IMPACTS OF AGRI-ENVIRONMENTAL POLICIES ON LAND ALLOCATION AND PRICES

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Abstract. We develop a Ricardian framework with heterogeneous land quality to analyse how policies used to support farm incomes, reduce negative agri-environmental externalities and enhance the provision of positive externalities influence land allocation decisions and land prices. Four agri-environmental policy instruments are considered: a uniform area payment, a quality-dependent area payment, a mandatory buffer strip policy and a voluntary buffer strip payment. We also analyse how general tax and monetary policies may affect agricultural land prices. The theoretical framework is illustrated by an application to Finnish agriculture.

Keywords. Land allocation, land rents, agri-environmental policies.

1. Introduction

Government intervention is still pervasive in agriculture. The different ways governments intervene to achieve one or several objectives are clearly not equivalent because some types of policy instruments are more efficient and/or less production and trade distorting than others. Chosen policy instruments may affect the amount of crop produced, input use intensities and land allocation. Even decoupled instruments may entail some or all of these effects. As a result, it is important to closely examine what types of effects each policy instrument causes.

Using a static and riskless single-output partial equilibrium of the farm sector, Hertel (1989) compares the impacts on production, exports, input demands, consumption prices and land prices of export, output and input subsidies that have equal cost or deliver equal support to farmers. Within this framework where land supply is imperfectly elastic, the production and trade effects of output payments are shown to be lower than those of export and input subsidies (provided the subsidised input and land are substitutes). Dewbre et al. (2001) use a similar framework to compare the production, trade and income effects of four policy instruments (a market price support, an output subsidy, area payments and input subsidies to purchased inputs). Payments based on land use are shown to be the most efficient, followed by output subsidies, market price support and subsidies based on use of purchased inputs. The ranking of production and trade distortion effects is just the reverse with payments based on use of purchased inputs being the most distorting.

In this paper, we develop a static and riskless Ricardian model of heterogeneous land quality. Within this framework, we 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). Instruments retained therefore 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. More precisely, we consider an area payment policy, a cross-compliance measure here represented by a buffer strip of a predetermined size, and a buffer strip payment granted to farmers for buffer strip sizes in excess relative to the minimum buffer strip area.

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). Some recent studies suggest that the present value model does not fully explain farmland values and prices. Other determination factors include the consumptive component (the intrinsic value of land for the owner), the speculative component and transaction costs (Tsoodle et al., 2003). However, Falk and Lee (1998) results suggest that these other components essentially play a role in the short run explaining land price deviations from the values implied by the present value model, while farmland prices return to the present value over time, i.e., in the long run.

Our present value model is considerably simplified by considering that the discount rate is the same for each source of returns (on this point see, for example, Weersink et al. (1998) or Goodwin et al. (2003) who attach different discount rates to return components in function of their origin, market returns versus government payments). In addition, the common discount rate is assumed constant over time. These assumptions are restrictive. However, our objective here is not to assess the relationship between cash (i.e., uncapitalised) rents and land values. It is to analyse how agri-environmental programmes may affect cash rents. 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

In this section we work out the preliminaries needed for the analysis of land price determination in a Ricardian model of heterogeneous land quality. These preliminaries entail analyzing the production and land allocation decision subject to EU policies.

Drawing on our brief characterization, 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 reform of the Common Agricultural Policy (CAP).

(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. Specifically, we assume that the buffer strip payment, $b(\hat{m})$, is positive but decreasing for $\hat{m} = m - \overline{m} > 0$, with $b(\hat{m}) = 0$ 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 package consisting of a combination of these instruments, the farmer has to choose the rate of fertilizer application, the size of the buffer strip and allocation of land into cultivation. These decisions entail many possibilities. The farmer may not establish buffer strips at all and refuse to receive crop area payments. Alternatively, he may establish the mandatory buffer strip only to obtain the area payment, or a larger buffer strip to obtain in addition buffer strip payments. These decisions depend on the agricultural production conditions which we focus on next, but drawing on previous literature we can anticipate that larger buffer strips will most likely be established on lower quality parcels allocated to agriculture (see, e.g., Lankoski and Ollikainen, 2003; Lankoski et al., 2004).

