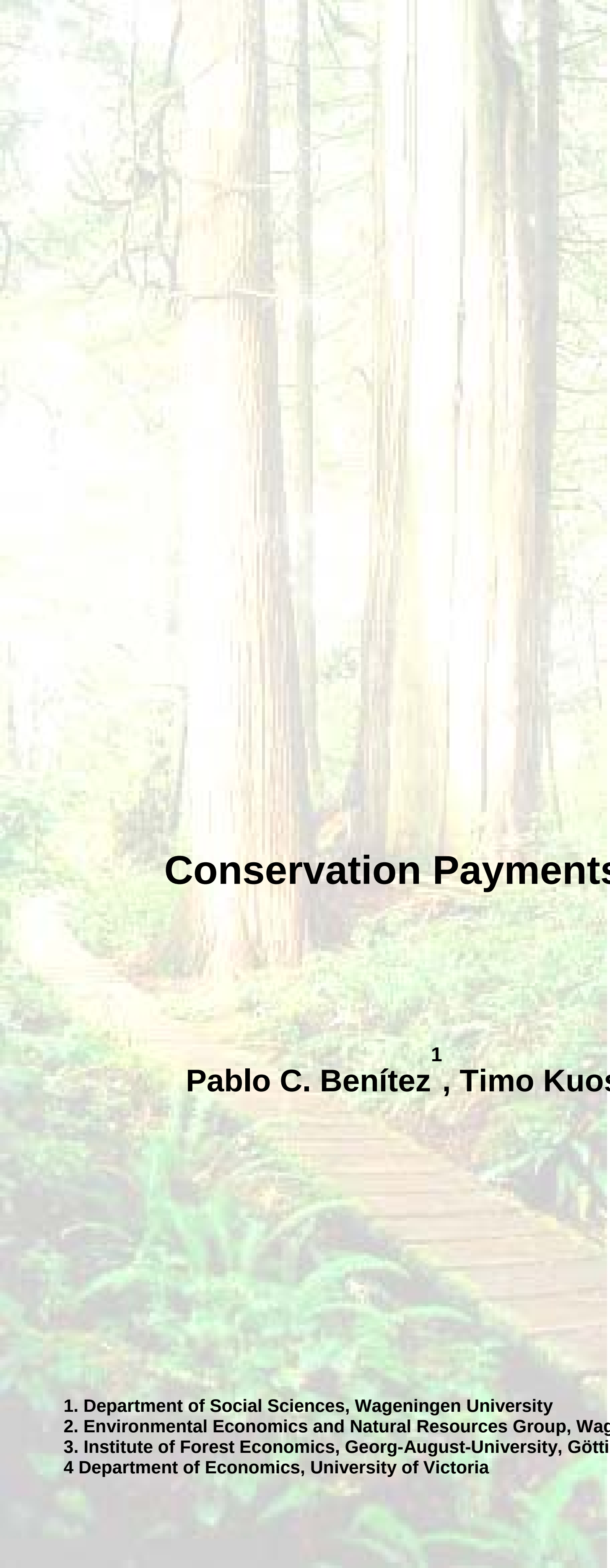

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Conservation Payments under Risk: A Stochastic Dominance Approach

Pablo C. Benítez[1], Timo Kuosmanen[2], Roland Olschewski[3] and G. Cornelis van Kooten[4]

1. Department of Social Sciences, Wageningen University
2. Environmental Economics and Natural Resources Group, Wageningen University
3. Institute of Forest Economics, Georg-August-University, Göttingen
4 Department of Economics, University of Victoria

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REPA Research Group
Department of Economics
University of Victoria PO Box 1700 STN CSC Victoria, BC V8W 2Y2 CANADA
Ph: 250.472.4415
Fax: 250.721.6214
http://repa.econ.uvic.ca

Conservation Payments under Risk: A Stochastic Dominance Approach

Abstract

Conservation payments can be used to preserve forest and agroforest systems in developing countries. To explain landowners' land-use decisions and determine the appropriate conservation payments, it is necessary to focus on risk associated with agricultural price and yield volatility. A theoretical framework is provided for assessing land-use allocation problems under risk and setting risk-efficient conservation payments when returns are not necessary normally distributed. Stochastic dominance rules are used to derive conditions for determining the conservation payments required to guarantee that the environmentally-preferred land use dominates, even when land uses are not considered to be mutually exclusive. An empirical application to shaded-coffee protection in the biologically important *El Chocó* region of West Ecuador shows that conservation payments required for preserving shaded-coffee areas are much higher than those calculated under the assumption of risk-neutrality. Further, the extant distribution of land has a strong impact on the required conservation payments.

Keywords: risk, conservation payments, land allocation, stochastic dominance, agroforest systems, portfolio diversification.

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Introduction

Forests and agroforest systems produce a variety of global benefits, including carbon uptake and biodiversity services. Without payments for these services, forestry might not be an attractive land use for private owners. This is certainly true for shaded coffee in West Ecuador, where cultivated area has been reduced at the expense of temporary crops and pasture. Conversion of shaded-coffee lands to annual crops and/or pasture releases stored carbon to the atmosphere and reduces biodiversity. International payments for carbon storage or biodiversity conservation may help prevent land conversion.

A variety of economic models have been used to evaluate the effect of land-use policies that enhance the environmental services from forests. Econometric approaches have provided insights into the aggregated impact of carbon uptake and conservation policies (Stavins; Deininger and Minten; Plantinga, Mauldin and Miller; Plantinga, Alig and Cheng); general equilibrium models have been used for predicting changes due to environmental payments (Callaway and McCarl); and optimal control models have strengthened knowledge concerning mitigation of climate change through forestry (Sohngen and Mendelsohn 1998, 2003; van Kooten). The evaluation of conservation policies rarely takes into account risk, a factor that is often decisive in allocating land uses (Collender and Zilberman; Just and Pope). Here we focus on the landowner's allocation problem under risk and evaluate how risk-efficient conservation policies could be implemented for maintaining existing shaded-coffee areas in West Ecuador.

Mean-variance (MV) analysis is a classical approach to risk management (Markowitz). Widely used in the financial world, its application is limited to situations where returns are normally distributed or the decision-maker's utility function is quadratic, conditions not always met when considering forests and other natural resource assets (Heikkinen and Kuosmanen).

MV also fails to show dominance in cases where almost every farmer would prefer one land use over another (Leshno and Levy). Suppose that a landowner is to choose between land uses *A* and *B*, where $\sigma_A > \sigma_B$. No matter how much greater E(*A*) is than E(*B*), the MV approach is unable to tell us that *A* is unambiguously better than *B*. It is unable to recommend a (risk-free) conservation payment that would make the landowner choose land use *A* over *B*.

