Impacts of agri-environmental policies on land allocation and land prices

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Contributed paper prepared for presentation at the International Association of Agricultural Economists Conference, Gold Coast, Australia, August 12-18, 2006

1. Introduction

In this paper we develop a Ricardian model of heterogeneous land quality. Within this framework, the main objective of this paper is to analyse how policies used to support farm incomes, reduce negative externalities or enhance provision of positive externalities may influence land allocation decisions and land prices. Our analysis is oriented to the European Union (EU) and the instruments retained aim to fit the main features of the current situation in the EU in a similar vain as in Guyomard et al. (2004), but focusing more on land prices.

Farmland is here valued for its productive component using the present value approach where the current value of a parcel is measured as the sum of the expected future cash flows discounted according to their respective risks (Goodwin et al., 2003). Our objective is to analyse how agri-environmental programmes may affect cash rents, since a prediction about the direction of cash rents will be equivalent to a prediction about the direction of land prices under the assumption that policies influence farmland prices essentially through their impacts on cash rents.

2. Agri-environmental policies in a Ricardian framework

We focus on the following policy instruments:

(i) A *crop area payment s*, which can alternatively be fixed over all qualities or be dependent on land quality, reflecting compensation from the removed price subsidy.

(ii) A *buffer strip of a predetermined* size denoted by $\overline{m}$. It is a precondition for obtaining crop area payment, representing thus in a simple and simplified way cross-compliance entailed in the June 2003 CAP reform.

(iii) *A buffer strip payment b(m)* paid for the part of buffer strip exceeding the mandatory

> size of the buffer strip and modelled as a function. This buffer strip payment is decreasing in the size of the buffer strip. More specifically, we assume that the buffer strip payment, $b(\hat{m})$, is positive but decreasing for $\hat{m} = m - \overline{m} > 0$, but $b(\hat{m}) = 0$ for $\hat{m} = m - \overline{m} = 0$, that is, for the mandatory buffer strip size. To analyze the comparative statics of the buffer strip payment, we actually express it as $\varepsilon b(\hat{m})$ but normalize for most of the discussion ε to 1.

Under a policy consisting of a combination of these instruments, the farmer has to decide upon two things. He has to choose the rate of fertilizer application and the size of the buffer strip and he has to decide allocation of land into cultivation. We assume that agricultural production is carried out under heterogeneous land quality. The land can be classified into parcels which are of the same size and homogeneous in land quality. Land quality differs over parcels. We rank the land quality by a scalar measure *q*, with the scale chosen without loss of generality so that minimal land quality is zero and maximal land quality is one, i.e., $0 \le q \le 1$. Let *G(q)* denote the cumulative distribution of *q* (acreage having quality *q* at most), while *g(q)* is its density, which is by assumption continuous and differentiable. The total amount of land is thus

$$G = \int_0^1 g(q)dq\,. \tag{1}$$

Suppose for simplicity that there is only one representative cereal crop to capture area allocated to crop production. A part of land can naturally be allocated to other agricultural uses as well. Other agricultural use is described by allowing land use for pasturing or fallowing purposes. The cereal crop is produced under constant returns to scale technology on each parcel of quality *q*.

Agricultural output per unit of land area, y, is a function of land quality q and the fertilizer application rate l, $y = f(l;q)$. The production function is increasing and concave in fertilizer and land quality, that is, $f_l(l;q) > 0$, $f_{ll}(l;q) < 0$, $f_q(l;q) > 0$, $f_{qq}(l;q) < 0$. As for the other agricultural use of land we assume that the revenue per unit of land area generated by this other use is π^F. Moreover, we assume for simplicity that it is independent of soil quality. Let L_A denote the share of land allocated to crop and L_F the share of land allocated to other use.

