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Forest planning and productivity-risk trade-off through the Markowitz mean-variance model

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ABSTRACT

In order to make a comparative assessment between productivity and risk, we study the forest planning by means of the Markowitz mean-value (M-V) portfolio model. By weighting the forest productivity with factors of future climate change effects, we compute the optimal tree species mixes, within reach of forest managers, in ninety French administrative departments. Considering three different productivity measures (wood production, carbon sequestration and economic valorization) and their respective variances, we find that: a) the empirical allocation lies between the optimizations of wood production and economic valorization; b) forest managers prefer low variance to high productivity, i.e. their revealed risk aversion is high; and c) unlike maximizing wood productivity or carbon sequestration, which leads to similar portfolios, maximizing the economic value of wood production decreases both the levels of wood production and carbon sequestration. Under high risk aversion, the economic valorization would lead to a high species specialization, which is very unlikely in reality. In all considered scenarios, the objectives set out in the Kyoto Protocol would be attained, which puts into question its relevance in terms of additionality.

1. Introduction

Due to climate variations, as well as biotic and abiotic disturbances, the services provided by forest ecosystems are characterized by their strong fluctuations. Furthermore, climate change is expected to alter the provision of these services in a way that is far from being fully-understood (Millar et al., 2007). On one side, the increase of the CO_2 atmospheric concentration may lead to the *carbon fertilization effect*, according to which the growth rate of tree species should increase (Soulé and Knapp, 2006; Knapp et al., 2001). On the other side, climate change may accentuate the risk of tree mortality (Allen et al., 2010; Lindner et al., 2010; Dale et al., 2000).

The objective we have set is to describe a methodology that, selecting a particular mix of tree species, could help to shape the forest ecosystems such that the provision of services is both maximized and resilient to external shocks. For instance, the optimal mix of tree species could lower the risk of seeing the level of forest services deteriorated in the face of climate change.

As regards the forest management, we consider the preferences of forest managers to lie within a continuum between risk aversion and risk neutrality. Put differently, when forest resources are treated as investments that could generate a level of expected utility, their managers would not invest in a combination of tree species – a silvicultural portfolio – if a more favorable portfolio, with different expected return and risk, was achievable. In that sense, the forest manager is considered to be rational, for he or she will be looking for a portfolio that generates the greatest expected utility (Kumar et al., 2014).

The trade-off between the expected return of a portfolio of assets and its combined variance has initially been discussed by Markowitz (1952) through his mean-variance (M-V) model. The latter then extensively applied, as an arbitrage tool, to numerous economic sectors, including forestry (Pasalodos-Tato et al., 2013). In such a model, a specific weighted combination of assets, such as tree species, is selected in order to minimize the portfolio variance subjected to a given target return or, equivalently, so as to maximize the expected return given an acceptable level of variance.

When applied to forestry, the portfolio analysis has been employed from the point of view of the forest managers when they behave as investors, where the investments in timberland are balanced against other types of investments (e.g. stocks or bonds) in order to maximize the portfolio financial return (Thomson, 1991; Wan et al., 2015). Alternatively, the M-V model has been employed as a decision aid tool to deal with risk and uncertainty, with a portfolio of tree species analyzed either at the stand level (Knoke et al., 2008; Knoke, 2008; Roessiger et al., 2011), the management level (Knoke et al., 2005; Neuner et al., 2013), or the regional level (Brunette et al., 2014).

Most of the studies aforementioned are based on the historical distribution analysis, choosing a distribution, fitting its parameters to the

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observed one, and using Monte Carlo simulations to produce random series. Contrariwise, this paper follows the work by Brunette et al. (2014) and directly uses historical data issued from the French National Forest Inventory (IGN). The main advantage of such method is that it requires less data and needs fewer assumptions on the distribution choice and parameters. However, by using historical distributions, we are faced with potential overfitting issues when the results are projected toward other time periods, and may also underestimate the extreme events with fat tailed distributions.

While our model considers three objectives that can be assigned to forest ecosystems (Wood Production — WP, Carbon Sequestration — CS, Economic Value — EV), the optimization has been conducted using the species and department specific historical observations of tree growth.

The literature in forest ecology usually states that, for individual trees or tree populations, a declining growth level, as compared with the species potential, presents a high mortality risk, for the indicator reflects the tree vigor and is indicative of its survival likelihood (Buchman et al., 1983; Bigler et al., 2004; Dobbertin, 2005). Moreover, many recent works suggest that a high variance in tree growth reflects a high risk of mortality (Ogle et al., 2000; Suarez et al., 2004; McDowell et al., 2010; Heres et al., 2012). Thereby, the environmental stress produces an exaggerated variation of tree-rings, such that greater sensitivity to stress comes down to greater mortality (Hogg et al., 2005; Linares and Camarero, 2012). The amplitude of variation of productivity is thus considered to be a measure of risk (Tilman et al., 1997; Andreu et al., 2007; Slimani et al., 2014).

This paper extends the Markowitz portfolio selection of Brunette et al. (2014): (a) for different levels of risk aversion exhibited by forest managers; (b) for different climate change scenarios during the optimal allocation; (c) to different maximization objectives, such that WP is compared with CS and EV.

