Framework of stochastic gross margin volatility modeling of crop rotation with farm management practices

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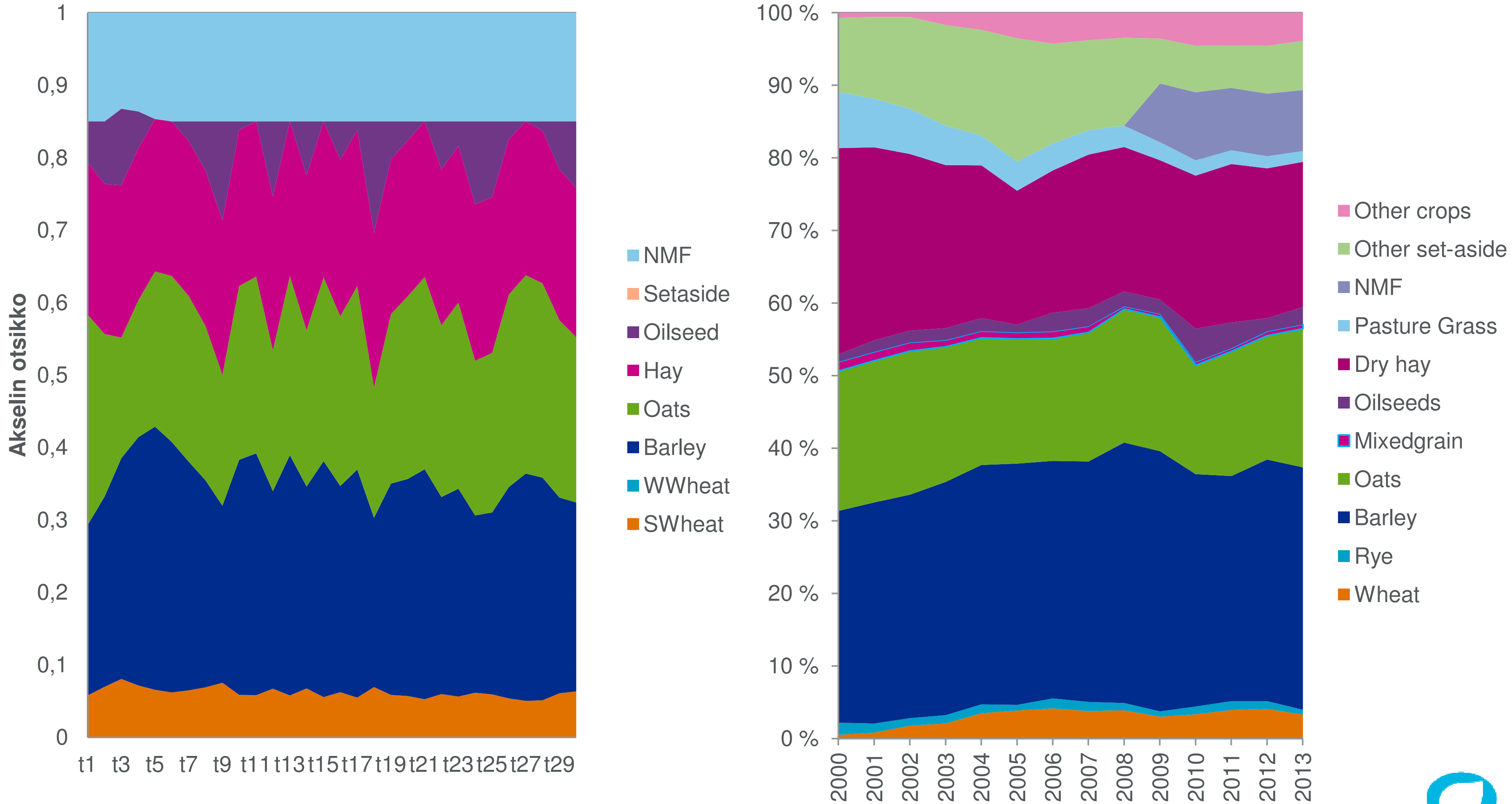
DP models with risk aversion through mean-variance specification is already implemented in Luke and applied in North Savo region

- Liu, X., Lehtonen, H., Purola, T., Pavlova, Y., Rötter, R. & Palosuo, T. 2016. Dynamic economic modelling of crop rotations with farm management practices under future pest pressure. Agricultural Systems (2016), pp. 65-76 DOI: 10.1016/j.agsy.2015.12.003
- Lehtonen, H., Liu, X. and Purola, T. 2016. Balancing climate change mitigation and adaptation with socio-economic goals at farms in northern Europe. In: Paloviita, A. and Järvelä, M. (Eds) 2015. Climate Change Adaptation and Food Supply Chain Management (Routledge Advances in Climate Change Research), Routledge, London, 264 pp. ISBN13: 978-1138796669;

  http://www.tandf.net/books/details/9781317634034/. p. 132-146.