Let p and c denote the respective prices of crops and fertilizer. We divide fixed costs per hectare into two classes, to those that depend on the size of actually cultivated parcel (I) and to costs independent of this size (F). We then can express the profit function of a representative farmer for a parcel of quality q as follows,

$$\pi^A = (1-\hat{m})\left[pf(l;q) - cl - I + s\right] + b(\hat{m}) - F \, . \tag{2}$$

Solution to maximization problem (2) may contain two types of parcels, those in which only mandatory buffer strips are established and those in which larger buffer strips are used. If voluntary buffer strip payment is absent, the problem of the farmer is

$$\pi^A = (1-\overline{m})\left[pf(l;q) - cl - I\right] + s - F \, . \tag{2'}$$

In the former, both fertilizer application and buffer strip size are chosen. For the latter the only free choice is to choose fertilizer application. We analyze in what follows the farmer’s choice under (2). The simpler case of (2’) can readily be derived from the more general analysis. The first-order conditions characterizing the farmer’s optimal choices for (2) are

$$\pi_l^A = pf_l - c = 0 \tag{3a}$$

$$\pi_m^A = -pf(l;q) + cl + I - s + b'(\hat{m}) = 0\,. \tag{3b}$$

From (3a) and (3b), the fertilizer application rate and the buffer strip size should be chosen to equate marginal revenue with their marginal costs. As shown elsewhere, the optimal fertilizer application rate and buffer strip size will vary across parcels due to differences in land quality (Lankoski and Ollikainen, 2003). On any given parcel, the comparative statics of the exogenous parameters on the use of inputs can be condensed to: $l = l(\underset{+}{p},\underset{-}{c},\, \underset{0}{s},\underset{0}{\varepsilon},\underset{0}{I},\underset{0}{F})$, $m = m(\underset{-}{p},\underset{+}{c},\, \underset{-}{s},\underset{+}{\varepsilon},\underset{+}{I},\underset{0}{F})$. The crop price increases the fertilizer application rate and decreases the size of buffer strips. Note that an increase in the producer price support works like an increase in the crop price. Neither crop area payments nor buffer strip payments affect the fertilizer application rate. They do affect, however, the buffer strip size. Crop area payments decrease the buffer strip size while buffer strip payments increase it. Finally, fixed costs depending on the size of actually cultivated part of parcel (*I*), have no effect on fertilizer intensity, while they increase the size of the buffer strips. Costs independent of this size (*F*) are neutral in terms of fertilizer use and buffer strips.

The allocation of land between crop production and other agricultural use will depend on the chosen policy instruments. We assume that the lower quality land will be allocated to other agricultural use (such as fallow) and the higher quality land to crop production. Recall the share of land allocated to crop production is denoted by L_A. Defining the total amount of relevant land allocated either to crop production or other agricultural use by 1, allows us then to express the other land use form, L_F, simply as $L_F = (1 - L_A)$. To obtain a solution where land is allocated to both uses, we assume that crop production yields higher profits than fallowing in high quality lands, while for low quality land the opposite holds.

As a result, the farmer maximizes his profits by allocating the land according to its quality and resulting rents between crop production and fallowing as follows

$$\max_{L_A} \int_0^1 \left[\pi^{A^*} L_A + \pi^{F^*} (1 - L_A) \right] g(q) dq \, , \tag{4}$$

where *'s refer to restricted profit functions which indicate the maximum rents obtainable from each parcel subject to exogenous market and policy parameters. By differentiation, the condition characterizing the critical land quality, q^c, can be expressed as $\pi^{A^*}(p, c, s, \varepsilon, I, F) = \pi^{F^*}$. Hence, the critical quality, defining the allocation of land between crop production and fallowing is obtained at the point where the rents from each use are equal. Above this land quality threshold the rents from crop production are higher than rents from fallowing, and vice-versa. From this critical quality condition the land area devoted to crop production can be defined as $H_A = \int_{q^c}^{1} g(q) dq = G(1) - G(q^c)$. The effects of exogenous parameters on land devoted to crop production can be obtained by differentiating this formula. We express the effects of changes in any exogenous variable as $\frac{\partial H_A}{\partial \theta} = -g(q^c) \frac{\partial q^c}{\partial \theta}$, where θ is an element of the vector of all exogenous variables. We first differentiate critical quality condition to see how the critical land quality depends on the exogenous parameters, that is we solve for $\frac{\partial q^c}{\partial \theta}$, to get,

