Assessing the adaptation of arable farmers to climate change using DEA and bio-economic modelling

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Introduction

Climate change (CC) affects agricultural production all over the world. Future farming systems are challenged to adapt to the changing socio-economic and bio-physical environment in order to remain competitive and to meet the increasing requirements for food and fibres. Identifying technological trends and exploring possible adaptation strategies is crucial for designing future farming systems and effective agricultural and environmental policies. Identification of current "best" farm practices and assessment of many alternative adaptation options is necessary for comprehensive explorations. The increased occurrence of extreme events, price volatility, variation among individual farms (in terms of available resources and objectives) and investment decisions should be also taken into account. The objective of this article is to assess the impact of CC on arable farming systems in Flevoland (the Netherlands) and to explore the adoption of different adaptation strategies. We applied Data Envelopment Analysis (DEA) that uses empirical data from individual farms to identify "best" current farm practices and derive relationships regarding current farm management. A Bio-economic farm model was used to simulate the behaviour of individual farmers and explore regional CC scenarios for 2050. Impacts of gradual CC change on crop yields but also the impacts of the increased occurrence of extreme events were taken into account. Adaptation options were identified in workshops while possible price changes were simulated.

Materials and Methods

The Farm System SIMulator (FSSIM) is a bio-economic farm model that simulates the farmer's behaviour within a scenario setting (Janssen et al., 2010). FSSIM consists of two main components: i) the agricultural management component (FSSIM-AM), where current and alternative production activities are quantified (with respect to inputs and outputs), and ii) the mathematical programming component (FSSIM-MP) that allocates optimally the available farm resources to the different activities by maximizing gross margin and by accounting implicitly through calibration for other objectives of the farmer. Given the optimum farm plans and the identified input-output relationships, a number of bio-physical and economic indicators are quantified. DEA was used to recover relationships between important inputs and outputs involved in arable farming in Flevoland. Inputs, outputs and farm resources of 85 representative, individual farms from the Farm Accounting Data Network were used. To assess current farm management, the 85 farms were ranked based on their capacity to convert inputs into outputs and the best farm practices were identified. To explore changes towards 2050, regional CC scenarios from the Royal Dutch Meteorological Institute (KNMI) were combined with socio-economic scenarios (Riedijk et al., 2007). A Bio-physical model (WOFOST) was applied to calculate the crop yields and their fertilizer inputs for the scenario of globalized economy with a simultaneous strong increase of temperature and atmospheric CO_2 concentration (A1-W) (Table 1) while a semi-quantitative and participatory approach (ACC) was used to quantify the impacts of extreme events (e.g. prolonged wet periods in spring, dry conditions in spring and summer) on crop yields and quality (Schaap et al., 2011). Relevant adaptation options for preventing yield losses due to increased occurrence of prolonged wet periods in spring and dry conditions in spring and summer were identified after interaction with stakeholders (Table 2). Given the current set of production options and the expected changes in the input-output relationships because of CC, the available agricultural activities of the future were generated. The partial equilibrium model CAPRI (Britz et al., 2007) was used to simulate prices for the future scenario, considering impacts of CC and technological developments on crop yields. FSSIM-MP was used to simulate each of the 85 individual arable farms and calculate farm performance in different model runs: 1) FSSIM was calibrated to current input-output levels (*Base*), 2) expected increase of yields in 2050 because of temperature rise, longer growing seasons and increased atmospheric CO_2 concentration, but also yield losses due to the increased occurrence of extreme events were taken into account (*Yield*), 3) relevant adaptation options presented in Table 2 and all their possible combinations, were evaluated (*Adapt*), 4) the impact of simulated prices for 2050 calculated by CAPRI were assessed (*Price*), 5) the consequences of increasing scale of production, through hiring land and labour, increasing capital inputs and extending livestock activities were evaluated (*Scale*). Specifications of model run 2 to 5 are additive (conditions of 2 are added to 3 etc.).