- **HOWEVER climate change, e.g. changes in mean and variance of crop yiels, still not yet taken into account**
  - **Recently, such crop modelling results have become availble for wheat as well, not only for barley**
  - **Still CC impact available for 2 cereals crops only, while most farms cultivate more than 2 crops**

Simulated (low disease pressure, median price, left) land use over 30 years vs observed land use (right) on cereals farms in North Savo region Finland 2000-2013 **)



**) Lehtonen, H., Liu, X. & Purola, T. 2016. Balancing Climate Change Mitigation and Adaptation with Socio-Economic Goals at Farms in Northern Europe..

Background

- Agricultural practice is facing multiple challenges under volatile commodity markets, inevitable climate change, mounting pest pressure and various other environment-related constraints.
- We must analyse the volatility of prices and yields as a system, not separately.
  - Ex-ante systemic volatility may be smaller than when accounting only yield or individual price volatility.
  - Cross-price correlation matters and it needs to be modeled
  - Correlation between prices and yields also matters.

Dynamic programming (DP) approach

- In DP, we solve the optimal management pattern over time
- The method implicitly takes into account that the farmer can learn more about CC as time is elapsed
  - An example: land use decisions may be update from year to year if year-to-year changes in climate are in favour of specific crops
- In a DP model, we must establish links between successive years
  - How do prices evolve from year to year?
  - How does yield change from year to year?
- DP is dynamic modelling approach which utilises the Markov property. This implies that the variables used in the model provide so much information about the operating environment of a farm that is is possible to make informed decisions.

Two crops case

- Assume that there are two crops (1 and 2)
- Farmer can choose how much of each crop is cultivated each year
- Proportion of land area that is allocated to crop 1 in year t is A_t and proportion allocated to crop 2 is $1\text{-}A_t$
  - Price of crop 1 is $P_{t,1}$ and
  - Price of crop 2 is $P_{t,2}$
  - Water-limited yield of crop 1 is $Y_{t,1}$ and
  - Water-limited yield of crop 2 is $Y_{t,2}$
- There is an input price vector. The price level of inputs is represented by parameter $P_{t,\mathrm{input}}$
- Prices and yield are volatile and vary over time

Return on cultivation

- Expected return from the cultivation is

$$r_t = r_{t,1}A_t + (1 - A_t)r_{t,2}$$

$$= (Y_{t,1}P_{t,1} - a_{t,1}P_{t,input})A_t + (Y_{t,1}P_{t,1} - a_{t,2}P_{t,input})(1 - A_t)$$

Where r_1 and r_2 represent return on crops 1 and 2, a refers to input costs and oher parameters are as explained in the previous slide

Portfolio variance

- The variance of *r* in this portfolio is represented by the variance of individual alternatives (σ_1 ja σ_2) and their covariance (*c*).

$$\sigma_t^2 = \sigma_1^2 a_t^2 + \sigma_2^2 a_t^2 + 2a_t(1 - r_t)c\sigma_1\sigma_2$$

➔ To know variance, it is important to know

a) how much resources are committed to each alternative and
b) what is their variance and covariance. Variance of individual *r*'s is determined by the variance and covariance of input price, output price and yield.

Volatility and parameter changes over time

- Changes in yields and prices over farm type can be decomposed

  Price observed in the next year

  = current price

  + systemic year-to year change in price (e.g. trend)

  + uncertainty about exact magnitude of systemic change

  + random variation in prices in the absense of systemic change (i.i.d.)