$$\frac{\partial q^c}{\partial p} = -\frac{\pi_p^A}{\pi_q^A} < 0\,;\ \frac{\partial q^c}{\partial c} = -\frac{\pi_c^A}{\pi_q^A} > 0\,;\ \frac{\partial q^c}{\partial s} = -\frac{\pi_s^A}{\pi_q^A} \leq 0\,;\ \frac{\partial q^c}{\partial \varepsilon} = -\frac{\pi_\varepsilon^A}{\pi_q^A} \leq 0\,,\ \frac{\partial q^c}{\partial I} = -\frac{\pi_I^A}{\pi_q^A} > 0\,;$$

$$\frac{\partial q^c}{\partial F} = -\frac{\pi_F^A}{\pi_q^A} > 0\,;\ \frac{\partial q^c}{\partial I} = -\frac{\pi_I^A}{\pi_q^A} > 0\,. \qquad (5)$$

where $\pi_q^A = pf_q > 0$ for the case of a uniform crop area payment and $\pi_q^A = pf_q + s'(q) > 0$ for a quality dependent area payment. From (5), we show that an increase in the crop price reduces the critical quality of land allocated to crop production while an increase in fertilizer prices increases this critical land quality. We also show that higher fixed costs, be they dependent on cultivated share of parcel (*I*) or not (*F*), increase the critical land quality.

Land allocation follows one-to-one changes in the critical land quality. We have for market parameters; $\frac{\partial H_A}{\partial p} > 0$, $\frac{\partial H_A}{\partial c} < 0$, $\frac{\partial H_A}{\partial I} < 0$; $\frac{\partial H_A}{\partial F} < 0$, and for policy parameters we have; $\frac{\partial H_A}{\partial s} > 0$, $\frac{\partial H_A}{\partial \overline{m}} < 0$; $\frac{\partial H_A}{\partial \varepsilon} > 0$. The comparative statics of land allocation with respect to crop area payments, mandatory buffer strip size and voluntary buffer strip payment show that these instruments are not decoupled at the extensive margin.

3. Crop land price determination

Our time horizon is that of long run and it is assumed that the amount of land is fixed, that is, by the distribution of land qualities. Under these assumptions, our Ricardian framework provides a simple but effective implicit model of land price determination. In this model, the rent earned by the minimum quality of land equals the rent earned in pasture or fallowing, π^F. All land of higher quality earns a positive Ricardian crop rent equal to $\pi^{A}(q)-\pi^{F}$. This difference equals zero for the minimum quality of land in crop production. In our model the supply of land of each quality is fixed by the nature. Demand for land of each quality depends on crop rents. Every parcel which produces a positive crop rent is demanded for crop production. Hence, demand is positive for all parcels yielding zero or positive crop rent. The marginal willingness to pay for crop land equals that of other agricultural use at the critical land quality q^{c}. Below this quality level, the marginal willingness to pay for crop land falls short of that for e.g. pasturing and fallowing purposes.

What said above means simply that, under fixed supply of land, demand for this land determines solely the price of the crop land (see, e.g., Palmquist, 1989). Demand in turn is defined by the rents derivable from crop production. Hence, the price of crop land of any quality *q* can be simply determined as the sum of the intertemporal services it provides. In crop production this simply means the present values sum of the rents it provides over infinite time horizon. Denoting the price of land of quality *q* by *P(q)*, we thus have

$$P(q)=\int_{0}^{\infty}\pi(q)e^{-rt}dt=\frac{\pi^{A^{*}}(q)}{r}, \tag{6}$$

where *r* is the discount rate and the star indicates that we have the restricted profit function which, recall, indicates the maximum profits attainable subject to exogenous parameters.