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., $0 \le q \le 1$ (Lichtenberg, 1989). 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

$$G = \int_0^1 g(q)dq \,. \qquad (1)$$

Suppose for simplicity that there is only one representative cereal crop to capture area allocated to crop production. Part of land can naturally be allocated to other agricultural uses as well. These alternative agricultural uses are 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, that is, $y = f(l;q)$. 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 land use form, 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 uses. These two land use forms exhaust, by assumption, the whole available land.

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

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

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 payments are absent, the profit function reduces to

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

In the former equation (2), both fertilizer application and buffer strip size are chosen. For the latter (2'), the only free choice is 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

$$\pi_l^A = pf_l - c = 0 \qquad (3a)$$

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

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; Lankoski et al., 2004). On any given parcel, the comparative statics of the exogenous parameters on the use of inputs can be condensed to

$$l = l(p,c,s,\varepsilon,I,F) \qquad (4a)$$
$$(+, -, 0, 0, 0, 0)$$

$$\hat{m} = \hat{m}(p,c,s,\varepsilon,I,F) \qquad (4b)$$
$$(-, +, -, +, +, 0)$$

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 buffer strips. Costs independent of this size (*F*) are neutral both in terms of fertilizer use and buffer strips.[ii]

If the policy entails a mandatory buffer strip only (or if the farmer does not accept voluntary buffer strip payments for some parcels), then (2') alone would characterize his economic decision. Fertilizer application would then depend positively on the crop price and negatively on the fertilizer costs, but not on the area payment, the size of the mandatory buffer strip and the two types of fixed costs, i.e.,

$$\underset{(+,\,-,\;0,\;0,\;0,\;0)}{l = l(p, c, s, \overline{m}, I, F)} \qquad (4c)$$

Results in (4a) - (4c) suggest that the crop area and the buffer strip payments are decoupled in fertilizer margin intensity on the cultivated land of quality *q* (equations 4a and 4c). But they are not decoupled on the land parcel of this quality as they have an impact on the size of the buffer strip (equation 4b).

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

$$\max_{L_A} \int_0^1 [\pi^{A*} L_A + \pi^{F*}(1 - L_A)] g(q) dq\,, \qquad (5)$$

where the stars 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

$$\pi^{A^*}(p, c, s, \varepsilon, I, F) = \pi^{F^*}\,. \qquad (6)$$

According to (6), the critical quality, defining the allocation of land between crop production and fallowing is obtained at the point where rents from each use are equal. Above this land quality threshold, rents from crop production are higher than those from fallowing, and vice-versa.

Clearly, solution in (6) is a function of all exogenous variables. When these exogenous variables change, land allocations change too. From (6), the land area devoted to crop production can be defined as

$$H_A = \int_{q^c}^{1} g(q)dq = G(1) - G(q^c)\,. \qquad (7)$$

The effects of exogenous parameters on land devoted to crop production can be obtained by differentiating this formula, accounting for the fact that the critical land quality is implicitly defined by (6). 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 (6) 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,

$$\frac{\partial q^c}{\partial p} = -\frac{\pi_p^A}{\pi_q^A} < 0\,;\ \frac{\partial q^c}{\partial c} = -\frac{\pi_c^A}{\pi_q^A} > 0\,;\ \frac{\partial q^c}{\partial s} = -\frac{\pi_s^A}{\pi_q^A} \le 0\,;\ \frac{\partial q^c}{\partial \varepsilon} = -\frac{\pi_\varepsilon^A}{\pi_q^A} \le 0\,,$$
$$\frac{\partial q^c}{\partial I} = -\frac{\pi_I^A}{\pi_q^A} > 0\,;\ \frac{\partial q^c}{\partial F} = -\frac{\pi_F^A}{\pi_q^A} > 0\,. \qquad (8)$$

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. The remaining derivates can be obtained from equation 2.