An alternative to MV analysis is the more general choice rule based on stochastic dominance (SD). This technique sets minimum restrictions on landowners' utility functions and is valid for all types of return distributions. While stochastic dominance had been limited in its applicability for solving portfolio problems with diverse options, recent advances have extended possible applications (Shalit and Yitzhaki; Kuosmanen; Post).[1] In this study, we use SD for situations with and without diversification possibilities, in contrast to traditional SD studies where diversification has not being considered (Harris and Mapp; Johnson and Cramb; Williams et al.). We also extend the SD literature on first- and second-order marginal conditional SD and apply the framework to land use in a developing country.

We begin our investigation with a brief review of stochastic dominance rules. We then provide a theoretical framework for the determination of risk-efficient conservation payments under different stochastic dominance criteria. The theoretical model is applied to a West Ecuador case study. The study area is described, relevant data are provided and major findings of the empirical application are discussed. Some conclusions follow.

Stochastic Dominance Rules

Assume that a landowner must decide whether to invest in forestry/agroforestry, *f*, or an alternative crop, *g*, with cumulative net revenue distribution functions given by $F(x)$ and $G(x)$, respectively. Forestry dominates the crop alternative by first-order stochastic dominance (FSD) *iff*,

$$G(x) - F(x) \geq 0, \ \forall x \in \mathrm{R}, \text{ with at least one strict inequality.} \qquad (1)$$

The FSD criterion has an intuitive interpretation in terms of the von Neumann-Morgenstern expected utility theory: if one investment alternative dominates another, every non-satiated investor (with non-decreasing utility function, $U' \geq 0$) will prefer the dominant alternative. While this criterion seems reasonable, it is not very discerning. In practice, the cumulative distributions of net returns of the two investment alternatives often intersect, in which case FSD cannot discriminate between the alternatives.

If investors are risk averse in addition to insatiable (i.e., $U'' \leq 0$ and $U' \geq 0$), second-order stochastic dominance (SSD) could be used to choose between them. Formally, forestry dominates cropping in the SSD sense *iff,*

$$\int_{-\infty}^{x} \left(G(z) - F(z) \right) dz \geq 0 \ \forall x \in \mathrm{R}, \ \text{ with at least one strict inequality} \qquad (2)$$

In words, SSD requires that the area under the cumulative density function for forestry is always smaller than the area under the cumulative density function for the crop. Every risk-averse, non-satiable investor prefers the investment alternative that dominates by SSD.

In empirical analysis, the probability distributions G and F are unknown and must be estimated from available data. Hence, we consider a finite, discrete sample of observations on returns in forestry and a crop alternative over T periods, which we interpret as states of nature. We assume the states are drawn randomly without replacement from a common pool of possible states. States are assumed to be identically and independently distributed such that each observed state is equally likely to occur in any period, and the occurrence of a state in one period does not influence the probability distribution in any other period.

Standard algorithms for identifying stochastic dominance utilize pair-wise comparisons of sorted series of net revenue distributions (Levy 1992, 1998). Denote original time series of net revenues from forestry and cropping by $\mathbf{y}_f$ and $\mathbf{y}_g$, respectively, and the vectors of the re-arranged series sorted in ascending order by $\mathbf{x}_f$ and $\mathbf{x}_g$. Index t is used to indicate elements of the original series vector, while i indicates elements of the sorted series vector. From the sorted revenue series, we construct the cumulative sum vector $\mathbf{x}_f'$ with elements i as,

$$x'_{f,i} = \sum_{k=1}^{i} x_{k,t} \tag{3}$$

Following the same procedure, we get x_g'. We now express the empirical SD rules as follows (Levy 1992):

***FSD**:* Forestry dominates cropping *iff* $x_{f,i} \geq x_{g,i} \; \forall i = 1, \ldots., T$ (4)

***SSD**:* Forestry dominates cropping *iff* $x'_{f,i} \geq x'_{g,i} \; \forall i = 1, \ldots., T$ (5)

with at least one strict inequality holding in both cases.

The pair-wise comparisons of empirical revenue distributions apply to situations where land-use alternatives are mutually exclusive. If the land can be freely proportioned to smaller plots such that different crops are simultaneously cultivated in these plots, the rules based on pair-wise comparisons fail to account for the infinite number of different land-use portfolios. The case of non-exclusive land uses can be seen as example of portfolio diversification. Like any investor, the land owner can hedge the overall risk of the land portfolio by diversifying into different uses so that return fluctuations in different crops can at least partially cancel out.

Using portfolio weights $\mathbf{w} = (w_f, w_g)$ for forestry and cropping, the revenue portfolios are represented by vector $\mathbf{y}_p = w_f \mathbf{y}_f + w_g \mathbf{y}_g$. The key to empirical application of SD rules for portfolio analysis under portfolio diversification is to preserve the cross-sectional structure of revenues, because it is impossible to recover portfolio returns from the sorted revenue series;

for example, $w_f \mathbf{y}_f + w_g \mathbf{y}_g \neq w_f \mathbf{x}_f + w_g \mathbf{x}_g$ (see Kuosmanen). That is, we can always sort the revenue series in a different order, provided that all series are sorted using the same criterion.

Shalit and Yitzhaki and Post propose to sort all revenue series according to the portfolio returns $\mathbf{y}_p$, such that portfolio returns are in ascending order. Denote the resulting sorted portfolio revenue series by $\mathbf{x}_p^{\mathbf{w}}$, and the revenue series for forestry and cropping, sorted according to the portfolio revenues, by $\mathbf{x}_f^{\mathbf{w}}$ and $\mathbf{x}_g^{\mathbf{w}}$, respectively. While elements of $\mathbf{x}_p^{\mathbf{w}}$ are in ascending order, the elements of $\mathbf{x}_f^{\mathbf{w}}$ and $\mathbf{x}_g^{\mathbf{w}}$ are usually not. The rationale of sorting all series according to the portfolio returns is to guarantee that $\mathbf{x}_p = w_f \mathbf{x}_f + w_g \mathbf{x}_g$.