We now examine how exogenous parameters affect the price of crop land of quality *q*. We start with the market instruments, crop prices *p* and fertilizer unit costs *c*. Differentiating (6) with respect to p and c, and evoking the envelope theorem, yields $\frac{dP(q)}{dp} = \frac{\pi_p^{A^*}}{r} > 0$; $\frac{dP(q)}{dc} = \frac{\pi_c^{A^*}}{r} < 0$. Higher crop prices make crop production more profitable over all parcels and increase the price of land of each quality allocated to crop production. Higher fertilizer costs have just the opposite effect.

We continue with the agri-environmental policy parameters and first focus on the crop area payment. Recall that we allowed either for a uniform or quality-dependent area payment. Differentiating (6) with respect to s under these alternative assumptions yields: $\frac{dP(q)}{ds} = \frac{\pi_s^{A^*}}{r} > 0$; $\frac{dP(q)}{ds(q)} = \frac{\pi_{s(q)}^{A^*}}{r} > 0$; $\frac{dP(q)}{ds(\hat{q})} = \frac{\pi_{s(\hat{q})}^{A^*}}{r} = 0$. An increase in the uniform area payment increases the land prices for all crop land qualities. While an increase in the area payment dependent on quality q increases the price of this quality land, a higher area payment dependent on quality $\hat{q} \neq q$ has no effect on the land price of quality q. For the effects of a mandatory buffer strip and buffer strip payment, we obtain $\frac{dP(q)}{d\overline{m}} = \frac{\pi_{\overline{m}}^{A^*}}{r} \leq 0$; $\frac{dP(q)}{d\varepsilon} = \frac{\pi_\varepsilon^{A^*}}{r} \geq 0$. A higher buffer strip norm decreases the price of crop land while buffer strip payments increase the price of those qualities, where larger buffer strips are profitable.

We finally investigate how general tax and monetary policy affects crop land prices. Suppose that the tax authorities levy a tax, t, on the farm income with full tax deductibility of costs. In economic terms, this type of tax functions like a profit tax, that is, a tax on the rent from agriculture, being thus neutral in terms of agricultural production decision. As is well-known, adjusting the interest rate is one of the basic means of monetary policy. For this purpose we denote the discretionary policy parameter of the Central Bank of Monetary Union by *d*, thus $r = r(d)$. Moreover, we assume that $r'(d) > 0$. By increasing its market operations, the Central Bank can increase interest rate level, and vice-versa. Under these assumptions, the after-tax land price defined by our model becomes

$$\hat{P}(q) = (1-t)\int_0^\infty \pi(q)e^{-r(d)t}dt = (1-t)\frac{\pi^{A^*}(q)}{r(d)}. \qquad (7)$$

Differentiating (7) with respect to *t*, *r* and *d* yields: $\frac{d\hat{P}(q)}{dt} = -\frac{\pi^{A^*}}{r} < 0$, $\frac{d\hat{P}(q)}{dr} = -(1-t)\frac{\pi^{A^*}}{r^2} < 0$; $\frac{d\hat{P}(q)}{dd} = -(1-t)\frac{r'\pi^{A^*}}{r^2} < 0$. Higher profit taxes decrease land prices and so do higher real interest rates. Discretion towards higher interest rate has a similar effect, indicating that policy towards lower interest rates increases land prices. Thus, not only agri-environmental parameters determine land prices but also general macroeconomic policy parameters affect prices as well.