From (8), we see 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 start with the market parameters, crop prices, fertilizer costs and fixed costs. We have

$$\frac{\partial H_A}{\partial p} > 0\,,\ \frac{\partial H_A}{\partial c} < 0\,,\ \frac{\partial H_A}{\partial I} < 0\,;\ \frac{\partial H_A}{\partial F} < 0\,. \qquad (9a)$$

Market parameters, crop prices and fertilizer costs, affect as expected. Higher prices (fertilizer costs) shift the critical land quality to lower (higher) quality parcels, thus, increasing (decreasing) land under crop production. As expected, both types of fixed costs decrease the land allocated to crop production.

Policy parameters include crop area and buffer strip payments, as well as the mandatory buffer strip size. By differentiation, we have

$$\frac{\partial H_A}{\partial s} > 0\,,\ \frac{\partial H_A}{\partial \overline{m}} < 0\,;\ \frac{\partial H_A}{\partial \varepsilon} > 0\,. \qquad (9b)$$

The effects of crop area payments are particularly interesting to detail. An increase in the uniform area payments, or a uniform increase in all quality dependent area payments, increases profitability over all parcels, thus shifting the critical land quality to lower quality lands. This, naturally, increases land area allocated to crop production. If the size of the crop area payment depends on land quality, any increase in the area payment for a given quality (but not for others) will affect the critical land quality and land allocation only if this increase takes place for the next parcels just below the critical quality. Increasing the size of the mandatory buffer strip decreases land in crop production. The reason is obvious. Rents from all parcels decrease as more land is allocated out of production. Therefore, for some lower quality parcels, rents from fallowing become higher and land is allocated to these

purposes. A higher buffer strip payment shifts the critical quality downwards and hence, increases land allocated to crop production.

In sum, 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. This feature has been shown to hold for area payments in Lichtenberg (2002). Now this finding is enlarged to buffer strip payments.

3. Crop land price determination

We are now in a position to start our analysis of the determination of agricultural land prices. To facilitate our analysis, we make the following assumptions. All markets are perfect and all agents have perfect foresight. Capital and labour are perfectly mobile in the economy and earn fixed, competitive return. Our time horizon is that of long run. 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

$$P(q) = \int_0^\infty \pi(q) e^{-rt} dt = \frac{\pi^{A^*}(q)}{r}, \qquad (10)$$

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 (10) with respect to p and c, and evoking the envelope theorem, yields

$$\frac{dP(q)}{dp} = \frac{\pi_p^{A^*}}{r} > 0\,; \quad \frac{dP(q)}{dc} = \frac{\pi_c^{A^*}}{r} < 0\,. \qquad (11)$$

Results are as expected. 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. In the case of quality-dependent area payments, we must distinguish between own effects of s(q) and cross effects of s(q^) on the price of land of quality q. Differentiating (10) with respect to s under these alternative assumptions yields

$$\frac{dP(q)}{ds} = \frac{\pi_s^{A^*}}{r} > 0\,;\ \frac{dP(q)}{ds(q)} = \frac{\pi_{s(q)}^{A^*}}{r} > 0\,;\ \frac{dP(q)}{ds(\hat{q})} = \frac{\pi_{s(\hat{q})}^{A^*}}{r} = 0\,. \qquad (12)$$

From (12), 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

$$\frac{dP(q)}{d\overline{m}} = \frac{\pi_{\overline{m}}^{A^*}}{r} \leq 0\,;\ \frac{dP(q)}{d\varepsilon} = \frac{\pi_{\varepsilon}^{A^*}}{r} \geq 0\,. \qquad (13)$$

According to (13), 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.

To collect, we have demonstrated that

Proposition 1. Agri-environmental determinants of crop land prices.
Under heterogeneous land quality, perfect markets and perfect foresight, crop land prices vary across land qualities and depend on market parameters and policy instruments. While higher crop prices, crop area and buffer strip payments generally increase land prices, higher fertilizer costs and higher mandatory buffer strip decrease it.