Following Shalit and Yitzhaki, we apply SD rules (4) and (5) to revenue series sorted according to the portfolio revenues rather than separately for each crop, to get the so-called marginal conditional stochastic dominance (MCSD) rules. Again, we form the cumulative sum vectors $\mathbf{x}_f^{\mathbf{w}\prime}$ and $\mathbf{x}_g^{\mathbf{w}\prime}$, as in (3). The first- and second-order marginal conditional stochastic dominance (FMCSD and SMCSD) rules are defined as follows (see Shalit and Yitzhaki):[2]

FMCSD: Forestry dominates cropping *iff* $x_{f,i}^{\mathbf{w}} \geq x_{g,i}^{\mathbf{w}} \;\; \forall i = 1, \ldots., T$ (6)

SMCSD: Forestry dominates cropping *iff* $x_{f,i}^{\mathbf{w}\prime} \geq x_{g,i}^{\mathbf{w}\prime} \;\; \forall i = 1, \ldots., T$ (7)

with at least one strict inequality holding in both cases.

Shalit and Yitzhaki show that if an asset (here forestry) dominates another asset (crop) by SMCSD, then every non-satiated risk averse investor (landowner) will be better off if the portfolio weight of the dominating asset is increased at the expense of the dominated one. One can verify that FMCSD implies that every non-satiated landowner (irrespective of risk preferences) will benefit from an increase in the portfolio weight of the dominating asset at the expense of the dominated one.

Stochastic Dominance for Determining Conservation Payments

Stochastic dominance provides a framework for estimating the conditions under which forestry is a risk-efficient land-use choice. Assume that forests are privately owned with well-established property rights and that landowners have a basic set of common preferences: they maximize expected utility, their utility function is non-satiated and they are risk averse. Under these assumptions, second-order stochastic dominance is the appropriate decision tool for land-use choice. In addition, we need to identify farms' diversification possibilities. SD comparisons of unmixed alternatives might lead to wrong results when they are not mutually exclusive and the correlation coefficients of returns are below a certain threshold value (McCarl et al.).

Empirical evidence of deforestation patterns indicates whether or not diversification exists on a farm. The typical case without diversification possibilities is seen in relatively small farms where fixed costs associated with different crops restrict them to be mutually exclusive. Diversification is seen in the more general situation where landowners divide their initial forest into parcels that are allocated for different uses. We evaluate both possibilities.

Mutually exclusive land uses

Consider the case where a forestland owner faces the possibility of investing in new crops where, given size limitations, she can only plant one crop at a time (land uses are mutually exclusive). Using SD analysis and pair-wise comparisons of forestry with the alternative land uses, three mutually exclusive situations that result in high to low deforestation can be distinguished:

(A) Forestry is not a risk-efficient land use, so at least one land use dominates forestry, and retaining forests is not an option. There is then a high chance that deforestation occurs.

(B) Forestry is a risk-efficient land use, but not the only one. Depending on preferences of individual landowners some farm-forests will be converted and others not.

(C) Forestry is the only risk-efficient land use – forestry dominates all other land uses. This guarantees keeping all existing forests (zero deforestation).

Dominance among A, B and C can be influenced by a conservation payment, s. We determine minimal payments, s_{min}, that guarantee that at least *some* landowners consider forestry as the optimal land use (limiting situations A and B), but payments below s_{min} have no impact. Also, there will be a payment s_{max} where *all* landowners find forestry the optimal land use (limiting situations B and C). Any payments above s_{max} represent an inefficient use of financial resources. In order to find s_{min} and s_{max} under FSD, we recognize that the non-stochastic conservation payment shifts the cumulative distribution function of forestry returns to the right. Thus, each $x_{f,i}$ from forestry is now $x_{f,i} + s$. Using FSD conditions (4), we get (with formal proof in Appendix I):

FSD: $$s_{min}=\min_i(x_{g,i}-x_{f,i}) \text{ and } s_{max}=\max_i(x_{g,i}-x_{f,i}). \quad (8)$$

Similarly, using (5) we get for SSD (see Appendix I):

SSD: $$s_{\min} = \min_i \left(\frac{x_{g,i}{}' - x_{f,i}{}'}{i} \right) \text{ and } s_{\max} = \max_i \left(\frac{x_{g,i}{}' - x_{f,i}{}'}{i} \right). \quad (9)$$

The level of payment for a risk-neutral landowner, for whom $s_{max}=s_{min}=E(x_{g,i}-x_{f,i})$, lies between the FSD limits. The upper and lower bounds in SD analysis emerge due to heterogeneity of landowners' preferences. If all of them had the same utility function, we would have $s_{max}=s_{min}$ based on direct expected utility analysis. If we know little about their utility function, as in FSD, we expect a broad range between s_{max} and s_{min}. Further knowledge of the utility function (e.g., $U'' \leq 0$, making SSD valid) narrows this payment range.[3]

The conditions for s_{min} and s_{max} could be extended to cases where more than one alternative land use exists. By comparing forestry with each of the alternative land uses, we obtain a single s_{max} and s_{min} for each comparison. The overall s_{max} is the maximum of all the individual s_{max} and the overall s_{min} is the maximum of all the individual s_{min}, where s_{min} and s_{max} are measures of the efficiency of land use *f*. Large values of s_{min} represent land uses that are least risk efficient, while small values of s_{max} represent risk-efficient land uses that nearly dominate all other land uses.

Land uses with diversification possibilities

The previous minimum and maximum bounds pertain to the case where all land is assigned to a single use. Applying the previous insights to the FMCSD criteria, we get the following minimum and maximum payments (see Appendix I):

FMCSD: $$s_{\min} = \min_i \left(x^{w}_{g,i} - x^{w}_{f,i} \right) \text{ and } s_{\max} = \max_i \left(x^{w}_{g,i} - x^{w}_{f,i} \right) \tag{10}$$

Similarly, the minimum and maximum payments under SMCSD are (see Appendix I):

SMCSD: $$s_{\min} = \min_i \left(\frac{x^{w}_{g,i}{}' \text{-} x^{w}_{f,i}{}'}{i} \right) \text{ and } s_{\max} = \max_i \left(\frac{x^{w}_{g,i}{}' \text{-} x^{w}_{f,i}{}'}{i} \right) \tag{11}$$

Note the similarity of these conditions with the ones for FSD and SSD, with the only difference that here the series are sorted according to portfolio revenues. The FMCSD (SMCSD) conditions give the minimum and maximum bounds for the conservation payment to guarantee that all non-satiated (and risk averse) landowners have no incentive (marginally) to increase the weight of cropping in the land portfolio. If there is only one alternative crop (*g*), these bounds fully exhaust the diversification options. However, if there are multiple alternative crops (say *g* and *h*), then the bounds should be constructed such that there is no portfolio of alternative crops that dominates forestry in the sense of MCSD.