4. Empirical application to Finnish agriculture

We now apply our analysis to Finnish agriculture. Prices, costs, and subsidies/payments are from year 2003. The parameter values used in this application are reported in Appendix. In addition to fertilizer costs, also other variable costs (such as seeds, plant protection, fuel, etc.) of cultivation are included, as well as labour and machinery costs (machinery costs include depreciation, repair, insurance, interests). The profit earned from growing wheat on any given production unit is given by

$$\pi_i^A = (1-\hat{m})[p\alpha_i(1-\gamma e^{-\beta l_i}) - cl_i - \chi - \varphi + s] - k \quad \text{for } i = 1, .., 20 \qquad (8)$$

where χ represents expenditures per hectare for all variable inputs except fertilizers, φ is labour cost per hectare and k is machinery cost per hectare. We use the Mitscherlich nitrogen response function for wheat, $y = \alpha(1-\gamma e^{-\beta l})$, where y is yield per hectare, l is nitrogen use per hectare, and α, β and γ are parameters. Land quality is incorporated through the parameter α in order to calibrate nitrogen response function to the actual yield levels at a certain fertilizer use in Southern and Southwestern Finland. Land quality is assumed to be uniformly distributed with a minimum quality set to reflect the quality of typical set-aside land allocated to long-term fallowing. Parameter α is assumed to be linear in land quality, that is, $\alpha = \mu_0 + \mu_1 q$. The model contains 20 production units of differential land quality.

Policy instruments and policy packages are described in Table 1. Reflecting our theoretical model, we include both versions of crop area payments, uniform and quality-dependent area payments. Both area payment policies can be modified by combining them with cross-compliance requirements. In our model this cross-compliance requirement is defined by a mandatory buffer strip policy. These assumptions define our policy experiments 1 to 4 as described in Table 1.

Table 1. Alternative agricultural income support and agri-environmental policies

Policy	Properties
Policy 1	**Uniform crop area payment s.** CAP compensation payment (€ 269 per hectare), LFA support (€ 150 per hectare) and national support (€ 105) for wheat. Each production unit is thus entitled to total payment of € 524 per hectare.
Policy 2	**Quality dependent crop area payment s(q).** Average quality production unit receives area payments totalling of € 524

	per hectare. Lowest quality unit is entitled to € 472 per ha and highest quality unit earns € 582 per ha.
Policy 3	**Policy 1 plus environmental cross-compliance** A mandatory 3-meter-wide buffer strip.
Policy 4	**Policy 2 plus environmental cross-compliance** A mandatory 3-meter-wide buffer strip.

The alternative to cultivation is fallowing arable land. We assume that the net-return for fallow land is independent of land quality. The fallow land is entitled to a CAP compensation payment (€ 207 per hectare) and LFA support (€ 150 per hectare). Given that the costs of establishment and management are 35 €/ha, the net return to fallow is € 322 per hectare.

Following our theoretical analysis, we start with the "preliminaries" and collect in Table 2 the effects of the four policy experiments on fertiliser use per parcel, buffer strip size, land allocation, total wheat production, per-hectare profits for wheat cultivation and total profits including the return for fallow land, and finally budget costs. For per-hectare fertilizer use and profits, we present the mean and the spread.

Table 2. Effects of alternative policy scenarios on fertilizer use, land allocation, production, per-hectare and total profits, and budget costs.

Policy	Fertilizer use kg	Buffer strip, %	Land allocation Wheat : fallow	Total production, kg	Profit, €/ha	Total profit, €	Budget cost, €
Policy 1	137.9 (129.9 – 145.6)	-	16 : 4	62 563	367.5 (327.3 – 408.2)	7168	9812
Policy 2	139.5 (133.3 – 145.6)	-	13 : 7	51 840	398.8 (331.6 – 466.4)	7439	9614
Policy 3	135.3 (126.9 – 143.4)	0.015	17 : 3	65 044	364.7 (322.5 – 407.4)	7166	9979
Policy 4	137.4 (131.3 – 143.4)	0.015	13 : 7	51 063	398.5 (331.8 – 465.6)	7435	9614

