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Farm level dynamic economic modelling of crop rotation with adaptation practices

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Abstract— We develop a dynamic economic model of crop rotations, with various adaptation practices, to be used in simulating crop rotation patterns at farm level under different scenario over 30 years. First results for Northern Savo region are presented. Future applications may include more specific crop modelling and crop protection research results in integrative economic analysis.

Index Terms— Dynamic optimisation, agriculture, crop yield, climate change adaptation, farm economy.

1 Introduction

Agricultural practice is challenged by increasingly volatile commodity markets, climate change and increasing environmental constrains. While positive impacts may be anticipated for Northern Europe, increasing climatic variability with higher frequency of extreme events, pest pressure and continuous changes in the markets may present challenges for agriculture in Nordic countries (Hakala et. al., 2011). Crop rotation could maintain the soil productivity, reduce disease risk and pest damage, and thus mitigate yield risks. (Maynard et. al., 1997; Hennessy, 2006). Rotation could decrease the intensive usage of synthetic chemicals inputs and mitigate the greenhouse gas emission. However, fungicide treatment is an efficient against a variety of plant diseases with reasonable costs (Purola, 2013) and it is particularly important in the future when increasing disease pressure is to be realized at northern latitudes. Soil improvements are also needed to maintain yields more varying weather conditions.

The aim of our research is to develop a dynamic economic model of crop rotations, with various adaptation practices, to be used in simulating crop rotation patterns at farm level under different scenario over 30 years. We applied our model on an empirical case study in Northern Savo region.

2 Methodology

Consider a farmer managing a specific farmland, composed of equally sized 10 parcels within the farm $(p_1,\ldots,p_{10})$. A rational farmer plants annual or multi-year crops on an annual basis. Assuming that a farmer decides his sequence of crops planted every year based on the discounted expected income and associated income variance, for that reason this approach is known as E, V decision rule.

Considering farm level, output prices are fixed. The farmer needs to identify optimal sequence of crops, which can be grown in rotation during the next periods of H years. The dynamic model of optimal crop rotation can be formulated and can be solved via relaxed mixed integer nonlinear programming. Define crops types with the superscript i. The expected prices (per ha) of individual crops represented by $P(c^i)$(deterministic vector) of over time. Subsidies per ha of each crops a constant vector described as $S(c^i)$. $C(p,t,c^i)$ is a cost function for cultivating a crop c^i at a parcel p at year t. Maximization of the discounted profit function of the farmer's rotation plan can be specified in (1):

$$\max_{A(p,t,c)} \sum_{t=1}^{H}\sum_{p}^{10}\sum_{i=1}^{M} e^{-rt}\big(Y\big(A(p,t,c),p,t,c\big)A(p,t,c)P(c)+S(c)-C(c)\big)-\Phi\sum_{t-1}^{H}\sum\nolimits_{c}\sum\nolimits_{c2} e^{-rt}A'XA \tag{1),}$$

$$w.r.t.$$

$$\sum_{\forall c} A(p,t,c^i)=1, \tag{2),}$$

where e^{-rt} defines the discount factor, and variable $A(p,t,c)$ (which may be a continuous variable or a mixed integer variable, depending on the size of the field parcel and the possibility of splitting the field parcel for more than one crop) describes allocation of land parcel p for a crop c^i at the year t. $\Phi A'XA$ is the "risk component", representing risk tradeoff/reward of allocating the land on riskier crops, through gross-margin covariance matrix *X*. A "risk aversion coefficient" (Φ) implies how much a farmer can accept risks. Equation (2) provides a constraint, which guarantees total land allocation of each field parcel every year. Then, yield function $Y(A(p,t,c),p,t,c)$ describes the yield of a crop c^i on an equally sized parcel p at year t as follows:

$$Y(A(p,t,c^i)=\begin{cases} Y_{MEAN}(p,c^i)Y_{RED}(p,t,c^i)(1+L(p,t)+F(p,t,c^i)-D(p,t,c^i) & if \quad i=barley \\ Y_{MEAN}(p,c^i)Y_{RED}(p,t,c^i)(1+L(p,t)) & if \quad i=other\,than \quad barley \end{cases} \tag{3),}$$

where $Y_{MEAN}(p,c^i)$ is endogenously given mean yield of the crop c^i on a parcel p. $L(p,t)$ is a response function of liming treatment; $F(p,t,c^i)$is a linear response function of fungicide treatment; $D(p,t,c^i)$is a disease loss function of barley1. $T(c^i,c_2^i)$is an endogenously given transition matrix (crop yield penalty matrix), which describes a fraction of yield that can be lost due monoculture.

