Agri-Environmental Program Compliance in a Heterogeneous Landscape

by

Jussi Lankoski, Erik Lichtenberg, and Markku Ollikainen

WP 08-05

Department of Agricultural and Resource Economics
The University of Maryland, College Park

Agri-Environmental Program Compliance in a Heterogeneous Landscape

Jussi Lankoski
OECD Directorate for Trade and Agriculture,
2 rue André-Pascal; 75775
Paris Cedex 16, France.
Jussi.LANKOSKI@oecd.org

Erik Lichtenberg
Department of Agricultural and Resource Economics
University of Maryland, College Park, MD. USA
elichtenberg@arec.umd.edu

and

Markku Ollikainen
Department of Economics and Management
P.O. Box 27, FIN-00014
University of Helsinki, Finland.
markku.ollikainen@helsinki.fi

WP 08-05

Agri-Environmental Program Compliance in a Heterogeneous Landscape

Abstract

Heterogeneity of agricultural landscapes may necessitate the use of spatially targeted instrument combinations to implement the social optimum. But compliance with these policies may require costly enforcement. This paper examines the design of agri-environmental policies featuring two of the most commonly used instruments, reductions in fertilizer application rates and installation of riparian buffers. While compliance with buffer strip requirements is verifiable at negligible cost, fertilizer application is only verifiable through costly monitoring. We derive optimal subsidies for fertilizer reduction and buffer strip set-asides and enforcement strategies for the cases of low and excessive monitoring costs. An empirical simulation model suggests that enforceable policies can come close to replicating socially optimal crop production, nitrogen runoff, and overall welfare without requiring increases in overall subsidy expenditures, at least under conditions characteristic of Scandinavia. Sensitivity analysis suggests that these conclusions may carry over to areas with higher overall land quality as well.

Key words: nutrient runoff, monitoring, enforcement

JEL classification: Q15, Q18, H23

1. Introduction

There is a growing interest in reformulating agricultural policies of the European Union in ways that reflect the multifunctional aspects of agriculture. This entails encouraging the provision of positive environmental services (e.g., scenic landscapes, wildlife habitat, cultural heritage) and discouraging the provision of negative ones (e.g., water quality impairment from fertilizers, sediment, and pesticides) (OECD 2003a). This tendency is especially transparent in the EU's recent Mid-Term Review 2003 policy reform of the Common Agricultural Policy (CAP). This policy reform introduced the Single Farm Payment (SFP) scheme, in which most of the direct payments under CAP were decoupled from production and paid in a single, lump-sum farm payment based on 2000–2002 historical production levels. As a precondition to obtain SFP, farmers must meet certain environmental cross-compliance requirements. The Mid-Term Review also introduced so called modulation, in which the EU's funds will be shifted from direct aids and market support to more targeted rural development and agri-environmental policy measures.

In sum, the CAP is being restructured towards more decoupled income support payments with environmental cross-compliance requirements, and towards more targeted and differentiated agri-environmental payment programs. For instance, in order to reduce nutrient runoff from field parcels many EU countries implement fertilizer use reduction measures and/or buffer strips as a part of either environmental cross-compliance criteria or as a criteria in more targeted agri-environmental payment programs (for general overview see e.g. OECD 2003b).

Refinements of agricultural and agri-environmental policies create new problems, however. The more targeted and differentiated instruments are, the harder it is to achieve compliance, necessitating an increased enforcement effort. Available policy instruments provide a range of measures from those that are difficult to monitor and enforce to those that are relatively easy to verify and enforce. Consider for example the case of fertilizer use reduction and riparian buffer strip requirements, mentioned above. Variability in yields due to land quality, weather, varietal choice, timing of application, and similar factors make it impossible to determine compliance with fertilizer reduction requirements without soil testing. A uniform riparian buffer is enforceable at low costs. However, problem of enforcement is present when it is optimal to differentiate buffer strip requirements according to land quality and the latter is not observable at negligible cost. Soil testing is expensive, so that efficient monitoring and enforcement schemes have at least the potential of lowering implementation costs significantly.

Enforcement can be an especially significant obstacle to effective implementation of agri-environmental requirements and policies. The environmental compliance requirements that accompany income support measures (environmental cross compliance) or agri-environmental payments (direct compliance) are not self-enforcing. There is no automatic verification. Variations in output can be due to microclimate, managerial ability, or other factors that cannot be disentangled from cheating on environmental compliance without on-site monitoring. Agri-environmental compliance typically has no effect on the quality of output, either. These measures are costly for farmers because they reduce agricultural productivity, giving farmers a clear incentive to cheat by falsely claiming to have implemented them. Compliance monitoring is costly, making it important to devise efficient compliance monitoring schemes to ensure that agri-environmental policy goals are met.

The problem of how governments should design compliance monitoring strategies when environmental compliance requirements are not self-enforcing has been analyzed in economics since Becker's seminal work (1968); Polinsky and Shavell (2000) survey applications to public policy. Downing and Watson (1974), Harford (1978), (1987) and Malik (1992) introduced the topics of noncompliance and costly-enforcement to environmental economics (for recent advances, see Sandmo 2002; Rousseau and Prost 2005 provide an interesting case study). In the context of agri-environmental policy, Choe and Fraser (1999) derive optimal monitoring strategies and incentive payments when farmers can exert either low or high compliance effort and monitoring is costly. Kampas and White (2004) examine the impacts of monitoring costs the relative efficiency of alternative agri-environmental policy mechanisms. Fraser (2002, 2004) investigates the effects of penalties for non-compliance but does not consider monitoring costs.

This paper examines the optimal design of agri-environmental policies featuring two of the most commonly used compliance requirements, reductions in fertilizer application rates and installation of riparian buffers, which differ in terms of compliance monitoring cost as well as efficacy. In contrast to Choe and Fraser (1999), we assume a continuum of land quality (and thus types of agents). We assume that land quality is perfectly observable at negligible cost, so that compliance with one component of environmental compliance, buffer strip requirements, is verifiable at negligible cost. This assumption reflects the fact that the current Integrated Administration and Control System (IACS) in the EU allows monitoring of land use and thereby crop area payments at low cost.[1] For the other component of environmental compliance, restrictions on fertilizer application, we employ two alternative assumptions. In the first case, fertilizer application is verifiable through costly monitoring. In the second, it is non-verifiable or verifiable only at excessive cost.[2] In this latter case, buffer strip requirements and associated payments are the only enforceable policy instrument. We extend the conceptual framework of Lichtenberg (2002, 2004) and Lankoski and Ollikainen (2003) to encompass these efficient monitoring strategies given realistic limits on penalties. We then apply that framework empirically using an empirical model reflecting Finnish agricultural and environmental conditions.