Results and Discussion

Results of DEA show that existing arable farming systems in Flevoland are very close to technical efficiency and only 5% of the existing farm practices can produce the same amount of outputs with fewer inputs. Moreover, simulations with FSSIM showed that almost 40% of the existing arable land in Flevoland is used in a way that profit is maximized. Yield changes due to temperature rise, and increased atmospheric CO_2 even with increased occurrence of extreme events (*Yield*) result in substantial increase in production of all main crops assuming an increase of fertilizer use (45%) (Figure 1). The increased occurrence of extreme events reduced yields, but these do not offset the projected increases due to gradual CC. Offering adaptation options in the *Adapt* scenario resulted in slightly higher gross margins (Figure 1a). The most preferable adaptation options are those of increasing sowing densities (43 % of the area), and soil organic matter content (19% of the area) because of the low investment requirements. GPS steering is selected for 8% of the land and by those farmers where capital is not the main limiting resource. The simulated price increase of main crop outputs is much lower than the price increase of inputs. As a result, in the *Price* model run the gross margin decreases substantially (Figure 1a). Total production of potatoes, onions and sugar beet decreases while the revenues from livestock activities and soft wheat production increases substantially. Input levels also decrease (Figure 1b). The percentage of land where GPS steering and automatic inflation is used increases (20 and 14%) because of lower capital requirements. Allowing for increasing scale of production by hiring more labour, renting more land and increasing capital inputs (*Scale*), improved the farm's gross margin. It can be concluded, that the A1-W scenario will result in reduction of farm income, decreased demand for labour and land, and diversification of production. CC will have a positive impact on crop yields in the Netherlands. However, the projected input/output price ratio has a larger impact. A combination of adaptation options like increasing sowing densities and soil organic matter content, and precision agriculture techniques were simulated to be adopted by farmers to avoid the impact of extreme events.

Table 1: Changes in crop yields and fertilizer use as calculated by WOFOST model for A1-W scenario (2050) versus current yields.

	Current Yield (tons/ha)	Yield change (%)		Fertilizer change (%)
		Gradual CC	CC + extreme events	
Soft wheat	8	14	14	17
Potatoes	57	7	6	9
Sugar beet	74	30	30	37
Vegetables	66	20	8	25
Other arable crops		20	20	25

Table 2: The impacts of adaptation option on the inputs and outputs of an average year in 2050

	Additional input requirements				Beneficial effect on production				
	Capital (1000 €)	Mainten -ance (€)	Labour* (hrs/ha)	Energy (€/ha)	Potatoes (%)	Onions (%)	Sugar beet (%)	Wheat (%)	Other arable output (%)
More org. matter top soil	0		10	100	1.5%	1.5%	0.2%	0.2%	0.2%
GPS steering	20	300	10		5.2%				
Automatic inflation	20	300	8		3.3%				
Irrigation in Spring	25	400	40	100		6.5%			
Re-sowing	0.5		25	250		3.1%			
Higher sowing density	0.5					0.5%			
Irrigation in Summer	25		40	100		12.6%			

*Additional labour and energy requirements are calculated based on the farm specific areas of potatoes and onions.

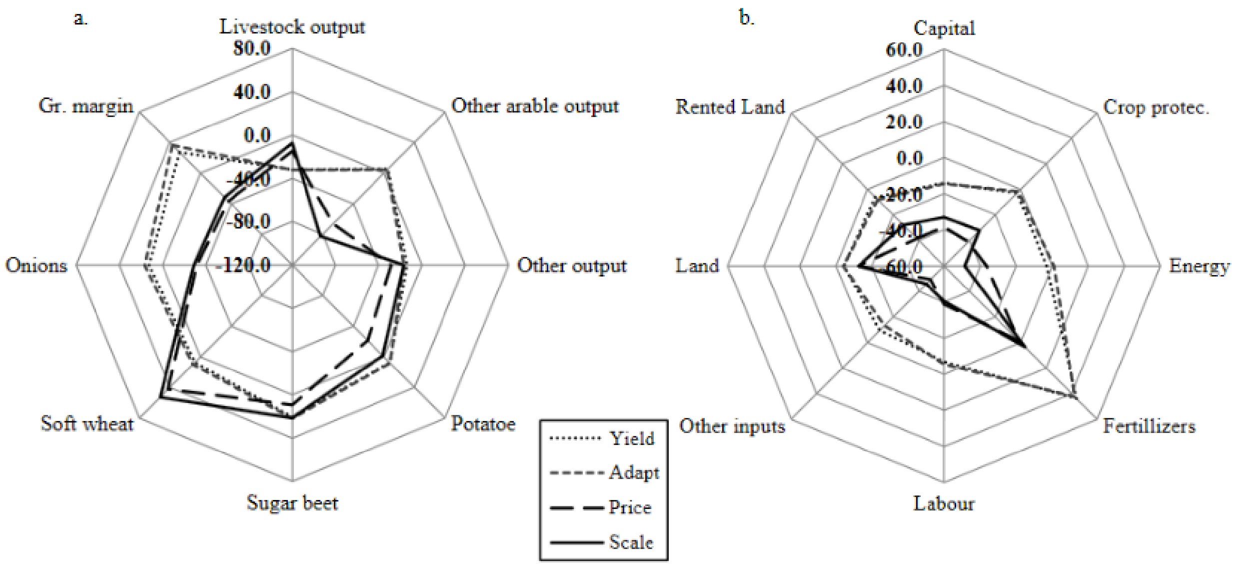

Figure 1. Average simulated levels (for 85 farms) of a) outputs and b) inputs in different model runs, expressed in percent change from Base model run.

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