Since the current portfolio weights are denoted by **w**, we use v_g and v_h as the portfolio weights of crops *g* and *h* in the sub-portfolio that threatens to replace forestry as the land use. To take the diversification options fully into account, we need to solve the following max-min and max-max problems:

FMCSD:

$$s_{\min} = \max_{v_g, v_h}\left[\min_i\left((v_g x^{\mathrm{w}}_{g,i} + v_h x^{\mathrm{w}}_{h,i}) - x^{\mathrm{w}}_{f,i}\right)\right] \text{ and } s_{\max} = \max_{v_g, v_h}\left[\max_i\left((v_g x^{\mathrm{w}}_{g,i} + v_h x^{\mathrm{w}}_{h,i}) - x^{\mathrm{w}}_{f,i}\right)\right] \quad (12)$$

SMCSD:

$$s_{\min} = \max_{v_g, v_h}\left[\min_i \frac{1}{i}\left((v_g {x^{\mathrm{w}}_{g,i}}' + v_h {x^{\mathrm{w}}_{h,i}}') - {x^{\mathrm{w}}_{f,i}}'\right)\right] \text{ and}$$

$$s_{\max} = \max_{v_g, v_h}\left[\max_i \frac{1}{i}\left((v_g {x^{\mathrm{w}}_{g,i}}' + v_h {x^{\mathrm{w}}_{h,i}}') - {x^{\mathrm{w}}_{f,i}}'\right)\right] \quad (13)$$

subject to $v_g + v_h = 1$ and $v_g, v_h \geq 0$. In practice, these bounds can be solved by using linear programming (LP), with the LPs provided in Appendix II.

Case Study: Shaded-Coffee in West Ecuador

The study area is in the province of Manabí, located in the tropical lowlands of west Ecuador. The natural vegetation is a continuation of the *El Chocó*, a bio-geographical region known as one of the world's hotspots of biodiversity because of its species richness, high levels of endemism and stress from human activities (Myers et al.). Primary forests remain mostly in protected areas such as the Mache Chindul Reserve and the Machalilla National Park. Important areas of coffee plantations are found throughout Manabí, which constitutes one of the main areas for coffee production and where all coffee is produced under shade. While state and private actions increasingly protect primary forests, shaded-coffee systems that provide a buffer zone for biodiversity protection are being cleared. Government estimates suggest that coffee plantations have been reduced nationally by about 40% during the last decade (SICA).

We consider four land uses: shaded-coffee, highland rice, maize, and pasture for dairy cows and cattle. Time series for estimating yearly revenues are available for 1967-2002 from several government offices in charge of agricultural statistics. For coffee, rice and maize yield, we have data for 1991-2002 (SICA) and 1967-1990 (MAG), respectively.[4] Since these series correspond to country-level yield data, we convert them to provincial yields based on factors obtained from the 2000 census (INEC, MAG and SICA). For dairy and cattle, we use the assumption of constant yield. This approximation is valid due to the extensive nature of cattle grazing, where weather variability has a small impact on annual cattle growth. Cattle yield is estimated using a method described in Benítez et al. For the stocking density of 1.1 head per hectare found in Manabí province, the estimated growth in cattle live weight yield is 93 kg per year, while a dairy cow in this region yields 2.6 liters of milk per day (INEC, MAG and SICA). Since 41% of the livestock herd consists of dairy cows and 40% of them produce milk, annual production is calculated to be 172 liters/ha.

Producer prices for crops are available for the periods 1991-2002 (SICA) and 1978-1990 (Whitaker, Colyer and Alzamora). For the period 1967-1977, we estimate producer prices as a function of retail prices (INEC). In order to account for inflation and estimate net revenues in real terms, we convert prices into constant US$ for year 2000 based on Ecuador's consumer price index. In 2000, the local currency (*sucre*) was officially eliminated and replaced by the US dollar. Prices before 2000 are first converted into constant (year 2000) *sucre*, and then transformed into US dollars using the 2000 exchange rate; dollar prices after 2000 are converted into constant US dollars using the CPI.

Cost estimates are based on survey data from 2003. For coffee, costs include land preparation, planting, cleaning, pruning and shade control. Land preparation and planting costs are annualized using a discount rate of 5% and a period of 15 years.[5] For annual crops (maize and rice) costs include land preparation, seeds, planting, fertilizer, weeding and pest control. These costs are the same for all years except for seed costs, which depend on annual crop prices. Variable costs include harvest and transport costs. For cattle, costs include brush control, the opportunity costs of cattle stock, cattle losses, vaccines and pest control. The opportunity costs of cattle stock and costs associated with cattle losses also depend on annual (cattle) prices. General farm costs such as administration and fence maintenance are not included, since they have no influence on land-use choice. Based on this information, we estimate net revenues for each year as the product of price and yield minus costs.

Revenue trends

SD analysis is based on the assumption that each observed state of nature is equally likely to occur and that the probabilities do not change over time. This assumption is not valid if revenue follows a time trend, as is the case if crop yield (y) is a function of t:

$$y_t = a + bt + e_t. \tag{14}$$

Then $E(y_T) = a+bT$, for example, in contrast to the assumption that returns are equally likely to occur. However, returns can be de-trended before determining the SD of a series. A series can be de-trended in various ways, including curve fitting, first differencing, digital filtering and piece-wise polynomials, but we employ the most common procedure of curve fitting. We first test for the existence of significant trends in the yields and prices of each of the four land uses by applying the @trend function of E-views to (14).[6] Results indicate that maize yields have a statistically significant (at the 0.05 level of significance) increasing trend and rice prices a decreasing trend.

It is reasonable to expect that the increase in land productivity due to technological improvements (e.g., development of new seeds) has its limits and that yield growth should decrease over time. Nor can prices fall continuously. Therefore, a concave trend function (in our case logarithmic) is used. We test both a linear and logarithmic trend (see Table 1). Diagnostic tests of the residuals include White's heteroskedasticity test, a BP test for autocorrelation, and the Jarque Bera test for normality. Based on R^2 and diagnostic tests of the residuals, we select a linear model for both rice and maize.[7] We de-trend the series by adding the residuals of the linear regression to the expected value of equation (14) at time T. Then we re-estimate net revenues for maize and rice. By coincidence, the series with trends confirm our normality assumption, although, for the general case of non-normality, more comprehensive methods like GMM could be used.

Once the price and yield series are corrected for trend, we estimate net revenues. The descriptive statistics for the net revenue series, including the Jarque-Bera and Shapiro-Wilk tests for normality, are provided in Table 2. Non-normality is particularly evident for coffee and it is caused by both positive skewness and high kurtosis. This motivates the use of the SD approach, which is valid for any type of distribution.