The effects of market parameters are obvious. Interestingly, higher area payments, as neutral as they are in terms of production intensities, have the effect of providing higher rents and thereby of increasing crop land prices. This clearly is opposed by the decreasing effect of higher mandatory buffer strips. Hence, these two instruments have an a priori ambiguous overall joint effect on crop land prices. Therefore, we cannot a priory define whether a decoupled policy towards area payments combined with the cross-compliance requirement of mandatory buffer strips actually increases or decreases land prices.

Let us ask next whether uniform versus quality-dependent area payments affect crop land prices differently, or not. Obviously, this is an important issue as the main purpose of agri-environmental policies is not to let the support to capitalize in land prices. Our answer to this question is given in the following corollary.

Corollary 1.
For all parcels the uniform area payment being smaller than the quality dependent area payment, an increase in the uniform payment will induce a smaller effect on land prices than the quality dependent payment, and vice-versa.

Proof.
Consider any parcel j. Let $s > s(j)$. Then, for this parcel, $\pi^{A^*}[s] > \pi^{A^*}[s(j)]$. Conversely, if $s < s(j)$, then $\pi^{A^*}[s] < \pi^{A^*}[s(j)]$.

Corollary 1 has important implications. Quality dependent area payments will increase more the price of high quality lands than an average-type uniform payment. This might be an argument in favour of uniform payments.

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.[iii] 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

$$\hat{P}(q) = (1-t)\int_0^\infty \pi(q)e^{-r(d)t}dt = (1-t)\frac{\pi^{A^*}(q)}{r(d)}. \qquad (14)$$

Differentiating (14) with respect to t, r and d yields

$$\frac{d\hat{P}(q)}{dt} = -\frac{\pi^{A^*}}{r} < 0, \ \frac{d\hat{P}(q)}{dr} = -(1-t)\frac{\pi^{A^*}}{r^2} < 0; \ \frac{d\hat{P}(q)}{dd} = -(1-t)\frac{r'\pi^{A^*}}{r^2} < 0. \ (15)$$

The signs are obvious. 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, we have

Proposition 2. The effect of macroeconomic policy parameters on land prices.
Land prices are subject to general monetary and tax policies. These policies affect prices of each quality in a similar fashion. Higher profit taxes and interest rates decrease land prices over all qualities. Discretionary monetary policy towards higher (lower) real interest rate decreases (increases) land prices over all qualities.

Proposition 2 is important in showing that not only agri-environmental parameters determine land prices but also general macroeconomic policy parameters affect prices as well. It would be interesting to assess empirically what is the relative weight of these two types of parameters on land price levels. In the next section, we provide an answer to this question.[iv]

4. Empirical application to Finnish agriculture

We now apply our analysis to Finnish agriculture. For this purpose, we build a parametric model of agricultural production and land price determination for crop production. We use Finnish data to quantify the effect of alternative agricultural income support and agri-environmental policies on land prices in southern and south-western Finland. The production data come from studies performed on clay soils in southern Finland on which almost all wheat production occurs. Prices, costs, and subsidies/payments are from year 2003. 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 model is used to estimate input use, land allocation, production, profits and land prices under several policy environments.

4.1 A parametric model of wheat production

The profit earned from growing wheat on any given production unit is given by

$$\pi_i^A = (1-\hat{m})[p[\alpha_i(1-\gamma e^{-\beta l_i}) - cl_i - \chi - \varphi + s] - k + (\lambda - 0.5\omega\hat{m}_i)\hat{m}_i \quad for \text{ i = 1, .., 20} \quad (16)$$

where $(\lambda - 0.5\omega\hat{m}_i)\hat{m}_i$ is the buffer strip payment, 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. The parameter values used are reported in Appendix 1, Table A1.

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.

4.2. Empirical results

We report our results in three stages. We start with the case where uniform and quality-dependent area payments are paid alone or combined with the mandatory buffer strips (Tables 2 and 3). We then discuss the case where voluntary buffer strip subsidies are offered in addition to mandatory buffer strips (Tables 4 and 5). We finally report the effects of general tax policy (Table 6).