2. Land Allocation, Crop Production, and Runoff in a Heterogeneous Region

We use as a baseline the Ricardian model of Lankoski and Ollikainen (2003) that considers agricultural production in a region with heterogeneous land quality where farms are located along a river that drains the area. The land is divided into parcels which are of the same size and homogeneous in land quality (see Figure 1). Land quality differs over parcels and is ranked by a scalar measure q, with the scale chosen 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. It is further assumed that $g(q)$ is continuous and differentiable. The total amount of land in the region is $G(1)$.

It is assumed for simplicity that there are only two crops grown in this region, $j = 1,2$, both crops produced under constant returns to scale technologies with crop 1 better suited

---

[1] For instance, a recent empirical studies by Rorstad et al. (2007) and Ollikainen et al. (2007) show that in both Norway and in Finland the transaction costs related to crop area payments are less than 2% of the amount of subsidies paid.

[2] This is supported, for instance, in Ollikainen et al. (2007) who find that although more than 30% of the transaction costs accruing from agri-environmental payments are devoted to actual monitoring, the success achieved in controlling nutrient runoff is still very modest.

to lower quality land. Output of each crop per unit of land area, y_j, is a function of land quality q and the fertilizer application rate (fertilizer per unit of land area) l_j, $y_j = f^j(l_j;q)$. The production function is increasing and concave in fertilizer and land quality, that is, $f_l^j(l_j;q) > 0, f_{ll}^j(l_j;q) < 0$, $f_q^j(l_j;q) > 0$, $f_{qq}^j(l_j;q) < 0$. Let p_j and c denote the respective prices of crops and fertilizer and χ_j all other production costs per unit of land area for crop j. Let $L_j(q)$ denote the share of land of quality q allocated to use j.

Crop production generates negative environmental externalities via nutrient runoff. We assume that runoff for each parcel of land is a function $v_j((1-m_j(q))l_j(q), m_j(q))$ that depends on the crop, j, the amount of fertilizer applied to the parcel, $(1-m_j(q))l_j(q)$, and the share of the parcel devoted to the buffer strip, $m_j(q)$. For convenience, runoff from the residual use is assumed to be zero. Assume that runoff is uniformly mixed in the river, so that pollution damage depends on aggregate runoff, $Z = \int_0^1 \sum_{j=1}^2 v_j((1-m_j(q))l_j(q), m_j(q))L_j(q)g(q)dq$. Let D(Z) denote the convex cost of damage from runoff ($D'(\cdot) > 0; D''(\cdot) > 0$) in the watershed and γ the cost of establishing a buffer strip per unit of land area.

Land in agriculture also generates positive externalities in terms of open space, preservation of landscapes of important cultural significance, and similar environmental services. Let $A_j(q)$ denote the marginal value of these environmental services generated per unit of land of quality q allocated to crop j (inclusive of the share allocated to buffer strips).

The social welfare maximization problem can now be expressed as

$$\max_{l_j,m_j,L_j,Z} \int_0^1 \left[\sum_{j=1}^2 \left\{(1-m_j(q))[pf^j(l_j(q),q) - cl_j(q) - \chi_j] - \gamma m_j(q) + A_j(q)\right\} L_j(q)\right] g(q)dq - D(Z) \tag{1}$$

subject to the constraints

$$\begin{aligned} &Z = \int_0^1 \sum_{j=1}^2 v_j((1-m_j)l_j(q), m_j(q))L_j(q)g(q)dq \\ &L_1(q) + L_2(q) \leq 1 \ \forall \ q \end{aligned} \tag{2}$$

Let ζ be the Lagrange multiplier associated with the runoff (Z) constraint, and δ the

Lagrange multiplier associated with the constraint $L_1(q) + L_2(q) \le 1$. Then the first order conditions defining the optimal use of fertilizer, the size of the buffer strip and allocation of land among alternative uses in the social optimum are:

$$l_j : \left[p \frac{\partial f^j}{\partial l_j} - c \right] - \zeta \frac{\partial v_j}{\partial l_j} \le 0 \tag{3a}$$

$$m_j : -(pf^j - cl_j) - \gamma - \zeta \left(\frac{\partial v_j}{\partial m_j} - l_j \frac{\partial v_j}{\partial l_j} \right) \le 0 \tag{3b}$$

$$L_j : (1 - m_j)[pf^j - cl_j - \chi_j] - \gamma m_j + A_j - \zeta v_j - \delta \le 0, \text{j} = 1{,}2 \tag{3c}$$

$$Z : \ -D'(Z) + \zeta = 0 \tag{3d}$$

plus the constraints (2).

Under certain regularity assumptions (intuitively, that crop 2 is more profitable at land of maximal quality and more responsive to changes in land quality), condition (3c) also defines a unique critical quality, q^c, defined by

$$\begin{aligned}(1 - m_2)[pf^2(l_2, q^c) - cl_2 - \chi_2] - \gamma m_2 + A_2 - D'(Z)v_2 = \\ (1 - m_1)[pf^1(l_1, q^c) - cl_1 - \chi_1] - \gamma m_1 + A_1 - D'(Z)v_1\end{aligned}$$

at which the land allocation switches from one crop to another (see for example Lichtenberg 2002). Land of quality $0 \le q < q^c$ is allocated to crop 1; land of quality $q \ge q^c$ is allocated to crop 2; and, as Lankoski and Ollikainen (2003) show, the optimal buffer strip area for each crop decreases in land quality.

In the absence of government intervention farmers' decisions do not take into account either negative (runoff) or positive (landscape) externalities from agriculture. It is easy to see from condition (3b) that farmers will not maintain buffer strips in such cases because they receive no compensation for the lost rent (hence condition (3b) holds as a strict inequality). The privately optimal fertilizer application rate similarly ignores marginal runoff damage while land of each quality is allocated to the use that generates the highest rent without consideration of runoff damage or landscape benefits, hence the critical quality of land will be lower than the social optimum (see Lichtenberg 2002 and Lankoski and Ollikainen 2003).

3. Agri-Environmental Program Compliance with Costly Monitoring

The problem of agri-environmental policy is to find instruments that induce farmers to reduce fertilizer application rates, to establish buffer strips, and to adjust the allocation of land among alternative uses towards the social optimum. Conditions (1a)-(1e) indicate that the first-best choice of such agri-environmental policies entails a spatially targeted combination of a fertilizer tax (or subsidy for reducing fertilizer use) and a buffer strip subsidy. It seems reasonable to assume that spatially differentiated buffer strip requirements and corresponding subsidies can be enforced at low cost: Most countries have detailed soil surveys that allow them to devise spatially differentiated buffer strip requirements and buffer strip planting is easily verified by annual aerial surveillance or similarly low-cost forms of remote sensing. In contrast, enforcement of fertilizer taxes, subsidies, and/or restrictions on fertilizer use is problematic. First-best spatially differentiated fertilizer taxes or subsidized restrictions on fertilizer use are unenforceable without costly monitoring—and may be completely unenforceable if reliable soil testing methods are not available—while second-best differentiated fertilizer taxes and subsidies designed to induce farmers to report their private knowledge of fertilizer application rates truthfully are not self-enforcing due to the ease with which secondary markets can be established (Lichtenberg 2002).