Bootstrapping

Bootstrapping has been used to increase the power of empirical applications of stochastic dominance tests. One of the advantages is that bootstrapping smoothes the cumulative density function (CDF) in ways that mitigate problems associated with obtaining reliable estimates of order statistics (Nelson and Pope). In addition, it allows SD tests to be more discerning since it avoids inadvertent intersection of cumulative distributions.

A simple bootstrapping algorithm based on Nelson and Pope is employed. We first re-sample with replacement from the original empirical distribution function (EDF) and then find the average of each order statistic for computing a new EDF. The number of samples needs to be sufficiently large so that the resulting distribution will not be affected by additional re-sampling. In Figure 1, we provide an indication of the effect that bootstrapping of the coffee series (with 1000 samples) has on the original EDF. Irregularities are eliminated and the bootstrapped distribution is assumed to be the appropriate one for estimating the risk efficient conservation payments under FSD and SSD.

Results and Discussion

We now estimate the risk-efficient conservation payments under conditions of mutually exclusive land uses alternatives and when full portfolio diversification is allowed.

Mutually exclusive land uses

The FSD efficient land-use alternatives can be determined by direct observation of the intersections of the (bootstrapped) EDFs of the different land uses (Figure 2). The EDF for maize is always to the right of that of rice, indicating that maize dominates rice by FSD. Since the EDFs for coffee, pasture and maize all intersect, the FSD efficient set contains these three land uses. To rank the other land uses requires further differentiation, which we do using SSD.

Since maize dominates rice by FSD, it also dominates rice by SSD. Maize dominates coffee and coffee dominates rice by SSD, but there is no dominance relation between maize and pasture. Thus, the SSD efficient set consists of maize and pasture. These results explain some of the land-use choices in the study region. First, the conversion of existing shaded-coffee areas can be explained by the result that this land use is inefficient (under SSD). Second, pasture is the dominant land use in the region even though its expected revenues are lower than those of other land uses (Table 2), but this is justified on the grounds that it is a risk-efficient land use, where the low expected revenues are compensated by smaller variation in revenue.

Finding the risk-efficient payment for conservation requires estimates of s_{min} and s_{max} that, in turn, depend on the alternative land-use opportunities. We calculate the minimum and maximum bounds required to make coffee a risk-efficient land-use alternative, comparing coffee returns separately with each alternative land use. The results are reported in Table 3. Since coffee is FSD efficient, the lower bound s_{min} is equal to zero in the FSD case. The upper bound s_{max} varies annually between \$2/ha and \$55/ha. In the SSD case, the minimum conservation payment is \$30/ha (to break SSD dominance by maize). The maximum payment is \$55/ha, which would suffice to guarantee that coffee dominates all other alternatives.

These payments can be compared with those required under risk-neutrality, where only expected values matter. When the alternative to coffee is pasture, there is no need for a payment under risk-neutral conditions since the mean net return to coffee is higher than that for pasture. However, for all risk-averse landowners to prefer coffee over pasture requires a payment of $55/ha (based on SSD). Such a risk premium represents 70% of the (average) net revenues for coffee. These results stress the need for considering risk when implementing policy instruments aimed at conservation. Given the high variability of coffee revenues, it is risk and not expected values that discourages landowners. While provision of risk-free payments for protecting coffee areas is one strategy, a better one might be to incorporate risk-hedging strategies and insurance possibilities for small farmers, instruments that are slowly being developed in Ecuador's financial markets.

Non-exclusive land uses

The risk-efficient payment under MCSD depends on the current portfolio shares. We test this with an arbitrary, equally-weighted (50-50) portfolio of coffee and maize. To illustrate the concept of FMCSD, a plot of the portfolio (consisting of coffee $\mathbf{x}_f^w$ and maize $\mathbf{x}_g^{\mathbf{w}}$) and component net revenues series is provided in Figure 3 (panel A). (The axes in the figure have been switched to provide a better illustration.) One land use dominates another under FMCSD if there is no intersection of the individual land-use curves. As shown in the figure, both curves intersect, so we conclude that there is no FMCSD between coffee and maize for such portfolio. In panel B, the cumulative series for determining SMCSD are provided. Since the series for maize are always above the ones of coffee, maize dominates coffee by SMCSD. We conclude that second-order dominance does exist.

To obtain better estimates of the efficient conservation payments under the MCSD criteria, we interviewed 92 coffee producers, finding that 35% of them do not diversify their land use. The remainder employ different combinations of land uses that, on average, have the portfolio shares shown in Table 4. As in the case of no diversification, we estimate risk-efficient conservation payments that prevent marginal conversions of shaded-coffee to other uses. These results are also summarized in Table 4, where s_{min} and s_{max} payments under FMCSD and SMCSD are provided.

The results confirm the theoretical expectations. The level of a risk efficient payment depends on the given portfolio shares. The higher the share of coffee, the higher is the required conservation payment. In most of the portfolios analyzed, the payment s_{max} under MCSD is higher than under SSD. Importantly, under SSD and SMCSD, the minimum payment s_{min} is often the difference in expected net returns between coffee and maize. To understand this peculiarity, note that a payment s_{min} requires breaking the dominance of maize over coffee. Since the distribution of coffee has a greater spread than that of maize, this dominance can only be broken by adding a payment that results in both land uses having the same mean. Then maize can never dominate coffee by SSD.

Conclusions

In this article, we extend theoretical contributions for analyzing stochastic dominance tests with fully diversifiable portfolios (Post; Kuosmanen; Shalit and Yitzhaki) by including a first-order MCSD rule. We then apply the theory to the problem of identifying the magnitude of conservation payments needed to prevent land-use change that reduces biodiversity in developing countries. In particular, we introduce the concept of two efficiency measures for evaluating forestland use: (1) the minimum risk-free payment (s_{min}) required to ensure that forestry is not dominated by any other land use; and (2) the minimum risk-free payment (s_{max}) guaranteeing that forestry dominates all other land uses. Large values of s_{min} represent land uses that are least risk-efficient, while small values of s_{max} represent risk-efficient land uses that nearly dominate all other land uses. Knowledge of s_{min} and s_{max} helps to identify intervention strategies – payments for conservation – that can be implemented efficiently.