Table 3 presents the impacts of these four policy experiments on pre-tax land prices (column two) and its comparative statics, that is, land price changes in reaction to a 10 % increase in wheat prices, fertilizer costs, uniform area payments and land quality dependent area payments. The second column of Table 3 shows how the four policy experiments affect pre-tax land prices. One immediately verifies that these prices always increase with land quality, for a given policy experiment. One also notes that they are higher in policy experiments 2 and 4 where the area payment depends on land quality (and here it is assumed to increase with the land quality index) relative to experiments 1 and 3 where the area payment does not depend on land quality. This result shows that the crop area payment capitalises in land prices. Let us, for example, consider the land price for the highest land quality in experiments 1 and 2. In experiment 1, the highest quality land price is € 8164 per hectare for a payment of € 524 per hectare. In experiment 2, the highest quality land price is € 9327 euros per hectare for a payment of 582 euros per hectare (see Table 1). These figures show that an area payment increase by 11 % leads to a land price increase by more than 11 %, here 14.2 %.

Table 3. Effects of a 10% increase in the market and policy instruments on pre-tax land prices.

		Effects on pre-tax land prices of a 10 % increase in			
	Pre-tax land price, €/ha	Crop price	Fertilizer price	Uniform area payment	Quality-dependent area payment
Policy 1	7350 (6545-8164)	8117 (6980-9270)	7148 (6464-7840)	8184 (7172-9212)	-
Policy 2	7977 (6632-9327)	8530 (6637-10434)	7777 (6556-9003)	-	8466 (6568-10375)
Policy 3	7294 (6450-8148)	8103 (6982-9238)	7148 (6474-7829)	8184 (7187-9196)	-
Policy 4	7971 (6635 - 9312)	8512 (6634-10401)	7775 (6563-8993)	-	8464 (6580-10360)

The last set of results, collected in Table 4, deals with the effects of general tax and monetary policies on agricultural land prices. The first column defines the after-tax price of land while the next two present the effect of changes in the tax and discount rates, respectively.

Table 4. Effects of general tax and monetary policy on after-tax land prices (prices under wheat cultivation or fallow land)

	After-tax land prices (€/ha)		
	t = 25% r = 0.05	t = 35% r = 0.05	t = 25% r = 0.06
Policy 1 (wheat)	5513 (4909-6123)	4778 (4254-5307)	4594 (4091-5103)
Policy 2 (wheat)	5983 (4974-6996)	5185 (4310-6063)	4985 (4145-5830)
Fallow	4830	4186	4025

The tax applied to agricultural net revenue effectively decreases land prices. We also observe that increases in profit taxes (column 3) or interest rates (column 4) increases land prices. Interestingly, we empirically find that an increase of the profit tax from 25 to 35 % decreases land prices by the same percentage, 13.3 %, under both policy 1 and 2, while a 10% increase in fertilizer prices decreases land prices by only 2.9 % under policy 1 and 2.6 % under policy 2.

This illustrates that these general macroeconomic factors may have effects far more important than minor fine tunings in agri-environmental policies.

5. Conclusions

We developed a Ricardian model with land quality heterogeneity for analysing the effects of agri-environmental policies, as well as general tax and monetary policies, on agricultural land allocation and agricultural land prices. The theoretical framework was illustrated by an empirical application to Finnish agriculture focused on wheat producers who have to allocate their land between wheat and fallow. The empirical application supports the theoretical framework. We illustrated how market and/or policy parameters affect agricultural land prices and how changes in these parameters capitalise in land prices. In particular, we showed that uniform and quality-dependent area payments capitalise in land prices, more specifically that they capitalise differently in land prices for each parcel according to the quality of the latter.

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Appendix: Parameter values used in the numerical application

Parameter	*Symbol*	*Value*
Price of wheat	p	€ 0.128/kg
Price of nitrogen fertilizer	c	€ 1.15/kg
Expenditure for other variable inputs than fertilizers	χ	€ 186/ha
Labour costs	φ	€ 143/ha
Machinery costs	k	€ 168/ha
Area payments	s	
CAP compensatory payments		€ 269/ha
LFA support		€ 150/ha
National support		€ 105/ha
Mitscherlich nitrogen response function	α	4182 – 5164
	β	0,0104
	γ	0,7623