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

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Context

- The increase of the CO2 atmospheric concentration may lead to the carbon fertilization effect (Soulé and Knapp, 2006 ; Knapp et al., 2001).
- Climate change could also accentuate the risk of tree mortality (Allen et al., 2010 ; Lindner et al., 2010 ; Dale et al., 2000).
- Our objective is to help shaping the forest ecosystems through a particular mix of tree species.
- We consider the preferences of forest managers to lie within a continuum between risk aversion and risk neutrality.
- The trade-off between the expected portfolio return and its variance has been first emphasized by the mean-variance (M-V) model (Markowitz, 1952).
- The model has already been applied to forestry (Knoke et al., 2005 ; Knoke et al., 2008 ; Roessiger et al., 2011 ; Neuner et al., 2013 ; Pasalodos-Tato et al., 2013 ; Brunette et al., 2014 ; Wan et al., 2015).

Context

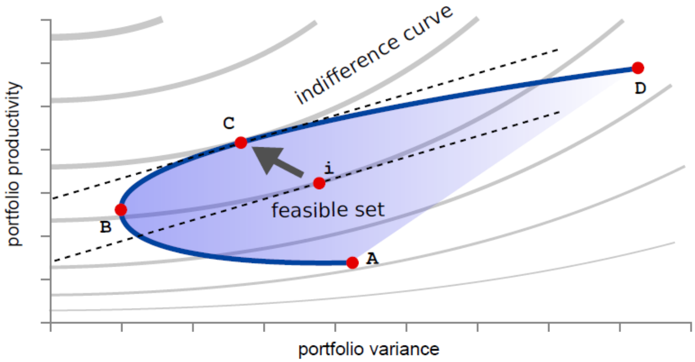
- A specific weighted combination of assets, such as tree species, is selected in order to minimize the portfolio variance subjected to a given target return.
- High variance in tree growth reflects a high risk of mortality (Ogle et al., 2000 ; Suarez et al., 2004 ; McDowell et al., 2010 ; Heres et al., 2012).
- We consider three objectives (Wood Production – WP, Carbon Sequestration – CS, Economic Value – EV), with the optimization through the species and department specific historical observations of tree growth.
- The results are the following :

  a. the empirical allocation stands between the optimizations of WP and EV ;
  b. forest managers exhibit high risk aversion ;
  c. maximizing WP or CS leads to similar portfolios ; under high risk aversion, EV would lead to a high specialization in tree species.

Methodology

- The productivity-variance space, where the set (such as point i) is enclosed by the blue curve and the upper segment of the parabola (B – D segment) represents the efficient frontier (EF).

FIGURE: Graphical representation of the portfolio allocation



Methodology

- The portfolio allocation problem is a strictly convex minimization problem :

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

- where x_i and y_i are the share and productivity of asset i, and $\sigma_{i,j}$ is the covariance between assets i and j.
- $\sum_i x_i y_i$ is the overall portfolio productivity and $\alpha \sum_i \sum_j x_i x_j \sigma_{i,j}$ its corresponding variance, with α the linear risk aversion coefficient.

Methodology

- We aim at revealing the risk aversion coefficient of point i (α_i) and compare its portfolio, through linear interpolation, with a point on EF characterized by the same risk aversion coefficient.
- The data from the French National Forest Inventory (IFN), on eleven tree species present in France, comprises the 1978–2009 time length. Productivity is derived as the volume growth divided by the occupied area.
- The climate change multipliers have been computed for 7 different species by LERFoB. The projections covered the years ranging from 2015 to 2085 for the IPCC scenarios a1b, a2 and b2, which are issued from the ARPEGE-Climate model.

Methodology

- We consider physical wood production (WP), carbon sequestration (CS) and economic valorization (EV, that is, the maximization of the forest rent).

- The carbon sequestration is obtained by multiplying the wood productivity by a CO2 factor F_s^{CO2} for each species s :

$$F_s^{CO2} = wd_s \times cc_{gs} \times expf_s^b \times expf_s^r \times \frac{44}{12} \qquad (2)$$

- where wd_s is the wood density by species (Chave et al., 2009 ; Zanne et al., 2009), cc_{gs} is the carbon content by group of species gs (Lamlom and Savidge, 2003) and $\exp f_s^b \times \exp f_s^r$ are the branch and roots expansion factors (Loustau, 2004).

Methodology

- We optimized the forest portfolio for the economic valorization objective, that is, the soil value obtained from the harvesting discounted value at the rotation end.

- The wood productivity per species in a given year ($y_{i,t}$) has been transformed into production ($Y_{i,t}$) multiplied by the species typical rotation length (T_i) and into value by multiplying the production by the roadside timber prices ($p_{i,t}$, in constant terms). The cash-flows have been discounted at a discount rate (dr) of 3%.