The methodology is applied to a West Ecuador case study, where shaded-coffee is compared with the most important alternative land uses in the region. Results indicate that (1) shaded-coffee is not a risk-efficient land use, no matter whether diversification is possible or not, which goes a long way towards explaining current land uses. (2) The payments required to preserve shaded-coffee areas are much higher than the compensation payments calculated under the assumption of risk-neutrality. (3) The extant distribution of land uses has a strong impact on the required conservation payment. (4) Land-use policy interventions need to incorporate risk-hedging strategies and insurance possibilities for small farmers, instruments that are slowly developing in Ecuador's financial markets.

Finally, the method for estimating risk-efficient conservation payments presented in this article could also be used to derive cost curves for environmental services. This may be particularly apt in the case of carbon sequestration as the Kyoto Protocol allows trading carbon offsets from forestry and agricultural activities. To derive a carbon uptake cost curve, it is necessary to first define a wide range of possible portfolios and then estimate the carbon level for each portfolio. The higher the share of shaded-coffee, the higher is the amount of carbon that is sequestered. For each portfolio, there is a corresponding level of compensation (or carbon uptake costs), and that information can be used to estimate a supply curve for carbon uptake services. The methodology can be used to examine portfolio diversification in the energy sector, where nuclear, renewable and fossil-fuel sources of energy are possible and portfolio shares are influenced by carbon taxes. These are areas of future research.

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Appendix I

Let f and g be two land uses with sorted net revenues series $x_{f,i}$ and $x_{g,i}$, respectively. We have the following propositions:

Proposition 1a. The payment level that guarantees first-order stochastic dominance of f over g is $s = Max_i(x_{g,i} - x_{f,i})$.

Proof. Denote by f^* the net revenue series of f that includes the conservation payment. FSD requires that $x_{f^*,i} \geq x_{g,i}$, $\forall i$. Since we know that net revenues of f^* equal f plus a non-stochastic payment (s), we have $x_{f^*,i} = x_{f,i} + s$. Replacing this in the previous expression yields $x_{f,i} + s \geq x_{g,i}$, $\forall i$. Thus, $s \geq x_{g,i} - x_{f,i}$, $\forall i$. Since this should hold for every pair-wise comparison on i, the payment needs to be at least as large as the maximum of the differences between $x_{g,i}$ and $x_{f,i}$, or $s = Max_i(x_{g,i} - x_{f,i})$.

Proposition 1b. The payment level that guarantees that f will not be dominated by g by FSD is $s = Min_i(x_{g,i} - x_{f,i})$.

Proof. If f is not to be dominated by g, we require, for at least one pair-wise comparison, that $\exists i \ni x_{f^*,i} \geq x_{g,i}$. This requires that $\exists i \ni s \geq x_{g,i} - x_{f,i}$. If this holds for one pair-wise comparison, f will not be dominated by g by FSD. Thus, $s = Min_i(x_{g,i} - x_{f,i})$.

Proposition 2a. The payment level that guarantees SSD of f over g is $s = Max_i\left(\frac{x'_{g,i} - x'_{f,i}}{i}\right)$.

Proof. SSD requires that $x'_{f^*,i} \geq x'_{g,i}$, $\forall i$. If we add a non-stochastic payment (s) for land use f, we get the cumulative sorted series for f^*: $x'_{f^*,i} = \sum_{t=1}^{i}\left(x_{f,t} + s\right) = \sum_{t=1}^{i} x_{f,t} + i \cdot s = x'_{f,i} + i \cdot s$.

Replacing the latter expression in the former gives $x'_{f,i} + i \cdot s \geq x'_{g,i}$, and $s \geq (x'_{g,i} - x'_{f,i})/i$, $\forall i$.

Thus, $s = Max_i\left(\frac{x'_{g,i} - x'_{f,i}}{i}\right)$.

Proposition 2b. The payment level that guarantees that *f* would not be dominated by *g* in second degree is $s = Max_i\left(\frac{x'_{g,i} - x'_{f,i}}{i}\right)$.

Proof. The proof follows the same reasoning as for 1b and 2a. Since we just need one *i* where $s \geq (x'_{g,i} - x'_{f,i})/i$ holds, the minimum of the differences is enough.

The proofs for the $s_{\min}$ and $s_{\max}$ conditions in the cases of FMCSD and SMCSD follow the same line of reasoning as in the preceding propositions, but use the series sorted according to revenue portfolios ($\mathbf{w}_f^w, \mathbf{w}_g^w$) instead of ones sorted by individual land-use revenue portfolios ($\mathbf{x}_\mathrm{f}$, $\mathbf{x}_\mathrm{g}$).

Appendix II

We find $s_{\min}$ under FMCSD and SMCSD by solving the following LPs:

FMCSD

$$s_{\min} = \max_{\sigma, v_g, v_h} \sigma$$
$$s.t.$$
$$\sigma \leq \left((v_g x^{\mathrm{w}}_{g,i} + v_h x^{\mathrm{w}}_{h,i}) - x^{\mathrm{w}}_{f,i} \right) \quad \mathrm{i} = 1, \ldots, T$$
$$v_g + v_h = 1 \quad \text{and} \quad v_g, v_h \geq 0$$

SMCSD

$$s_{\min} = \max_{\sigma, v_g, v_h} \sigma$$
$$s.t.$$
$$\sigma \leq \frac{1}{i}\left(\left(v_g x^{\mathrm{w}}_{g,i}{}' + v_h x^{\mathrm{w}}_{h,i}{}' \right) - x^{\mathrm{w}}_{f,i}{}' \right) \quad \mathrm{i} = 1, \ldots, T$$
$$v_g + v_h = 1 \quad \text{and} \quad v_g, v_h \geq 0$$

Since σ is constrained to be less than or equal to the objective of the original max-min problem ∀ *i* = 1,…,*T*, and since at least one of the inequalities must be binding in the optimal solution, σ represents the minimum bound. Thus, setting portfolio weights v_g and v_h to maximize σ will give the solution to the max-min problem.

The objective function for the max-max problem is linear, so the LP solution gives the extreme values $v_\mathrm{g} = 1$ and $v_h = 0$, or vice versa. Thus, the maximum bound ($s_{\max}$) is calculated in two steps. First, make a pair-wise comparison between forest and all other crops and find $s_{\max}$ for each comparison, following equations (10) and (11). Then, choose the larger $s_{\max}$.

Table 1. Tests for Trends in Series for Rice Price and Maize Yield, Manabí, 1967-2002.

Model	R^2	White hetero., no cross terms, p-value	BP test, 2 lags, p-value	J. Bera test, p-value
Rice_price				
Linear trend	0.407	0.376	0.08	0.069
Logarithm trend	0.278	0.611	0.01*	0.173
Maize yield				
Linear trend	0.658	0.00004*	0.2	0.394
Logarithm trend	0.492	0.034*	0.0048*	0.01*

*Significant with 5% confidence level

Table 2. Summary Statistics for Net Revenues Series of Land-use Systems in Manabí, 1967-2002.