As the portfolio expected output is computed from the historical data, the implicit assumption is that the expected productivity of species would be equivalent to the ones currently observed. However, this invariability assumption is mitigated by the fact that the portfolio simulations are conducted at a relatively small scale, that is, the French administrative departments.

Through simulations, our model yields the following results: a) the empirical allocation stands between the optimizations of wood production and economic valorization; b) forest managers prefer low variance to high productivity, i.e. their revealed risk aversion is high; and c) unlike maximizing wood productivity or carbon sequestration, which lead to similar portfolios, maximizing the economic value of wood production decreases both the levels of wood production and carbon sequestration. Under high risk aversion, considering the economic value, rather than the wood productivity, would lead to a high specialization in tree species. This is neither likely nor desirable due to the risk which would result from low diversification, not to mention the change of scenery. Considering either scenario, the objectives set out in the Kyoto Protocol would be attained.

After this starting section, the methodology we have used is presented in Section 2. Section 3 is devoted to illustrating simulation examples. Section 4 concludes.

2. Methodology

All the possible combinations of species define the feasible portfolio set. Fig. 1 portrays the productivity-variance space, where the set (such as point i) in enclosed by the blue curve and the upper segment of the parabola (B–D segment) represents the *efficient frontier* (EF), that is, all the optimal allocations achievable by the decision maker. Thereby, no risk can be lowered at the expense of the productivity level and no productivity can be enhanced without increasing the risk. Productivity itself can be defined in different terms. For instance, Section 2.4 takes physical growth of timber production, carbon sequestration and soil

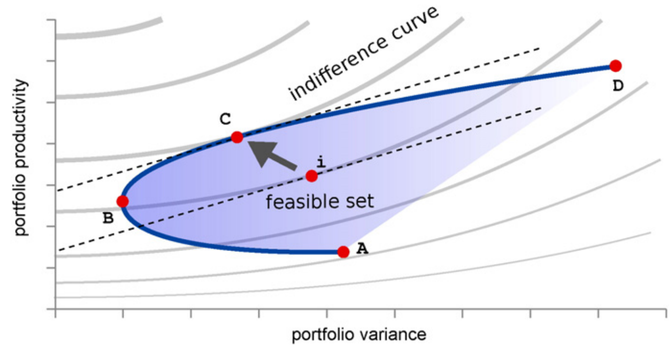

Fig. 1. Graphical representation of the portfolio allocation.

expectation value as different expressions of productivity. The indifference curves between productivity and variance (the thicker the line, the greater the utility) are drawn in gray.

Under the standard neoclassical assumption of concave utility functions with respect to a single good, indifference curves in the productivity-variance space become convex (Pennacchi, 2007, ch.2). EF being concave (Merton, 1972), this guarantees the presence of a single optimal point that maximizes the agent's utility.

At this optimal point (C), the tangent to the indifference curve is equal to the tangent to the efficient frontier, which equation is defined as $p=\alpha\times v+\beta$, where α is the linear risk aversion coefficient dp/dv – defined as the productivity (p) that agents require to accept more variance (v) –, and p and v refer to the overall expected productivity and variance of the portfolio. The parameter β is the intercept with the ordinates of the tangent, where variance is equal to zero. As indifference curves do not intersect, maximizing β corresponds to maximizing the utility of the certainty equivalent.

Point A is the one with the lowest portfolio combined productivity. Instead, B represents the point at which the portfolio variance is at its lowest, while the tangent to the efficient frontier has the highest value of slope. Choosing B as optimal point would imply an infinite risk aversion ($\alpha\rightarrow\infty$). Agents with α-level of risk aversion are expected to choose point C, at which the indifference curve and its tangent intersect the efficient frontier.

Mathematically, it boils down to solving the following quadratic problem, where α remains exogenous and must be pre-defined:

$$\begin{aligned} \max_{x_i,\beta} \quad & \beta \\ s.t. \quad & x_i \geqslant 0 \qquad \forall i \\ & \textstyle\sum_i x_i = 0 \\ & \textstyle\sum_i x_i y_i = \alpha \sum_i \sum_l x_i x_j \sigma_{i,j} + \beta \end{aligned} \tag{1}$$

where x_i is the share of asset i, y_i is its productivity and $\sigma_{i,j}$ is the covariance between assets i and j. In this way, $\sum_i x_i y_i$ is the overall portfolio productivity and $\sum_i \sum_j x_i x_j \sigma_{i,j}$ its corresponding variance. By substitution, Eq. (1) becomes:

$$\begin{aligned} \min_{x_i} \quad & \alpha \textstyle\sum_i \sum_j x_i x_j \sigma_{i,j} - \sum_i x_i y_i \\ s.t. \quad & x_i \geqslant 0 \quad \forall i \\ & \textstyle\sum_i x_i = 1 \end{aligned} \tag{2}$$

Finally, point D (where $\alpha=0$) is the highest portfolio productivity attainable by the decision maker. Despite its performance, it is more a degenerated solution where only the most productive species would remain.