- The discounted value has been transformed into the soil expectation value ($sev_{i,t}$) :

$$sev_{i,t} = \frac{y_{i,t} * p_{i,t} * T_i}{(1 + dr)^{T_i} - 1} \quad (3)$$

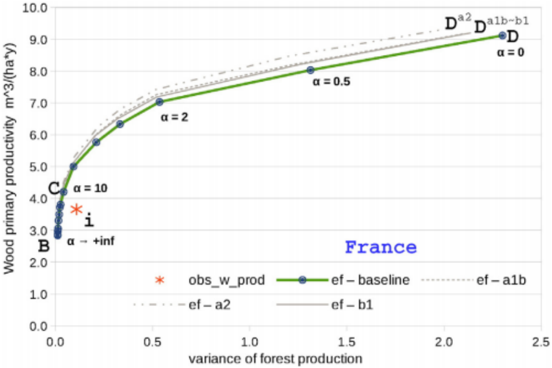
- In the EV maximization objectives, $sev_{i,t}$ are both used as productivity and means to build the economic value covariance matrix.

Simulations

- The efficient frontier was computationally obtained using a pre-defined set of 14 risk aversion coefficients, ranging from 0 (point D) to 10,000.
- We optimized the portfolio problem for point B by selecting the species which best performed in terms of minimum variance.
- To account for 90 administrative departments, 14 risk aversion coefficients, 3 climate change scenarios, 3 different objectives, 5 time spots, and two discount rates (0 and 0.03) a total of 117,180 simulations had to be run.
- We fall on a national level risk aversion coefficient equal to 70.58 $m^3 ha^{-1} y^{-1}$, that is, on average, forest managers would require an increase of 7.7 $m^3 ha^{-1} y^{-1}$ to compensate for a doubling of the current variance in wood production.

Simulations

FIGURE: Efficient frontier and actual allocation in France



Simulations

TABLE: Wood production, carbon sequestration and economic valorization on different points of the efficient frontier (optimization with respect to the wood production)

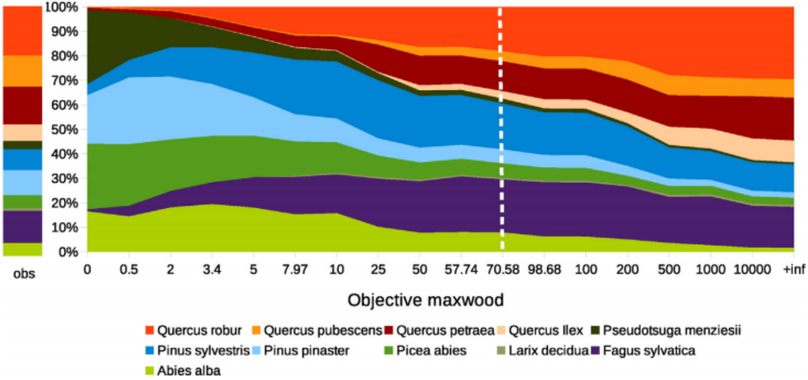
Climate change scenarios	a1b	a2	b1	baseline
Wood production ($Mm^3\ y^{-1}$)				
(currently observed: 55.4 $Mm^3\ y^{-1}$; 3.52 $m^3\ ha^{-1}\ y^{-1}$)				
Full risk aversion	45.6	47.0	46.5	43.8
Intermediate risk aversion	60.2	62.8	61.1	58.6
Risk neutral	136.7	139.5	137.0	136.3
Carbon sequestration (Mt $CO_2eq\ y^{-1}$)				
(currently observed: 78.8 Mt $CO_2eq\ y^{-1}$; 5.01 t $CO_2eq\ ha^{-1}\ y^{-1}$)				
Full risk aversion	69.4	71.8	71.0	66.3
Intermediate risk aversion	84.8	88.6	86.7	82.0
Risk neutrality	169.9	173.1	172.9	170.4
Economic valorization (M€ y^{-1})				
(currently observed: 3789 M€ y^{-1}; 240 € $ha^{-1}\ y^{-1}$)				
Full risk aversion	3849	3894	3880	3745
Intermediate risk aversion	3637	3734	3687	3373
Risk neutrality	5312	5278	5408	5426

Simulations

- Choosing a specific level of risk aversion significantly impacts the compositions in the optimal portfolios. Three different patterns can be identified.
- The first one is relative to the species that yield high portfolio productivity and risk : these species (P. abies, P. pinaster or P. menziesii) constitute an important part of the portfolio under risk neutrality.
- The second one includes the species (Q. robur, Q. petrea, Q. pubescent and Q. ilex) with specular characteristics : they bring stability to the portfolio to the detriment of its productivity. They increase with risk aversion.
- The third one displays intermediate characteristics and arises under the intermediate risk aversion (P. sylvestris and F. sylvatica). Its coefficients yield the highest portfolio diversification.
- Compared with the actual distribution, the model suggests an increased utilization of F. sylvatica, a partial substitution of P. pinaster with P. sylvestris and a general regression of Quercus, in particular Q. pubescent.