	Coffee	Maize*	Rice*	Pasture
Mean (2000 US$/ha)	78	108	57	53
Standard Deviation (2000 US$/ha)	86	56	61	18
Skewness	1.6	0.5	0.7	0.7
Kurtosis	6.5	3.5	2.8	2.3
Jarque-Bera p-value	0.000	0.4	0.2	0.2
Shapiro-Wilk. p-value	0.01	0.5	.07	0.01

* De-trended series

Table 3. Minimum and Maximum Conservation Payments Required to make Coffee a Risk-efficient Land Use (Year 2000 US$ per ha)

Decision criteria	Land use alternative to coffee					
	Maize		Rice		Pasture	
	s_{min}	s_{max}	s_{min}	s_{max}	s_{min}	s_{max}
FSD	0	53	0	2	0	55
SSD	30	48	0	0	0	55
Difference in means (Risk neutrality assumption)	30	30	0	0	0	0

Note: A value of zero is assigned when the estimated payment is negative.

Table 4. Required Payments for Shaded-Coffee Conservation based on Responses from 60 Interviewed Coffee Producers with Diversified Farms (Year 2000 US$ per ha)

Land-use shares of representative farms	Decision rule			
	FMCSD		SMCSD	
	s_{min}	s_{max}	s_{min}	s_{max}
Farms with two land-uses				
Coffee: 56%; Pasture: 44%	0	77	0	73
Coffee:55%; Rice:45%	0	107	0	46
Coffee: 79%; Maize: 21%	0	204	30	104
Farms with three land-uses				
Coffee: 36%; Rice: 11%; Pasture: 53%	0	107	0	74
Coffee: 47%; Maize: 15%; Pasture: 38%	0	204	30	104
Coffee: 68%; Maize: 20%; Rice: 12%	0	204	30	104
Farms with four land-uses				
Coffee: 34%; Maize: 6%; Rice:9%; Pasture: 51%	0	204	30	111

Note: A value of zero is assigned when the estimated payment is negative.