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[1] As we apply fungicide treatment only for barley, therefore the specific disease loss is also referred only to barley.

3 Parameter and Data Set

Model is implemented to a typical average sized cereal producing farm in Northern Savo where average size of all farms was 35 ha in 2011[2]. 17-year-avg-yields 1995–2012 are extracted data obtained from statistics of Finland. Variable costs and subsidies of four crops (table 1) are for most part adopted from a dynamic regional sector model of Finnish agriculture (DREMFIA). In addition, we obtained liming data from Käytännön maamies[3], and fungicide treatment is applied to only barley in the current version of the model. In Northern Savo region of Finland, the average pH value is around 6.1[4]. We generate six scenario based on price and disease pressure, which can be called S1-S6 described in details as follows: S1: high- disease-pressure vs. high-price; S2: high-disease-pressure vs. current-price; S3: high-disease-pressure vs. low-price; S4: low-disease-pressure vs. high-price; S5: low-disease-pressure vs. current-price; S6: low-disease-pressure vs. low-price (table 2).

TABLE1. CROP LAND, VARIABLE COSTS, SUBSIDIES AND PRICES USED IN THE MODEL

crop land	**Average yield kg/ha** $Y_{MEAN}(p,c^i)$	**Variable cost €/ha** $C_{variable}(c^i)$	**Subsidy €/ha** $S(c^i)$	**Current price €/kg**
Spring wheat	3068	590	585	0.172
Winter wheat	3031	640	596	0.172
Barley	2923	546	527	0.160
Oilseed	2786	544	527	0.144
Oats	1305	544	624	0.370
Set aside	-	277	401	
NMF[a)]	-	301	571	

Note: [a)] NMF refers to the natural management field

TABLE 2. CURRENT/LOW YIELD PENALTY MATRIX OF DISEASE PRESSURE : $T(c^i, c_2^i)$

Crops	**S.Wheat**	**W. Wheat**	**Barley**	**Oats**	**Oilseed**
S. Wheat	0.970	0.970	0.995	0.995	1.00
W. Wheat	0.970	0.970	0.995	0.995	1.00
Barley	0.990	0.990	0.990	1.00	1.00
Oats	0.995	0.995	0.995	0.990	1.00
Oilseed	1.00	1.00	1.00	1	0.70

4 Preliminary results

The results in Figure 1a, Figure 1b and Table 3 show the simulated development of land allocation over

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[2] www.pohjois-savo.fi
[3] http://kaytannonmaamiesfi.virtualserver27.hosting.fi/wp-content/uploads/2013/12/nopeavaikutteinen_2012.pdf
[4] Detailed information about input of liming response function and fungicide treatment available upon request.

the next 30 years under two example scenarios S1 and S6 when the risk aversion parameter is set up as 0.02. When price is high, not only are farmers willing to take risks cultivate riskier crops such as wheat and barley to obtain possible high gross margin, but adaptation practices such as rotation, liming and fungicide are likely to be applied at farm to reach high yield. Spring wheat and barley dominates the land allocation. Barley provides higher gross margins than spring wheat due to fungicide treatment and its resulting higher yield performance. Set aside would not be an option in land allocation decision for farmers under high price scenarios but nature management field may still be an option. When the price is low, farmers put their land on set-aside or NMF to the maximum proportion that regulation is allowed in order to minimize all farming costs. Figure 3 shows clearly that the pH in distant parcel 10 (7 km from the farm centre) is always lower than in the near parcel 1 (0 km).