In what follows, we extend the conceptual framework presented in the preceding section to model the kinds of agri-environmental program compliance policies currently used in Europe for reducing nutrient runoff in two situations: (1) when fertilizer use is verifiable through costly monitoring and (2) when fertilizer use is either non-verifiable or verifiable only at excessive cost, so that buffer strip requirements and associated subsidies are the only enforceable policy instrument. We assume that land quality is perfectly observable at negligible cost (e.g., because soils have already been mapped or where farmers have been required to report indicators of soil quality such as soil characteristics, yields, etc.) and that compliance with buffer strip requirements is verifiable at negligible cost (e.g., by annual aerial surveillance).

3.1. Fertilizer Use Verifiable with Costly Monitoring

Farmers receive three types of direct payments under existing policy regimes in Europe: a subsidy $b_j(m_j,q)m_j$ for planting a buffer strip of size m_j on land of quality q allocated to crop j, where the unit buffer subsidy schedule b_j varies according to buffer strip size but is fixed in advance by the government; an area payment $t_j(q)$ for land of quality q allocated to crop j (excluding buffer strips); and, when applicable, a subsidy for complying with restrictions on fertilizer use $s_j(q)[l_j^u(q)-l_j(q)]$, where l_j^u denotes unregulated fertilizer use.

Suppose that fertilizer use is perfectly verifiable through an annual soil test costing T per unit of land area and, as is commonly the case, that the penalty for being found non-compliant with fertilizer restrictions equals the loss of all subsidy payments. Farmers are assumed to be risk neutral, hence the threat of detection can be sufficient to ensure perfect compliance. We know that the farmer will be indifferent between cheating and complying if the expected return from cheating equals the certain return from compliance. Thus, the minimum inspection probability needed to ensure compliance from a farmer growing crop j on land of quality q is

$$\rho_j(q)=\frac{[1-m_j(q)]\left\{p[f^j(l_j^u,q)-f^j(l_jq)]-c[l_j^u(q)-l_j(q)]\right\}}{b_j(m_j,q)m_j(q)+[1-m_j(q)]\left[s_j(q)[l_j^u(q)-l_j(q)]+t_j(q)\right]} \tag{4}$$

Faced with such an inspection probability, the farmer will always comply and thus choose fertilizer, buffer strip size, and land allocation for crop j on land of quality q as defined by

$$p_j f_l^j(q)-c-s_j(q)=0 \tag{5a}$$

$$-\left\{p_j f^j(q)-cl_j(q)+s_j(q)[l_j^u(q)-l_j)q)]-\chi_j+t_j(q)\right\}-\gamma+b_j(m_j,q)=0 \tag{5b}$$

$$\begin{aligned}&[1-m_j(q)]\left\{p_j f^j(q)-cl_j(q)+s_j(q)[l_j^u(q)-l_j(q)]+t_j(q)\right\}\\&\quad+[b_j(q)-\gamma]m_j(q)-\delta(q)\le 0\end{aligned}. \tag{5c}$$

The socially optimal allocation of land between the two crops can be attained by restricting total agri-environmental subsidy payments per unit of land $[1-m_j(q)]\{s_j(q)[l_j^u(q)-l_j(q)]+t_j(q)\}+b_j(m_j,q)m_j(q)$ to the marginal value of positive environmental services generated by land of quality q allocated to crop j, $A_j(q)$. In what follows, we impose this restriction on total subsidy payments, so that the the minimum inspection probability needed to ensure compliance from a farmer growing crop j on land of quality q is

$$\rho_j(q)=\frac{(1-m_j)\left\{p[f^j(l_j^u,q)-f^j(l_jq)]-c[l_j^u(q)-l_j(q)]\right\}}{A_j(q)}. \tag{4′}$$

The government's optimization problem in this case is choosing fertilizer use, buffer strip size, total runoff, land allocation to maximize the value of agricultural output and environmental services generated by land in each crop (inclusive of buffer strips) net of runoff damage and enforcement costs subject to constraints on total runoff and land availability:

$$\max_{l_j, m_j, L_j, Z} \int_0^1 \left[\sum_{j=1}^{2} [1 - m_j(q)] \left\{ \left(1 + \frac{T}{A_j(q)} \right) [p_j f^j(l_j(q), q) - c l_j(q)] - \chi_j \right\} L_j(q) \right] g(q) dq$$
$$- D(Z) - \int_0^1 \sum_{j=1}^{2} \left[\frac{[1 - m_j(q)][p_j f^j(l_j^u(q), q) - c l_j^u(q)] T}{A_j(q)} + \gamma m_j(q) - A_j(q) \right] L_j(q) g(q) dq \tag{6}$$

subject to constraints (2).

The optimal fertilizer subsidy rate $s_j(q)$, buffer strip subsidy rate $b_j(q)$, and area payment $t_j(q)$ can then be derived by equating the government's optimization conditions with conditions (5a)-(5c), which characterize farmers' optimal choices. Following this procedure gives

$$s_j(q) = \frac{D'(Z) \dfrac{\partial v_j}{\partial l_j}}{1 + \dfrac{T}{A_j}} \tag{7a}$$

$$b_j(m_j, q) = -D'(Z) \left[\frac{\partial v_j}{\partial m_j} - l_j \frac{\partial v_j}{\partial l_j} \right] + \left[p_j \left(f^j(l_j^u) - f^j(l_j) \right) - c(l_j^u - l_j) \right] \frac{T}{A_j} + s_j [l_j^u - l_j] + t_j \tag{7b}$$

It is readily apparent from a comparison of equations (7a) and (7b) with equations (3a) and (3b) that the presence of enforcement costs induces the government to rely less on reductions in fertilizer use and more on buffer strip requirements than is socially optimal. The fertilizer subsidy equals marginal runoff damage from fertilizer use discounted by an enforcement cost factor. The fertilizer subsidy is less than the marginal runoff damage as a result, so that fertilizer use will exceed the social optimum for each crop on each quality of land. The buffer strip subsidy equals marginal runoff damage avoided plus the avoided expected inspection cost and the savings from lower fertilizer subsidy and area payments. The buffer subsidy exceeds avoided marginal runoff damage as a result, so that buffer strips will be larger than the social optimum for each crop on each quality of land.