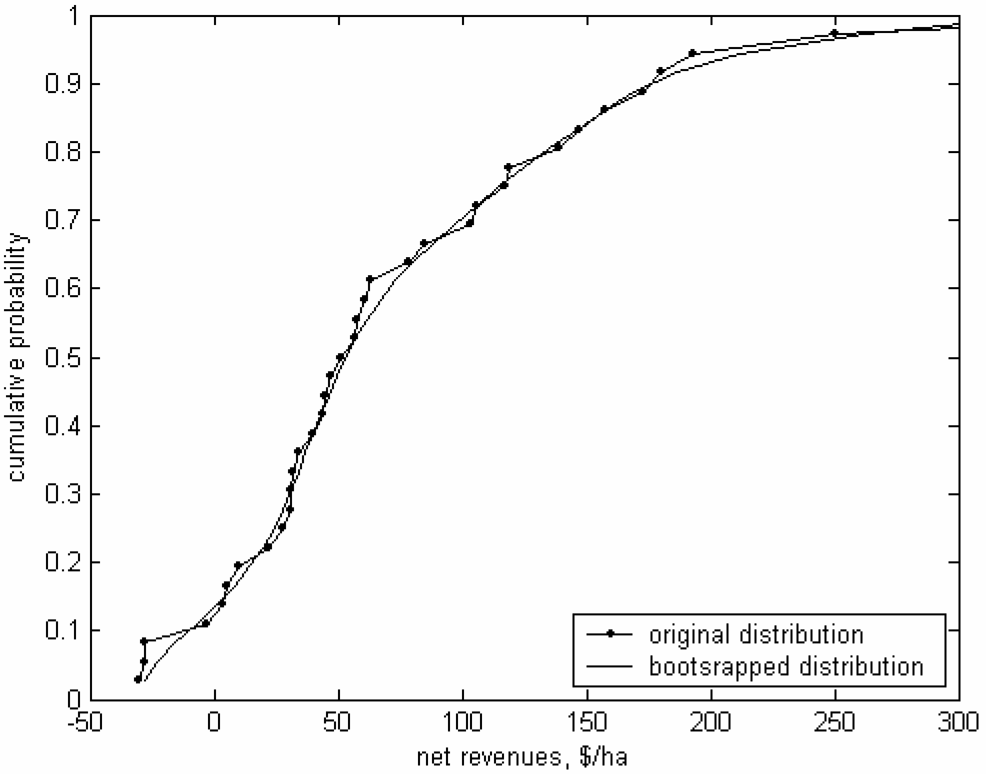

Figure 1. Original and Bootstrapped EDFs for Coffee

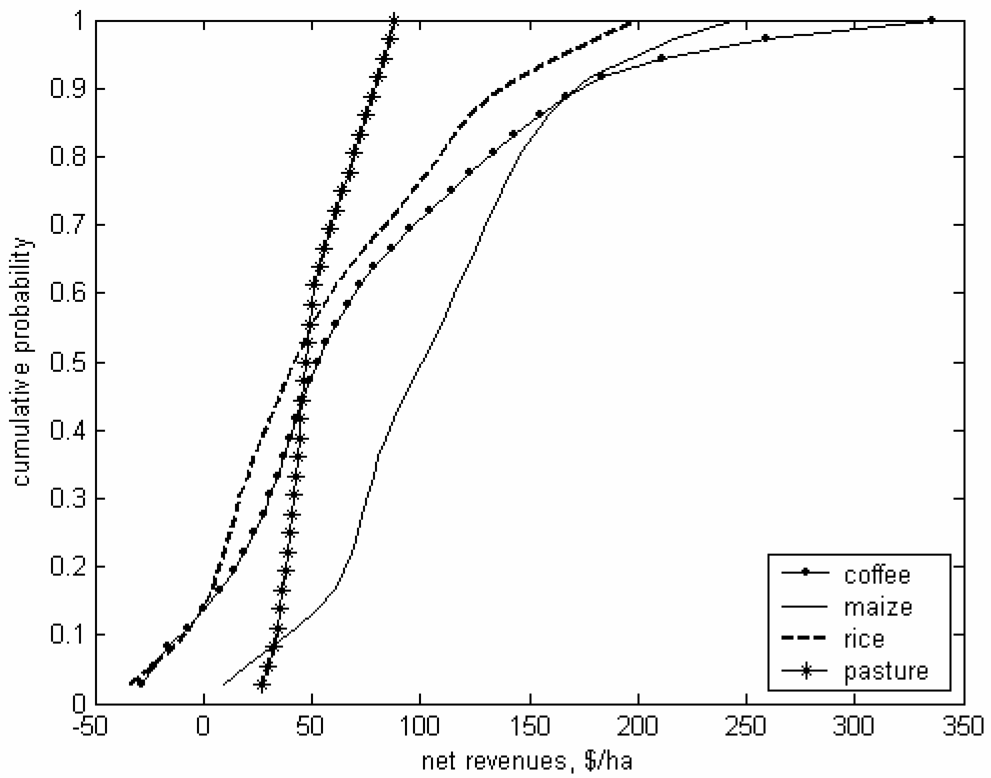

Figure 2. Bootstrapped EDFs for Major Land Uses in West Ecuador

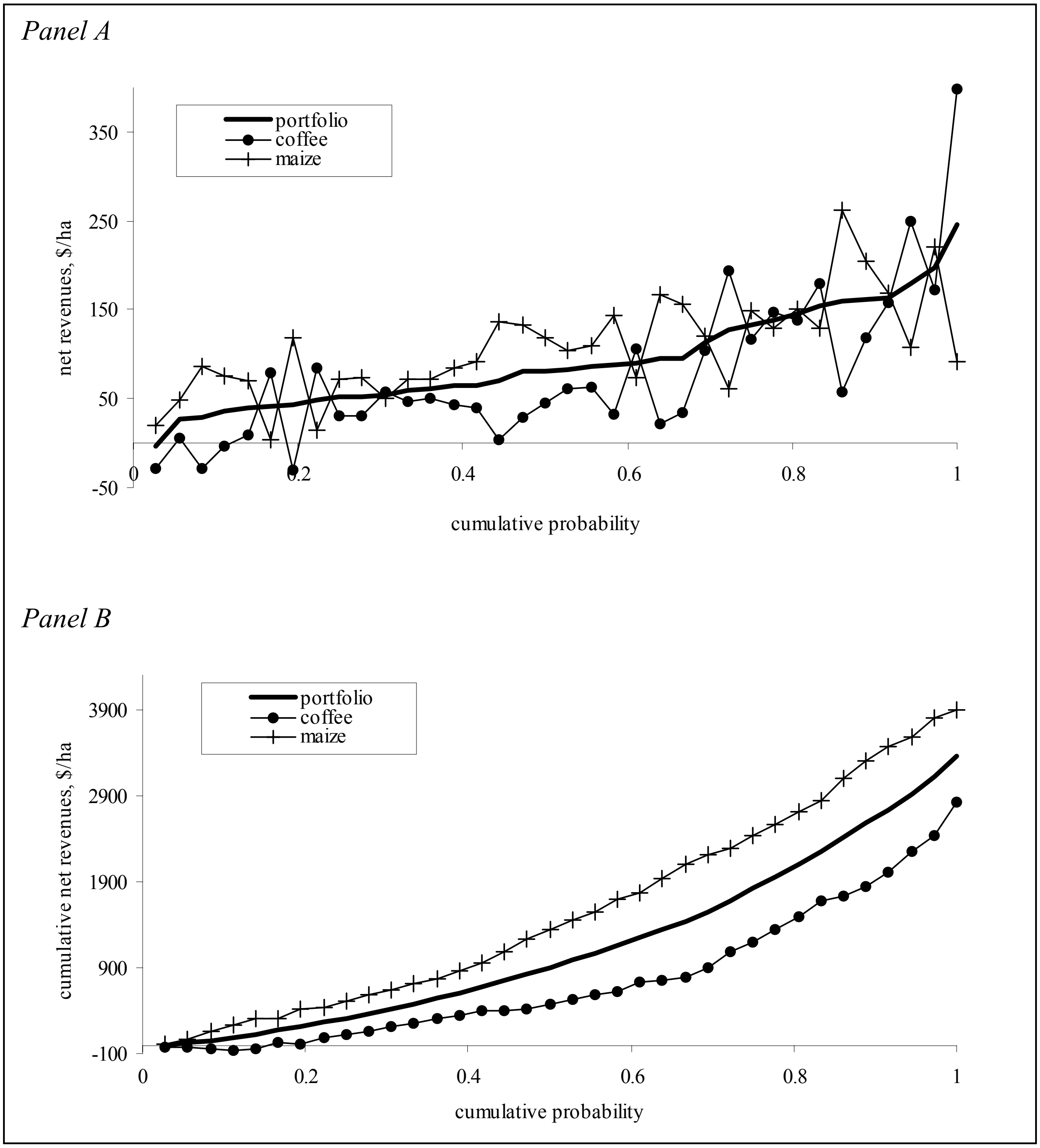

Figure 3. Graphical illustration of FMCSD (panel A) and SMCSD (panel B)

Notes

[1] Levy and Kroll extended the SD rules for investment choice between two risky assets by combining them with a risk-free asset. Shalit and Yitzhaki developed the so-called marginal conditional stochastic dominance rule, which tests if a marginal increase in the portfolio weight of one asset at the expense of another results in a dominating portfolio. The Shalit-Yitzhaki rule offers a necessary but not sufficient condition for portfolio efficiency. Kuosmanen presented the first necessary and sufficient test for portfolio efficiency. This approach has subsequently been further developed by Post.

[2] Shalit and Yitzhaki only consider the second-order MCSD rule. The first-order MCSD rule is an innovation made here.

[3] With data on risk aversion parameters, more discerning extensions of SD could be used to determine narrower bounds for s. For example, knowledge of the risk aversion range permits using stochastic dominance with respect to a function (see Williams et al.), while excluding extreme utility functions permits using almost stochastic dominance (Leshno and Levy).

[4] Data sources are from different publications, but most of the primary data on crop yield and prices were collected by the *Dirección de Información Agropecuaria* of the Agricultural Ministry. This work has been complemented in the last few years by the World Bank's SICA project, which attempts to improve information management and dissemination.

[5] Coffee has existed on some parcels for up to 80 years, although they have been renewed periodically.

[6] Testing yield and price separately is adequate given the small correlation between both series in the case of rice, maize and pasture. For coffee, there is some correlation between price and yield (correlation coefficient is 0.16), so we also tested the net revenue trends.

[7] For maize yield heteroskedasticity is ignored, which suggests that a more complex trend model might be more appropriate. However, we retain the linear model because of its simplicity and relatively high R^2, and to be consistent with the other series.