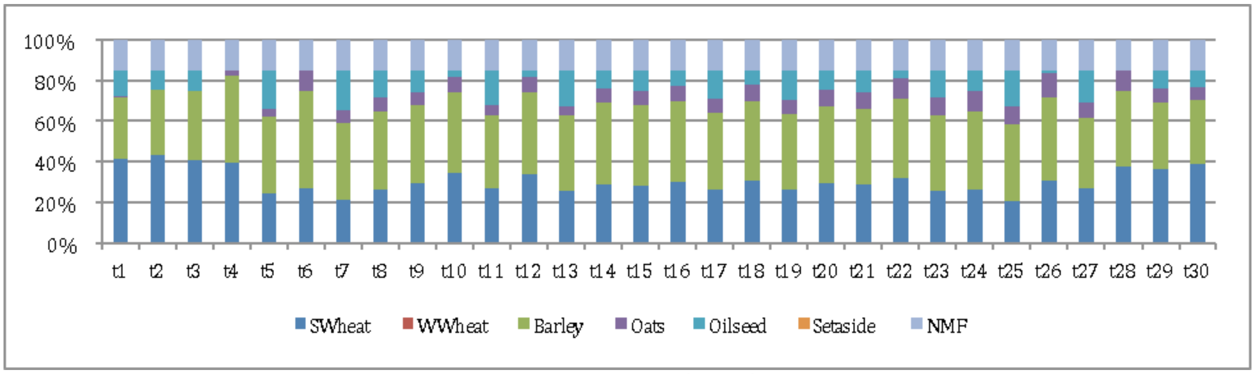

Fig. 2a. Land allocation under S1: high- disease-pressure vs. high-price **(+30 %)**.

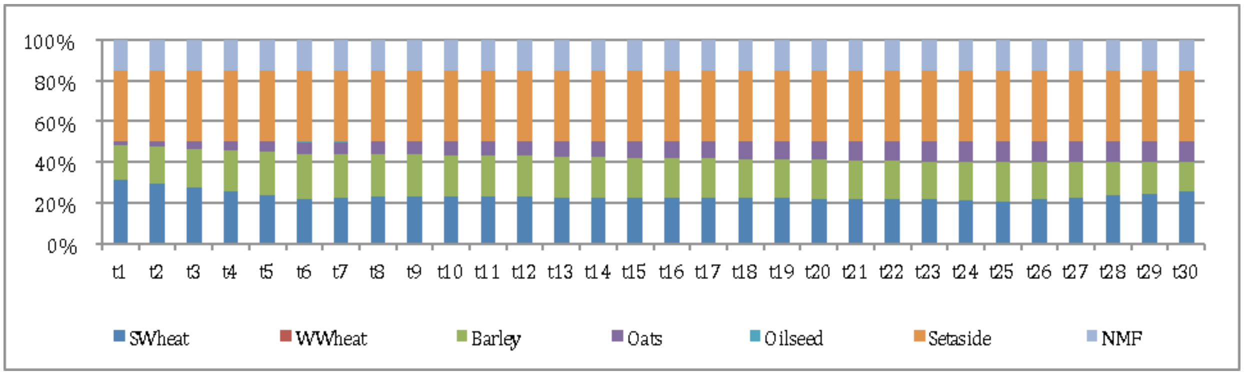

Fig. 2b. Land allocation under S6: low-disease-pressure vs. low-price (-30%).

TABLE 3. SIMULATED AVERAGE YIELDS, PROFIT , PH VALUE AND TIMES OF FUNGICIDE USAGE OVER THE NEXT 30 YEARS

		S1	S2	S3	S4	S5	S6
Average	Spring wheat	2941	2732	2623	3151	3119	2741

Yields	Winter wheat	-	-	-	-	-	-
	Barley	2639	2377	2261	3058	2749	2365
	Oats	2745	2549	2436	2970	2930	2553
	Oilseed	1349	1252	1188	1365	1358	1261
Gross margin €/ha/year		298	194	148	323	238	153
Fungicide, N		48	0	0	300	0	0
Average pH		6.57	5.86	5.52	6.59	6.49	5.52

5 Conclusions and Discussion

In this study, we develop a dynamic economic rotation model where we can optimize crop rotation system with various adaptation practices. Results indicate that crop rotation system favors more crops to tackle against increasing disease pressure. Market conditions such as high output prices play also a key role in providing incentive for farmers to utilize adaptation management. Low prices lead to cost minimization decreasing yields. Under sufficient prices, however, yield gap can be also narrowed down, or kept almost constant, by combining crop rotation with other management practices, despite increasing plant disease pressure. Interaction between different practices and also their influence to environment should be considered more closely. Liming doesn't only increase yield, it also decreases the need of phosphorus fertilization. Increasing disease pressure in the future is taken into account in breeding for more disease resistant cultivars. However, these robust cultivars might lose some of their yield potential. Therefore, the trade-off between fungicide treatment costs and yield gain is the decisive factor. The model can also be used in evaluating the value of new cultivars better tuned to increasing length of growing season and a possible worsening of early summer drought in future climate.

6 References

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