- Area payment and mandatory buffers strips

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

Policy experiment 1 assumes a uniform area payment of 524 euros per hectare (see Table 1). It results in the allocation of 16 hectares to wheat production and 4 hectares to fallow. For a budget cost of € 9812, total profits (wheat cultivation and fallow) amount to € 7168. Per-hectare wheat profits range between € 327.3 and 408.2, with an average value of € 367.5.

Policy experiment 2 assumes that the area payment is an increasing function of land quality, the highest (lowest) quality land receiving a payment of € 582 per hectare (€ 472 per hectare). This second experiment decreases the number of parcels allocated to wheat by 3 units and increases the number of fallow parcels by the same amount. Total wheat production is significantly reduced, by more than 17 %, due to the reduction in wheat area. For a budget cost of € 9614, total profits amount to € 7439. Relative to the first experiment, this second experiment increases total profits by 3.8 % and decreases budget costs by 2.0 %. The transfer efficiency of the quality-dependent area payment policy is thus greater than the transfer efficiency of the uniform area payment policy (0.77 versus 0.73, respectively).

Policy experiments 3 and 4 introduce cross compliance under the form of a mandatory 3-meter-wide buffer strip policy. In the case where the area payment does not depend on land quality, this cross-compliance requirement leads however to an increase in total wheat production because cultivated area of wheat increases (policy 3 relative to policy 1). This result may seem counterintuitive. Why would a reduction in wheat yields increase profitability of wheat cultivation? In practice, the result we obtain is an illustration of production in extreme agricultural conditions where, in the absence of support payments, agricultural profits are negative at the lowest quality parcels. In these circumstances, only lump-sum fixed payments make agriculture profitable. Under negative "operational profits" and low productivity, introducing a mandatory buffer strip as a cross-compliance requirement reduces the cultivated share dependent costs (*I*) more than the value of production decreases.[v] This makes the "operational profits" less negative and overall profits more positive, so that an additional parcel is allocated to wheat production (policy 3 relative to policy 1).[vi] By contrast, when the area payment is an increasing function of land quality introducing mandatory buffer strips as a cross-compliance requirement does not change wheat and fallow area. As a result, wheat production slightly decreases due to the buffer strips (policy 4 relative to policy 2).

These contrasted results highlight the importance of taking into account the whole set of policy instruments, and not each instrument separately. Moreover, policy instruments may produce perverse incentives for marginal low quality land. If we compare policy experiments 1 and 3, one note that the cross-compliance requirement reduces the transfer efficiency of the policy since total profits decrease while budget costs increase (the transfer efficiency of policy 3 is 0.72). In the case of policy experiments 2 and 4, the cross-compliance requirement also slightly decreases the transfer efficiency

of the policy since total profits decrease for an unchanged budget cost. But this transfer efficiency measure (agricultural profits on budget costs) does not include the environmental effects of the buffer strip that are likely to be positive.

We next turn to examine the effects of our policy experiments on agricultural land prices. 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, respectively, wheat prices, fertilizer costs, uniform area payments and land quality dependent area payments.

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 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 %.

The last four columns of Table 3 illustrate proposition 1, i.e., the fact that land prices increase with wheat prices and area payments, and decrease with input (fertilizer) costs.

- Voluntary buffer strip payments

We now turn to the case of voluntary buffer strip payments. These payments are combined either with policy 3 or with policy 4. From (20), recall that this payment takes the form $b(\hat{m}) = (\lambda - 0.5\omega\hat{m})\hat{m}$. Under our parameter values which reflect the Finnish situation (see Appendix 1), the number of parcels in wheat production with voluntary buffer strips depends on the policy scheme. Under uniform area payments in policy experiment 3, voluntary buffer strips are established on the 6 lowest quality parcels. Under quality-dependent area payments in policy experiment 4, voluntary buffer strips are established on the 3 lowest quality parcels only. The average share of voluntary buffer strips is 0.063 (with a range 0.102 - 0.025) with policy 3 and 0.0742 (0.107 - 0.042) with policy 4. The average buffer strip payment paid for the established voluntary buffer strip is € 17.5 (with a range € 31.2 - € 3.6) for policy experiment 3, and € 21.5 (with a range € 33.0 - € 9.9) for policy experiment 4.