- Similarly, changes in yields over time can be decomposed

  Yield observed in the next year

  = Current yield

  + systemic year-to-year change in yield (due to CC)

  + uncertainty about the exact magnitude of systemic change

  + random change in yields around the mean

Intra-annual dynamics

- When decisions about land use and other input use are made, the return on crops 1 and 2 for that year is unknown
- Input costs and land allocated to crops 1 and 2 are known by the time of seeding (i.e. in the spring at the latest)
- Sales revenues are observed at the end of season
  - Yield for year *t* is determined by the inputs used and weather conditions realized during the crop year (in the model this is reflected by water-limited yield)
  - Crop prices are determined by global and national changes, which may change due to aggregate yield obtained

The Bellman equation

Value of farm at time *t*

State variables

$$V_t(Y_t, P_t) = \max_{u_t}\{R_t(Y_t, P_t, u_t) + (1-r)E(V_{t+1}(Y_{t+1}, P_{t+1}))\}$$

Control variables (input choices)

Expectations operator

Discount factor

One-period net returns

St.	$Y_{t+1} = g_N(Y_t, u_t)$	(transition equation for the water-limited yield)
	$P_{t+1} = g_B(P_t) + \varepsilon_t$	(transition equation for prices)
	P_t and N_t are given	(initial state given)
	$V_{T+1}(Y_{T+1}, P_{T+1})$ given	(the terminal value of farm)

Mean-variance approach

- Mean-variance approach can be applied in DP
- The mean-variance approach attempts to find the combination of crops which result in high return on assets but low variance
- Covariability of gross margins between crops is in a key role in the mean-variance approach, as well as variance and mean yields of individual crops

➔ Max return, min var

  ➔ More stable return on assets

➔ The model can be calibrated against realised data

  ➔ However, the degree of risk aversion, e.g. a weight given for the variance of the utility function often needs to be used as a calibration parameter, to validate the model close to the observed land use pattern

Challenges of the approach

- Future variance of gross margins (profits) is hard to be estimated in the context of climate change
  - Crop yield means and variances per crop can be simulated using crop models
  - However, crop models have been applied and validated for few crops only – thus only few crops can be included
    - Wheat, barley, timothy yields have been simulated in the case of Finland – oats and oilseeds common as well
  - Future mean prices of inputs and outputs under different global scenarios could be available from global models e.g. CAPRI
  - However there are few attempts to simulate / evaluate price (co-variability) – and the price-yield correlation

Possible applications and simulations

- Develop scenarios for CC and markets
  - Most likely outcome vs. alternative realizations
- Needs to be simulated over different climate scenarios and RAPS (based on SSPs)
- We need crop model results on water limited yields and nutrient / other requirements of individual crops
  - Mean yields, nutrient /other inputs per crop
  - Realisations of yields on annual level, needed in including (co)variability
- Assuming no change in (co-)variability of inputs and output prices, one could estimate changed co-variability of gross margins (profits) at a farm level

Variance decomposition of wheat, barley and oil seeds in Finland (Liesivaara and Myyrä 2013)

	Wheat		Barley		Oilseeds	
Direct effects (%)	2000–2005	2006–2011	2000–2005	2006–2011	2000–2005	2006-2011
Yield	51.9*	30.1	57.2*	39.4	56.9*	49.0
Price	24.6	61.2*	14.3	44.7	23.2	39.9
Fertilizer	9.7	5.1	11.5	8.1	11.0	8.1
Seed	7.4	2.2	12.2	5.9	3.6	1.5
Pesticides	6.3	1.4	4.8	2.0	5.4	1.5
∑ Costs	23.4	8.6	28.5	15.9	19.9	11.1

Correlations between crop yield and own price appear to be quite weak
(cross-price correlation is stronger)

Winter wheat	**0.004**
Spring wheat	0.301
Rye	-0.241
Barley	-0.293
Oats	-0.272
Mixed grain	0.693*
oilseeds	0.173
dry hay	-0.120

Some early conclusions

- The suggested approach is consistent in terms of DP principles and mean-variance approach and can provide consistent results for farm scale risk analysis
- It is however hard to utilise the approach except assuming a farm with only few crops (those with crop modelling / other results of climate change effects on mean and (co-variance)
- Assuming no change in price (co)variability is a major simplification → results show farm level (or local) effects of changes in mean yields and yield (co)variability only

Some early conclusions 2

- Climate change is likely to increase crop yields – on some soils types - and their volatility in Finland (Tao et al. 2015)
  - ➔ This may increase the profitability of cultivation on average but increase the costs of risk
    - ➔ Crops which have stable yield will benefit
    - ➔ Input-output-ratio is also important
  - ➔ Covariability of yields between crops on one hand, and correlation between crop prices and between crop and fertilizer prices on the other hand will be essential in determining the optimal protfolio of crops to be cultivated
    - ➔ The areas of crops which revenues correlate at little (or negatively) are expected to increase in the portfolio

Thank you!

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