Finally, the constraint on total subsidy payments

$$A_j(q) = b_j(q)m_j(q) + [1 - m_j(q)]\left\{s_j(q)[l_j^u(q) - l_j(q)] + t_j(q)\right\} \tag{7c}$$

can be used together with equation (7b) to solve for the buffer subsidy and area payment the government should offer for each crop on each quality of land.

3.2. Soil Quality Observable, Fertilizer Use Unverifiable

Now suppose that fertilizer use is unverifiable by soil tests, e.g., because soil tests are insufficiently accurate to determine fertilizer use reliably, or, equivalently, that soil testing is just too expensive to be worthwhile. In such cases the government will need to rely on buffer strips alone to address problems of nutrient runoff. Assume as before that the cost of compliance monitoring for buffer strips is negligible and that total subsidy payments cannot exceed the marginal value of environmental services provided by land of quality q allocated to crop j, $A_j(q)$. Farmers will choose the unregulated level of fertilizer use for each crop on each quality of land, $l_j(q)$, and a buffer strip size defined by

$$-\left\{p_j f^j(l_j^u(q), q) - cl_j^u(q) - \chi_j + t_j\right\} + b_j(q) - \gamma = 0. \tag{8}$$

The government's problem is thus to choose buffer strip size, land allocation, and total runoff to maximize the value of agricultural output net of damage from runoff subject to constraints on total runoff and land availability,

$$\max_{m_j, L_j, Z} \int_0^1 \left[\sum_{j=1}^{2} \left\{(1 - m_j(q))[pf^j(l_j^u(q), q) - cl_j^u(q) - \chi_j] - \gamma m_j(q) + A_j(q)\right\} L_j(q)\right] g(q)dq - D(Z) \tag{9}$$

subject to constraints (2). The optimal subsidy in this case,

$$b_j(m_j, q) = -D'(Z)\left[\frac{\partial v_j}{\partial m_j} - l_j^u \frac{\partial v_j}{\partial l_j}\right] + t_j, \tag{10}$$

is set to induce farmers to allocate more land to buffer strips than is socially optimal.

4. Empirical Analysis: Wheat and Barley Production in Finland

We use an empirical model based on Finnish data to evaluate the social welfare performance of policy scenarios using area payments, fertilizer reduction subsidies or buffer strip payments alone or in a combination. The data come from studies performed on clay soils in Southern Finland on which almost all wheat and barley production occurs.

4.1 A Parametric Model of Crop Production and Environmental Services

The parametric model consists of the Mitscherlich nitrogen response function for barley (crop 1) and wheat (crop 2), an exponential nitrogen runoff function, and a function characterizing social damage from nitrogen runoff. We provide a brief description here; additional details can be found in Lankoski and Ollikainen (2003).

Nitrogen response for barley and wheat is modelled as $y_j = \alpha_j (1 - \delta_j e^{-\beta_j l_j})$, where y_j is yield per hectare, l_j is nitrogen use per hectare, and α_j, β_j and δ_j are parameters. Land quality is incorporated through the parameter α_j in order to calibrate the nitrogen response function to actual yield levels corresponding to a given fertilizer use in Southern and South-Western Finland. The parameter α_j is assumed to be linear in land quality, i.e., $\alpha_j = \mu_0 + \mu_1 q$. The model contains 40 production units of differential land quality.

The social cost of damage from nitrogen runoff is assumed to be proportional to aggregate nitrogen runoff, Z. The marginal cost of nitrogen runoff damage is assumed to be constant, D = € 3.57 per kilogram of nitrogen, and is taken from Yrjölä and Kola (2004). Nitrogen runoff from any given parcel of land is a nonlinear function, $z_j = [1 - m_j^{0.5}]\phi\, e^{-0.7[1-0.01(1-m_j)l_j]}$. The first term on the right hand side of equation, 1-$m_j^{0.5}$, models nitrogen uptake by buffer strips. The parameters are based on Finnish experimental studies on grass buffer strips (Uusi-Kämppä and Yläranta 1992, 1996). The second term, $\phi\, e^{-0.7[1-0.01(1-m_j)l_j]}$, represents nitrogen runoff from crop j generated by a nitrogen application rate of l_j per hectare when buffer strips take up a share of land m_j. The parameter ϕ calibrates this expression so that it equals the level of nitrogen runoff generated by a nitrogen application rate of 100 kilograms per hectare in the absence of buffer strips. Data from Finnish experimental studies suggest that ϕ = 15 kg of nitrogen per hectare. (Turtola and Jaakkola 1987, Turtola and Puustinen 1998).

Verification of farmers' input use and land allocation choices is feasible but potentially costly. Buffer strip size and planted crop area can be verified at negligible costs and we thus assume perfect, costless reporting of planted area and compliance with buffer strip requirements in this analysis. Nitrogen fertilizer use is typically monitored by soil nitrogen testing, whose cost is not negligible. The cost of such an inspection regime equals the probability of inspection times the cost of soil nitrogen testing, which is € 20 per hectare according to the Finnish Ministry of Agriculture and Forestry.

Other parameter values for our parametric model are reported in Table 1. We model a region bordering a 2000-meter stretch of river divided into 40 parcels of equal size, so that each parcel has a 50 meter border along the river. The total area of arable land is assumed to be 40 hectares, so that each parcel extends 200 meters away from the river. We use average prices of marketing year 2005 within the European Union. They may somewhat differ from the world market prices but, as they are used in all calculations, do not cause any bias when comparing policy scenarios.

4.2 Policy Alternatives

We use the empirical model to estimate nitrogen application rates, buffer strip widths, land allocations, farm profit and the social cost of damage from nitrogen runoff. We use as a benchmark a social optimum consisting of farm profit plus the social value of retaining land in farming ($Aj(q)$, which is assumed to equal the current LFA payment for southern Finland, € 168 per hectare, for both crops) less nitrogen runoff damage (equation 1 in the theoretical model). We use this benchmark to evaluate following three alternative agricultural policy and agri-environmental policy designs. Policy 1, which corresponds to current EU policy, consists of an arable crop area payment without enforcement of environmental compliance requirements and an area payment set equal to the current LFA area payment in southern Finland, € 168 per hectare for wheat and barley. Policy 2 combines optimal buffer strip payments and a subsidy for nitrogen application reduction with costly enforcement of nitrogen application compliance, as defined by equation 6 of the theoretical model. In this policy scenario total subsidy payments are fixed, so that the sum of crop area payments, buffer strip payments and nitrogen application reduction payments equals the existing LFA area payment. Policy 3 assumes that nitrogen use is either unverifiable by soil nitrogen testing or just too expensive to be worthwhile, so that government relies solely on buffer strips to meet water quality protection goals. Optimal buffer strip payments are derived under the restriction that the sum of buffer strip subsidies and crop area payments is fixed at the current LFA area payment for southern Finland.