Table 4 summarizes the effects of introducing voluntary buffer strip payments on fertilizer use per hectare, land allocation, wheat production, per-hectare and total profits, and budget costs.

Comparing Table 4 and Table 2 reveals the relevant differences. We first note that the average sizes of buffer strips are higher in policy experiments 3' and 4' relative to policy experiments 3 and 4, respectively. Land allocation does not change in policy 3' relative to policy 3. Due to the increased buffer strip size, average fertiliser use decreases. Wheat production decreases too. Per-hectare and total profits are practically unchanged, as are budget costs. The number of parcels allocated to wheat production increases by one unit in policy 4' relative to policy 4. This leads to an increase in wheat production although the average size of buffer strips increases. Per-hectare profits are (slightly) lower but total profits are practically unchanged. Budget costs increase from € 9614 in policy experiment 4 to € 9763 in policy experiment 4'.

Table 4. Effects of voluntary buffer strip payments with policy 3 or policy 4 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 3': policy 3 and buffer payment	133.1 (115.7 – 143.4)	0.032	17 : 3	64 019	365.0 (324.2 – 407.4)	7170	9976
Policy 4': policy 4 and buffer payment	135.2 (118.1 – 143.4)	0.027	14 : 6	53 984	393.2 (322.6 – 465.6)	7437	9763

Note: Buffer strip shares in this table refer to shares in total wheat area, including parcels for which only mandatory buffer strips are implemented.

Table 5 illustrates how land prices react when voluntary buffer strip payments are introduced. Comparing Table 5 and Table 4 shows that the differences are negligible. Land prices are slightly higher in policy 3' relative to policy 3. They are slightly higher in policy 4' relative to policy 4.

Table 5. Land prices under voluntary buffer strip payments

		Impact on pre-tax land prices (€/ha) of a 10 % increase in	
	Pre-tax land prices, €/ha	Crop price	Fertilizer price
Policy 3'	7299 (6485-8148)	8103 (6983-9238)	7154 (6507-7829)
Policy 4'	7864 (6452-9312)	8514 (6652-10401)	7765 (6576-8979)

- General tax policies

The last set of results, collected in Table 6, 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 6. Effects of general tax and monetary policy on after-tax land prices (prices under wheat cultivation of 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

Relative to Table 3, we note that the tax applied to agricultural net revenue effectively decreases land prices. In accordance with Proposition 2, 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. Concluding comments and policy implications

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. Our analysis was oriented to the EU. Accordingly, the agri-environmental policy instruments we retained aimed to fit some of the main features of the EU situation. We thus considered an area payment policy, undifferentiated with respect to land quality or land-quality dependent, a cross-compliance policy here represented by a mandatory buffer strip of a predetermined size, and a buffer strip payment policy granted to farmers for buffer strip sizes in excess relative to the minimum buffer strip area. 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 analytical part of the paper allowed us to define the comparative statics at the intensive margin of production, more precisely the comparative statics of fertilizer use and buffer strip size on a land parcel of a given quality. As expected, higher output prices decrease the size of the voluntary buffer strip while higher input costs increase it. Higher area payments decrease the size of the voluntary buffer strip while higher buffer strip payments increase it. In other words, crop area and buffer strip payments are not decoupled on a land parcel of a given quality as they affect the size of the voluntary buffer strip. The comparative statics of land allocation with respect to area payments, voluntary buffer strip payments as well as mandatory buffer strip sizes shows that these instruments are not decoupled at the extensive margin of production. In other words, they have an impact on agricultural land allocation choice. More precisely, a non differentiated area payment and a buffer strip payment increase land area allocated to agricultural production. Increasing the size of the mandatory buffer strip size decreases land area allocated to wheat production. Finally, the comparative statics of land prices show how market and policy parameters affect agricultural land prices. Higher output prices, area payments and voluntary buffer strip payments increase land prices while higher input costs and mandatory buffer strip sizes decrease it. General tax and monetary policies also have an impact on agricultural land prices and the empirical illustration shows that these macroeconomic factors can be far more important than minor fine tunings in agri-environmental policies.

