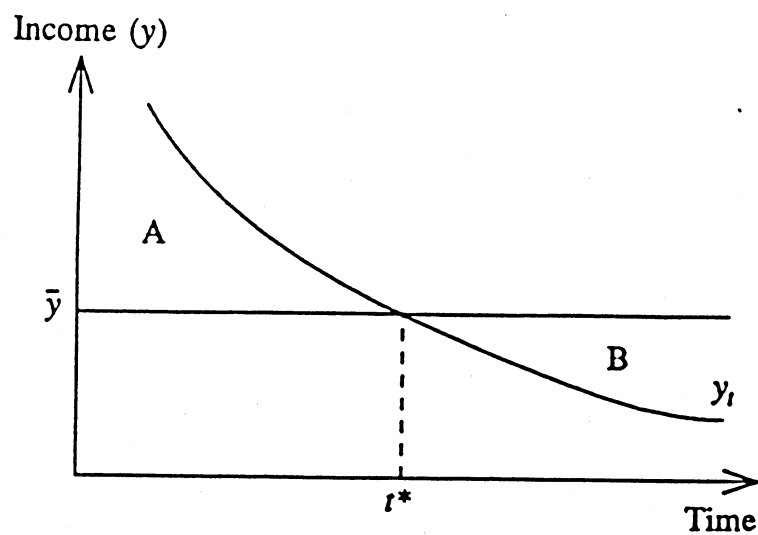


FIG. 1. Sustainability income derived from land

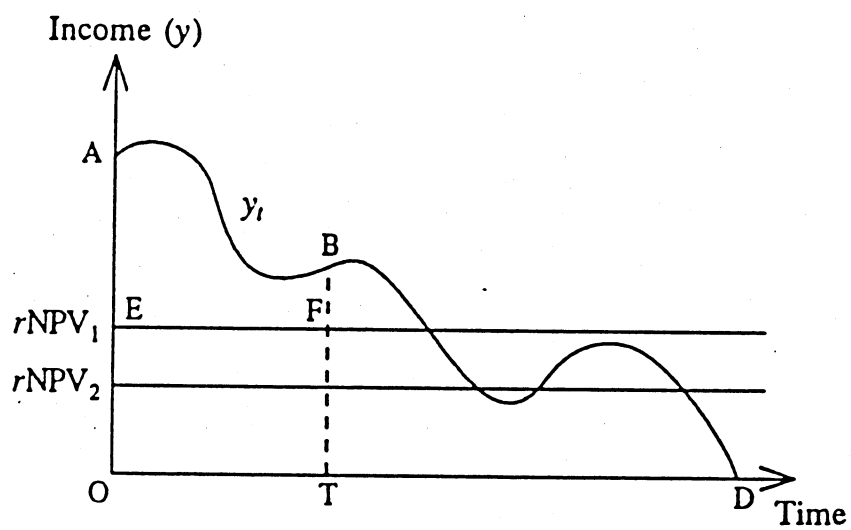
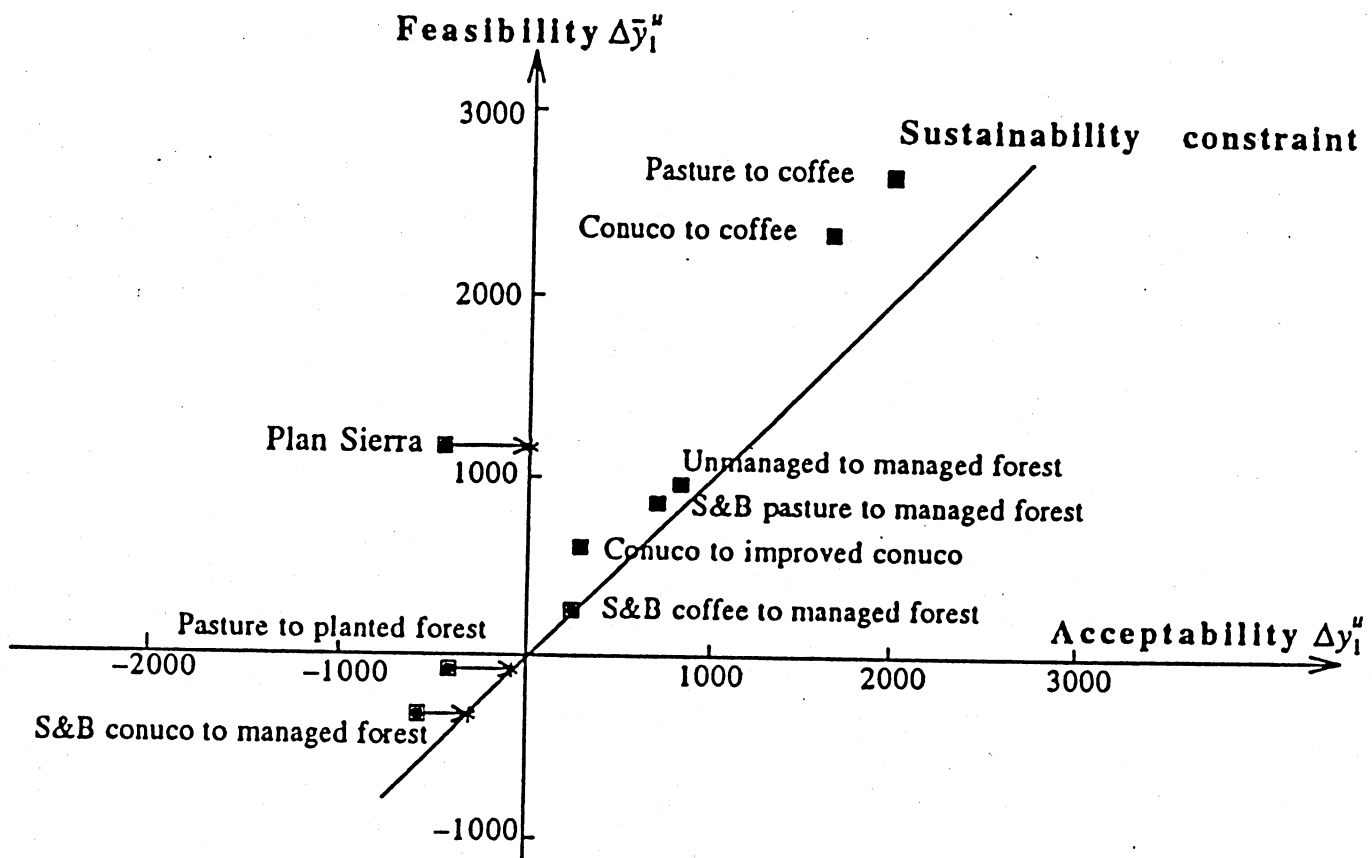


FIG. 2. Sustainability income across generation



Note: Project feasibility requires  $\Delta\bar{y}_1^u \geq 0$ , acceptability  $\Delta y_1^u \geq 0$ , and sustainability  $\Delta\bar{y}_1^u \geq \Delta y_1^u$ . These three constraints are satisfied in the first quadrant above the first diagonal. Tips of arrows represent  $(\Delta y_1^u, \Delta\bar{y}_1^u)$  after internalization of downstream and inter-generational externalities for projects which do not satisfy the feasibility-acceptability-sustainability constraints without compensation.

FIG. 3. Project evaluation under sustainability constraint: feasibility, acceptability, and sustainability of recommended transitions