4.3 Base Case Results

Tables 2 and 3 summarize aggregate outcomes in the social optimum and under the three policy alternatives outlined above. As indicated by the theoretical analysis, fertilizer application rates are increasing in land quality (Figure 1) while buffer strip areas are decreasing in land quality (Figure 2) for any given crop. Both exhibit discrete upward jumps at the critical land quality at which farmers switch from barley to wheat.

Note first that in the absence of environmental compliance (Policy 1) farmers use substantially more fertilizer than is socially optimal: about 15 percent more on barley and about 22 percent more on wheat (Figure 1). Moreover, it is profitable for farmers to plant wheat on some land that would be planted in barley in the social optimum so that difference in fertilizer use on this land is even higher. And of course it is unprofitable for farmers to set aside land in buffer strips hence they will not do so unless forced to. As a result, nitrogen runoff under Policy 1 is over a third higher than the social optimum (Table 2), suggesting that nitrogen pollution of surface water is a significant negative externality of farming in this region.

The combination of fertilizer and buffer subsidies with costly enforcement (Policy 2) is quite successful in lowering nitrogen runoff. Fertilizer application rates under this policy are only about 2 percent higher than socially optimal for barley and 4 percent higher than socially optimal for wheat. Buffer strip widths are substantially higher than socially optimal, on the order of 27-37 percent higher for both crops, with the difference for each crop narrowing somewhat as land quality increases, and 30 percent higher overall. Some additional reductions in overall fertilizer use and increases in overall buffer strip area are due to extensive margin effects: Under this policy barley is planted on some land (quality 27) that is socially optimal to plant in wheat (Figures 1 and 2). As a result, nitrogen runoff is actually lower than the social optimum by about 1 percent.

The level of monitoring required to enforce compliance is quite low, averaging 0.75 percent for barley and 1.69 percent for wheat. The minimal probability of inspection needed to ensure complete compliance is increasing in land quality, reflecting the fact that the gains from cheating are increasing in land quality. Overall, however, enforcement costs are negligible. The reason is straightforward. Subsidy payments are extremely large relative to income from farming (and hence the additional income from cheating), so that it takes only a small probability of detection for the expected loss of all subsidy payments to equal the gains from non-compliance. This result suggests that environmental compliance can be achieved at low cost even when compliance monitoring is costly, at least in areas where farm subsidies are already generous. The policy modeled here changes the composition of subsidy payments but not the overall level of subsidies; the only additional cost relative to current expenditures is that of monitoring, which can be kept quite low because fines for those caught cheating are quite large relative to the gains from cheating.

As one might expect from the fact that it uses two instruments to address the two objectives of maximizing farm income and minimizing environmental damage from nitrogen runoff, Policy 2 comes quite close to achieving the socially optimal welfare level, falling only 0.1 percent below it. Underproduction of crops relative to the social optimum is balanced by overcontrol of nitrogen runoff. The resulting net discrepancy in social welfare is entirely attributable to the cost of enforcement which, as noted above, is quite low in this case.

Policy 3, in which fertilizer reduction subsidies are unenforceable (or too costly to enforce), features buffer strips that are substantially higher than the social optimum, about 31 percent, but not much higher than a policy in which fertilizer reduction subsidies are enforceable at relatively low cost (only about 0.5 percent). Fertilizer use is about 18 percent higher than the social optimum. It is slightly lower than fertilizer use in the absence of environmental compliance (Policy 1) because it replicates the socially optimal land allocation. As a result, nitrogen runoff under this policy is only about 9 percent higher than the social optimum, suggesting that buffer strips are highly effective at reducing nitrogen runoff. Income from crop production above the social optimum largely balances damage from nitrogen runoff in excess of the social optimum, so that overall social welfare is almost 99 percent of the social optimum.

4.4 Sensitivity Analysis

The results of the base case analysis suggest that policies that provide enforceable subsidies for agri-environmental compliance measures while keeping total subsidy payments fixed at current levels can come quite close to replicating the social optimum, at least under Finnish conditions. Sensitivity analysis was used to examine the relative performance of these policies under the conditions of greater heterogeneity in land quality than in Finland. The sensitivity analysis assumed an upper bound on land quality 60 percent higher than the base case while keeping the lowest land quality level fixed. The mean yield of wheat with a 60 percent increase in maximum land quality is close to the highest country-level average yields in the European Union as a whole. The results of this sensitivity analysis are summarized in Tables 2 and 3.

With higher overall land quality, the social optimum features more land planted in wheat and less land planted in barley. Higher land productivity increases both fertilizer productivity and the opportunity cost of land set aside from crop production, hence the socially optimal use of fertilizer is substantially higher and the socially optimal use of buffer strips is substantially lower than in the base case. As a result, runoff in the social optimum is about 26 percent higher than in the base case.

In the absence of environmental compliance (Policy 1), farmers' use of fertilizer exceeds socially optimal levels both because of higher than optimal fertilizer application rates on each crop and because more land is planted to wheat than is socially optimal. The degree of overuse remains about the same relative to the social optimum, however: In the absence of environmental compliance, fertilizer use is about 15 percent higher than the social optimum on barley, 22 percent higher than the social optimum on wheat, and 20 percent higher than the social optimum overall, while runoff is 34 percent higher than the social optimum.

As in the base case, the combination of fertilizer and buffer subsidies with costly enforcement (Policy 2) is quite successful in lowering nitrogen runoff. Fertilizer application rates under this policy are about 2 percent higher than socially optimal for both barley and wheat. As in the base case, buffer strip widths are substantially higher than the social optimum, an average of 28 percent higher for barley, 18 percent higher for wheat, and 24 percent higher overall. With the increase in overall land quality it becomes efficient to rely relatively more on buffer strips and less on fertilizer reductions, as indicated by the fact that subsidy payments for buffer strips and fertilizer reductions are roughly equal in this scenario whereas in the base case fertilizer reduction subsidy payments are three times as large as buffer subsidy payments. Also in contrast to the base case, the land allocation under this policy is the same as the social optimum.

The level of monitoring required to enforce compliance remains quite low: The optimal probability of inspection averages 0.85 percent for barley, 2.86 percent for wheat, and 2.02 percent overall. As in the base case, the reason is again that subsidy payments are so large relative to crop income that it takes only a small chance of being caught to make the expected loss to equal the gains from cheating. The optimal probability of inspection is nevertheless substantially higher than in the base case. Higher overall land quality means higher returns to cheating, hence more intensive and costly enforcement. Thus, the cost of enforcement is more than double that under the base case.