Simulations

FIGURE: Species allocation by risk aversion

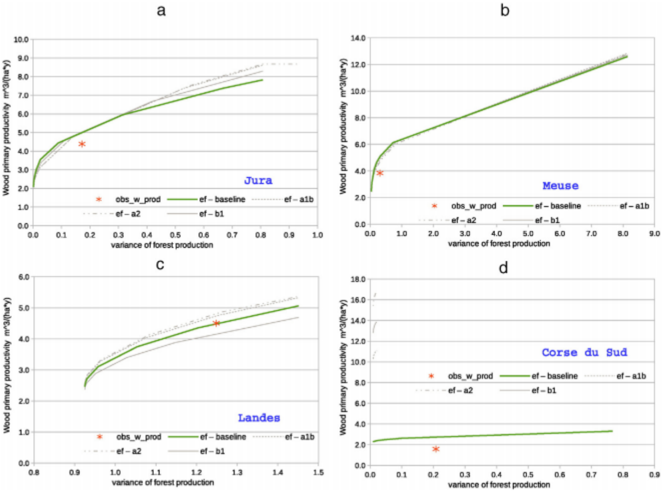


Simulations

- The majority of departments display allocations similar to the national one, with a preference for low variance at the expense of high productivity.
- A few departments, distinguished by risk neutrality and high productivity, turn out to be on EF. This is the case of Landes, Gironde and Haute Savoie.
- At last, some departments are distant from the optimal allocation (Corse du Sud, Pyrénées-Orientales).

Simulations

FIGURE: Efficient frontiers and current allocations in four French departments

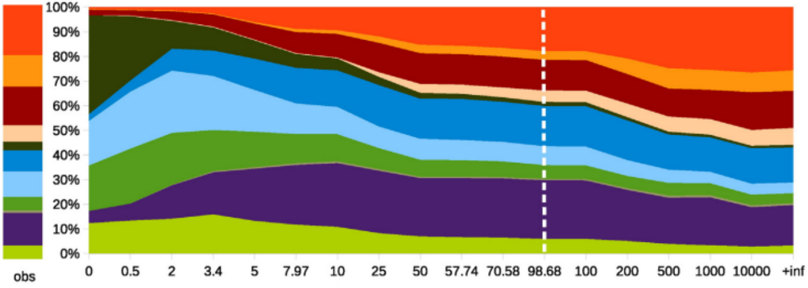


Simulations

- The empirical performance in carbon sequestration (78.8 $MtCO2eq\ y^{-1}$) is very close to what we find at the optimum. It is comparable to the French National Forestry Office figure obtained using the method of Loustau (2004) and Dupouey and Pignard (2001).
- The Kyoto protocol stipulates that, through forests, France ought to sequestrate around 66 $MtCO2eq\ y^{-1}$ per year up to 2020 (Colin, 2014). Either the Kyoto objectives are too lax or French forests are highly efficient when comes to sequestrating.
- In case the objective is to sequestrate carbon, the optimal species distribution is very similar to the one obtained when maximizing wood production.

Simulations

FIGURE: Species allocation under the carbon sequestration objective

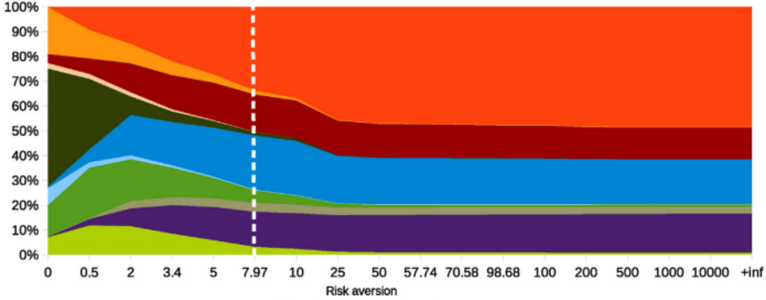


Simulations

- With the maximization of the economic value, considering the cost of waiting for the harvest, that is, the capital opportunity cost, yields very different species distributions.
- It also leads to a lower diversification, with a Shannon index of 1.79 for the observed risk aversion portfolio, against 2.09 when the objective corresponds to the wood or carbon maximization.
- Under very high risk aversion, the species diversification is further reduced, with the Shannon index decreasing to 1.43.

Simulations

FIGURE: Species allocation under the economic valorization objective



Conclusion

- In case of high level of risk aversion, we found that the empirical performance is close to efficiency.
- Given the small differences between the tree species in terms of carbon concentration, maximizing a portfolio for wood production amounts to maximizing it for carbon sequestration. This is our main result.
- When French authorities promote timber production, they turn out to target the fight against climate change. Would the Kyoto objectives, in terms of carbon sequestration, be more constraining in the future, the cursor should be moved to more risk neutrality.
- Private mechanisms of risk sharing, such as the insurance contracts, should be implemented, especially in the regions, like the French Southwest, where the forest owners are regularly subsidized in case of calamities.
- We also observe that forest managers both maximize physical wood production and soil expectation value. An interesting follow up could be to see whether this result is agent-dependent.

Thank you for your attention