The empirical application supports the theoretical framework. In addition, it illustrates how important it is to consider the whole policy package and not each measure independently, for assessing

the effects of a given instrument. This is because the latter may induce changes in agricultural land allocation. More precisely, we illustrated that a policy of crop area payments and mandatory buffer strips may have contrasted impacts on wheat production simply because adding a mandatory buffer strip to an area payment policy may have effects at the extensive margin of production by modifying agricultural land allocation. We also 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. First simulations suggest that the higher the quality, the greater the capitalisation. This result must however be considered as preliminary. It should be confirmed by further study. In the same way, our analysis should be completed by analysing how the policy instruments we considered affect agri-environmental externalities (nutrient runoffs, biodiversity and landscape diversity). This could de done using the analytical framework proposed by Lankoski and Ollikainen (2003).

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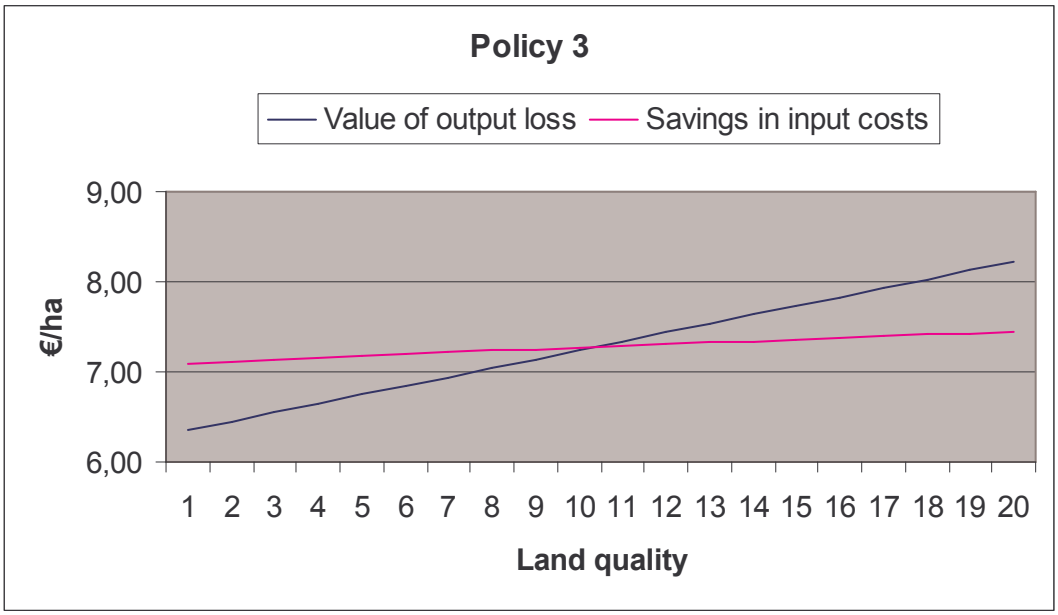
Appendix 1. Parameter values

Table A1. 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
Buffer strip payment	λ	375
	ω	340
Mitscherlich nitrogen response function	α	4182 – 5164
	β	0,0104
	γ	0,7623

Appendix 2. Cross compliance and the savings in input costs versus loss of output



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[iiii] It is an empirical question to define which cost items are dependent or independent on actually cultivated area. Here, we only would like to highlight that this difference has crucial economic implications for the choice of the buffer strip size.

[iii] We did not include this tax to our analysis of agricultural production decision because it is neutral in terms of economic decisions.

[iv] Finally note that any policy or economic evolution reducing the size of cultivation costs, either *I* or *F*, increases profits and thereby crop land prices.

[v] By "operational profits", we mean here the net profits over variable and parcel size dependent costs in (2) and (2'), that is, $pf(l;q) - cl - I$.

[vi] In Appendix 2 we illustrate that the savings in input costs dominate the value of yield loss due to cross-compliance over parcels 1 - 11.