As in the base case, the use of two instruments allows this policy to come close to replicating the social optimum. Slight overproduction of crops relative to the social optimum is almost completely balanced by slight undercontrol of nitrogen runoff. The resulting discrepancy between social welfare under this policy and that under the social optimum is extremely low, less than a hundredth of a percentage point. As in the base case, this discrepancy is attributable to the cost of enforcement, which remains quite low in relative terms.

Also as in the base case, Policy 3, which does not utilize fertilizer reduction subsidies, features buffer strips that are higher than both the social optimum. The relative discrepancy between the use of buffer strips under this policy and the social optimum is larger than in the base case—about 41 percent in this scenario compared to 31 percent in the base case. The relative difference in the use of buffer strips between this policy and Policy 2 is also larger, a result attributable to the higher opportunity cost of land. Fertilizer use under this policy is again lower than in the absence of environmental compliance (Policy 1) because, as in the base case, this policy replicates the socially optimal land allocation. Less control is exercised over nitrogen runoff is lower than in the base case, however: Nitrogen runoff is 15 percent higher than the social optimum in this scenario compared to only 9 percent higher in the base case. Higher income from crop production balances higher damage from nitrogen runoff to a slightly lesser extent than in the base case, but social welfare is still almost 99 percent of the social optimum.

5. Conclusions

There is growing interest in expanding the scope of agricultural policies to include environmental compliance requirements, such as incentives for providing positive environmental externalities from farming and reducing negative ones. Heterogeneity of agricultural landscapes typically necessitates the use of spatially targeted instrument combinations to implement the social optimum. Most agri-environmental policies considered to date in the literature are not self-enforcing, making it necessary to consider enforcement cost in policy design.

This paper examines the optimal design of agri-environmental policies featuring two of the most commonly used environmental compliance requirements, reductions in fertilizer application rates and installation of riparian buffers, which differ in terms of compliance monitoring cost as well as efficacy. Compliance with buffer strip requirements is verifiable at negligible cost while fertilizer application may be verifiable through costly monitoring, or may be verifiable only at excessive cost. In the latter case, buffer strip requirements and associated payments are the only enforceable policy instrument.

We develop a theoretical model of agricultural production and nitrogen runoff in a region with heterogeneous land quality. We use the model to derive optimal subsidy regimes for buffer strips and fertilizer combined for the case where fertilizer use is verifiable at reasonable cost and for buffer strips alone for the case where fertilizer use is not verifiable at reasonable cost. The former case requires enforcement via probabilistic monitoring with penalties for cheating, which we assume to be the loss of all agricultural subsidy payments; we derive the minimum probabilities of detection that ensure perfect compliance by risk neutral farmers for each quality of land. In both regimes (as well as the social optimum) a fixed area payment is used to ensure that total subsidy payments equal the marginal value of positive amenities generated by land in agriculture, so that implementation of either policy means a change in budgetary outlays equal only to expected enforcement costs. Both policy regimes are characterized by greater reliance on buffer strips and greater use of fertilizer than in the social optimum.

We examine the performance of these policies empirically using a simulation model that replicates conditions characteristic of Scandinavia. Nitrogen runoff in the absence of environmental compliance measures is substantially higher than the social optimum. The policy that combines fertilizer reduction subsidies, buffer strip payments, and random monitoring via soil testing performs quite well: Overcontrol of nitrogen runoff balances underproduction of crops almost exactly in value terms while the cost of enforcement is extremely low due to the fact that subsidy payments (hence losses from being caught cheating) are so large relative to income from crop production that infrequent monitoring is sufficient to deter cheating. Buffer strip requirements are substantially higher than the social optimum. The policy that relies on buffer strip payments alone also performs well, albeit not as well as a policy that combines buffer strip payments with fertilizer reduction subsidies. Sensitivity analysis indicates that the relative performance of these policies remains the same as overall land quality increases.

These results suggest that reorienting current European agricultural policies away from income supports toward payments for environmental improvements can achieve significant improvements in environmental quality with small, if any increases in overall spending by substituting payments for buffer strips, fertilizer reductions, and similar measures for portions of current area payments. Heterogeneity of land quality and the resulting need for targeted subsidies did not prove to be a significant obstacle in the cases considered here. It would be interesting to examine whether these results carry over to situations featuring greater diversity of crops and land quality

References

Becker, G. 1968. Crime and Punishment: The Economic Approach. *Journal of Political Economy* 76: 169-217.

Bäckman, S.T., Vermeulen, S. and Taavitsainen, V.-M. 1997. Long-term fertilizer field trials: comparison of three mathematical response models. *Agricultural and Food Science in Finland* 6: 151-160.

Choe, C. and Fraser, I. 1999. Compliance Monitoring and Agri-Environmental Policy. *Journal of Agricultural Economics* 50:468-487.

Downing, P. and Watson, W. Jr. 1974. The Economics of Enforcing Air Pollution Controls. *Journal of Environmental Economics and Management* 1: 219-36.

Fraser, R. 2002. Moral Hazard and Risk Management in Agri-environmental Policy. *Journal of Agricultural Economics* 53:475-487.

Fraser, R. 2004. On the use of targeting to reduce moral hazard in agri-environmental schemes. *Journal of Agricultural Economics* 55:525-540.

Harford, J. 1978. Firm Behavior under Imperfectly Enforceable Pollution Standards and Taxes. *Journal of Environmental Economics and Management* 5: 26-43.

Harford, J. 1987. Self-Reporting Discharges of Pollution and the Firm's Behavior with Costly and Limited Enforcement. *Journal of Environmental Economics and Management* 14: 293-303.

Kampas, A. and B. White. 2004. Administrative Costs and Instrument Choice for Stochastic Non-point Source Pollutants. *Environmental and Resource Economics* 27: 109-133.

Lankoski, J. and Ollikainen, M. 2003. Agri-environmental Externalities: A Framework for Designing Targeted Policies. *European Review of Agricultural Economics* 30: 51-75.

Lichtenberg, E. 2002. Agriculture and the environment. In B. Gardner and G. Rausser (eds.), *Handbook of Agricultural Economics*. Vol 2A: Agriculture and its Linkages. Amsterdam: North Holland. pp. 1249 – 1313.

Lichtenberg, E. 2004. Are Green Payments Good for the Environment? *Agricultural and Resource Economics Review* 33: 24-32.

Malik, A. 1992. Enforcement Costs and the Choice of Policy Instruments for Controlling Pollution. *Economic Inquiry* 30: 714-721.

OECD 2003a. Multifunctionality: the policy implications. OECD, Paris.

OECD 2003b. Agricultural Policies in OECD countries. Monitoring and Evaluation. OECD. Paris.

Ollikainen, M., J. Lankoski and S. Nuutinen. 2008. Policy-related transaction costs of agricultural policies in Finland. *Agricultural and Food Science*, forthcoming.

Polinsky, A. and Shavell, S. 2000. The Economic Theory of Public Enforcement of Law. *Journal of Economic Literature* 38: 45-76.

Rousseau S. and Proost, S. 2005. Comparing Environmental Policy Instruments in the Presence of Imperfect Compliance—A Case Strudy. *Environmental and Resource Economics* 32, 337-365.

Rørstad, P., Vatn, A. and Kvakkestad, V. 2007. Why do transaction costs of agricultural policies vary? *Agricultural Economics* 36: 1-11.

Sandmo, A. 2005. Effcient Environmental Policy with Imperfect Compliance. *Environmental and Resource Economics* 23: 85-103.

Simmelsgaard, S. 1991. Estimation of nitrogen leakage functions - Nitrogen leakage as a function of nitrogen applications for different crops on sand and clay soils. In: Rude, S. (ed.). Nitrogen fertilizers in Danish Agriculture - present and future application and leaching, Institute of Agricultural Economics *Report* 62 (in Danish: Kvaelstofgödning i landbruget - behov og udvasking nu og I fremtiden). English summary. Copenhagen. p. 135-150.

Turtola, E. and Jaakkola, A. 1987. Viljelykasvin vaikutus ravinteiden huuhtoutumiseen savimaasta Jokioisten huuhtoutumiskentällä v. 1983-1986. (in Finnish). Maatalouden tutkimuskeskus. Tiedote 22/87. Jokioinen. 33 p.

Turtola, E. and Puustinen, M. 1998. Kasvipeitteisyys ravinnehuuhtoutumien vähentäjänä. Vesitalous 1/1998: 6-11.

Uusi-Kämppä, J. and Yläranta, T. 1992. Reduction of Sediment, Phosphorus and Nitrogen Transport on Vegetated Buffer Strips. *Agricultural Science in Finland* 1: 569-575.

Uusi-Kämppä, J and Yläranta, T. 1996. Effect of Buffer Strips on Controlling Erosion and Nutrient Losses in Southern Finland. In: Mulamoottil, G., Warner, B.G. & McBean, E.A. (eds.). *Wetlands: environmental gradients, boundaries and buffers*. Boca Raton: CRC Press/Lewis Publishers, 221-235.

Yrjölä T. and Kola, J. (2004). Consumer Preferences Regarding Multifunctional Agriculture. *International Food and Agribusiness Management Review* 7.

Table 1. Parameter values used in the numerical application.

Parameter	*Symbol*	*Value*
Price of barley	p_1	€ 0.101/kg
Price of wheat	p_2	€ 0.111/kg
Price of nitrogen fertilizer	c	€ 1.2/kg
Expenditure for other inputs than fertilizer	χ_1	€ 161/ha
	χ_2	€ 182/ha
Social value of retaining land in agriculture:		
LFA payment	$A_j(q)$	€ 168/ha
Mitscherlich nitrogen response function		
Barley	α	3833 - 4761
	β	0.0168
	δ	0.828
Wheat	α	3842 - 5460
	β	0.0105
	δ	0.7624
Nitrogen runoff at average nitrogen use	ϕ	15 kg/ha
Cost of soil testing	T	€ 20/ha
Establishment cost for buffer strip	γ	€ 107/ha

Notes: Prices are from the year 2005. The price of nitrogen is calculated on the basis of a compound NPK fertilizer.
Sources: Bäckman et al. 1997, Turtola and Jaakkola 1987, Simmelsgaard 1991.

Table 2. Fertilizer Application, Buffer Strip Area, Crop Production, and Nitrogen Runoff under Alternative Policies

Policy Scenario	Crop Production (kg)		Nitrogen Fertilizer Used (kg)	Buffer Strip Area (ha)	Nitrogen Runoff (kg)
	Barley	Wheat			
Base Case					
Social Optimum	82,854	53,222	3589	0.87	468
Area Payments with No Environmental Compliance	85,281	62,098	4256	0	632
Fertilizer Subsidies with Costly Enforcement plus Buffer Strip Subsidies	86,272	49,807	3642	1.13	463
Buffer Strip Subsidies Only	86,528	56,538	4232	1.14	512
Maximum Land Quality 60% Higher than Base Case					
Social Optimum	57,886	140,444	4534	0.49	592
Area Payments with No Environmental Compliance	57,075	155,010	5458	0	792
Fertilizer Subsidies with Costly Enforcement plus Buffer Strip Subsidies	57,928	141,083	4616	0.61	593
Buffer Strip Subsidies Only	65,067	143,534	5429	0.69	679

Table 3. Farm Income, Subsidy Payments, and Nitrogen Runoff Damage under Alternative Policies

Scenario	Farm Profit	Nitrogen Runoff Damage	Subsidy Payments			Monitoring Cost	Social Welfare
			Fertilizer Payments	Buffer Strip Payments	Area Payments		
Base Case							
Social Optimum	3376	1684	0	0	6720	0	8418
Area Payments with No Environmental Compliance	3644	2256	0	0	6720	0	8108
Fertilizer Subsidies with Costly Enforcement plus Buffer Strip Subsidies	3349	1652	408	142	6170	8	8409
Buffer Strip Subsidies Only	3418	1828	0	410	6310	0	8309
Maximum Land Quality 60% Higher than Base Case							
Social Optimum	9144	2115	0	0	6720	0	13749
Area Payments with No Environmental Compliance	9456	2828	0	0	6720	0	13348
Fertilizer Subsidies with Costly Enforcement plus Buffer Strip Subsidies	9143	2117	281	283	6156	16	13746
Buffer Strip Subsidies Only	9242	2424	0	324	6396	0	13538

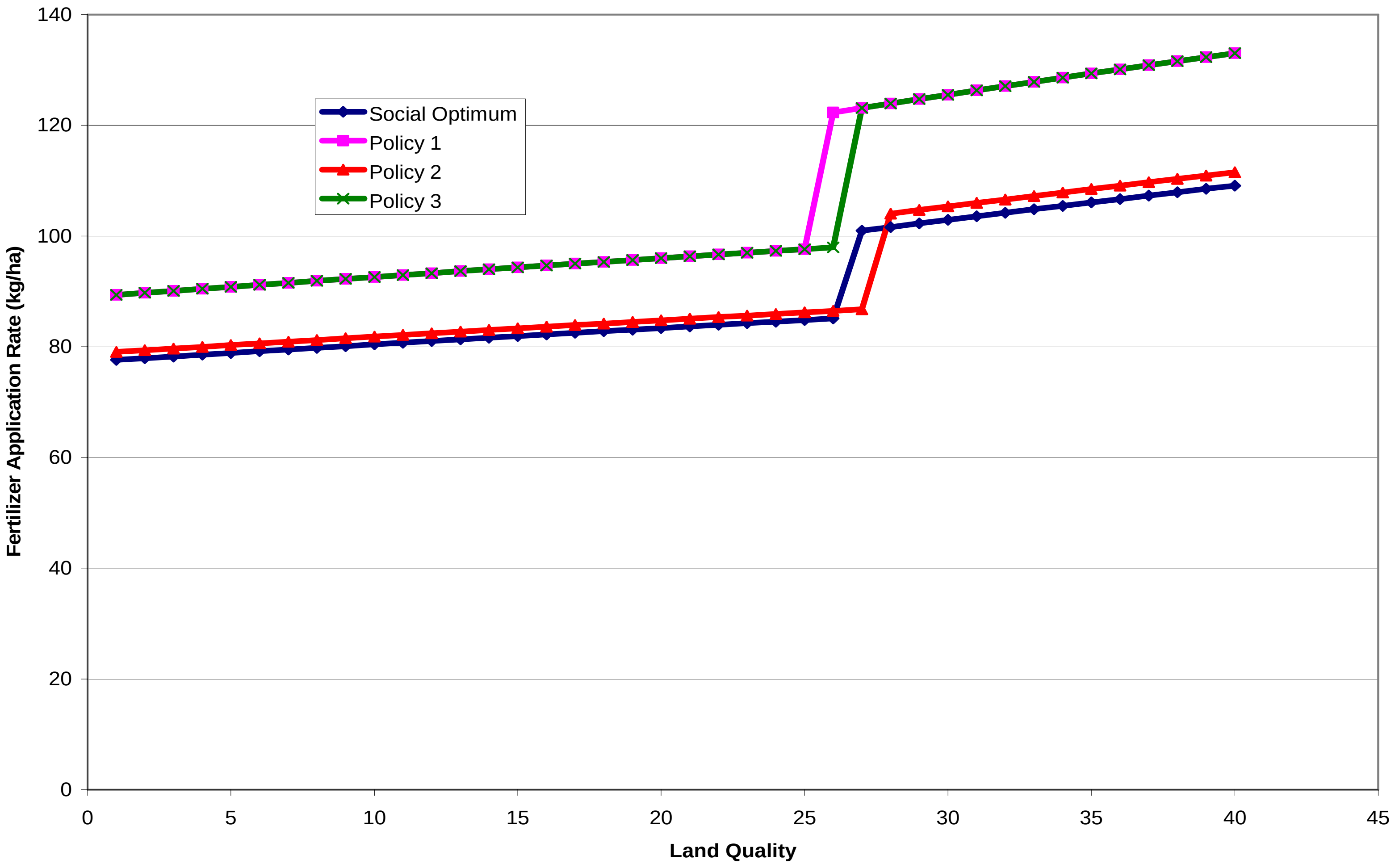

Figure 1. Fertilizer Application Rates on Different Qualities of Land

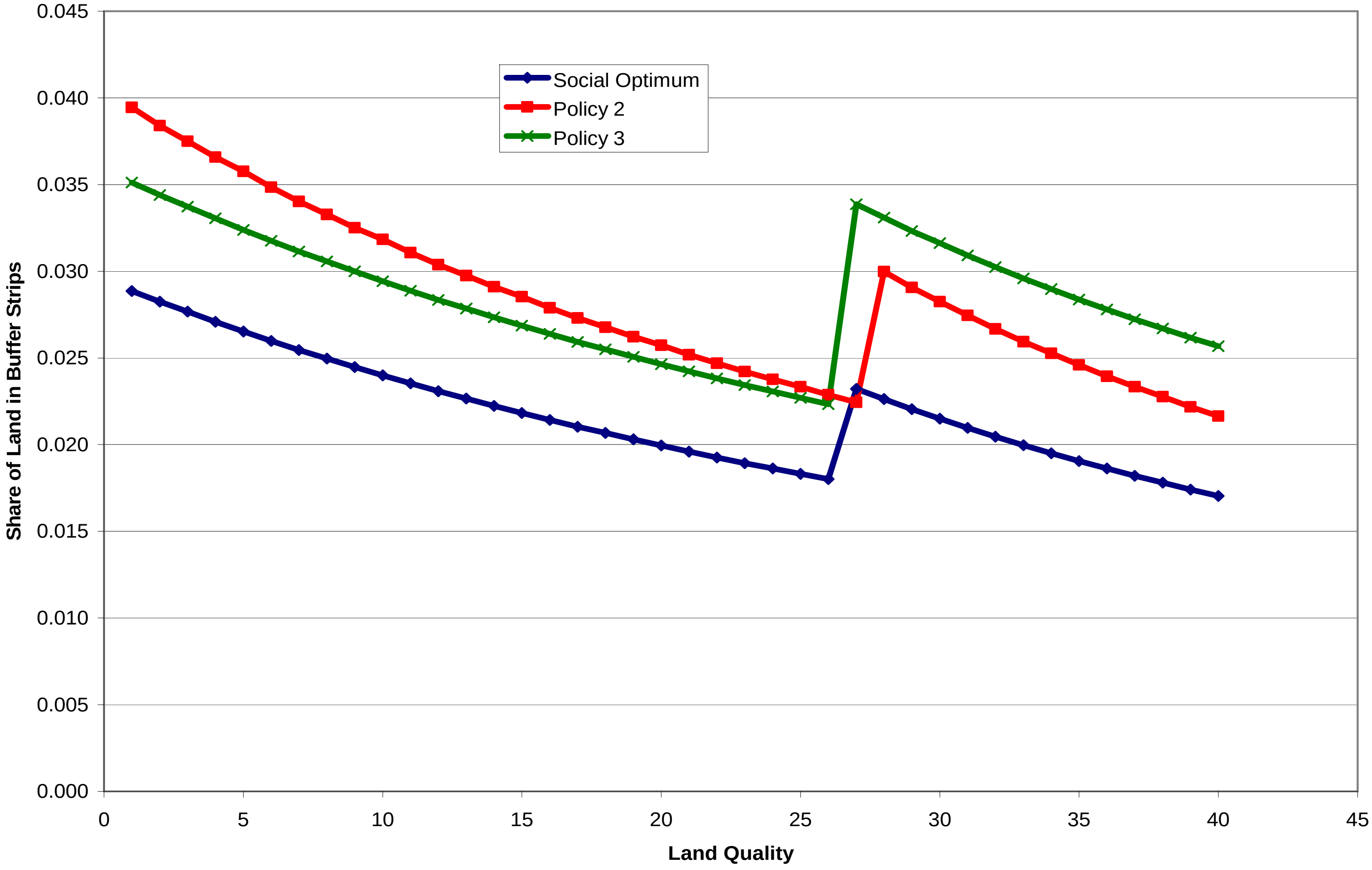

Figure 2. Buffer Strip Area on Different Qualities of Land