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# Agri-environmental program compliance under heterogeneous conditions

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*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.

*Keywords*— nutrient runoff, monitoring, enforcement

## I. INTRODUCTION

It is now widely recognized that agriculture produces a variety of environmental services—both positive and negative—in addition to farm commodities [1]. As a result, there is growing interest in reformulating agricultural policies in ways that encourage the provision of positive environmental services (e.g., scenic landscapes, wildlife habitat, cultural heritage) and discourage the provision of negative ones (e.g., water quality impairment from fertilizers, sediment, and pesticides) [2]. Such an interest is especially great in the European Union (EU) due to the need to restructure the Common Agricultural Policy (CAP) in light of budgetary pressures and new WTO restrictions and where there is less geographical separation between major farming and urban areas than in the United States, Canada, or Australia. Like the United States, many European Union countries currently complement CAP area payments and LFA support with measures such as environmental compliance requirements. Area payments affect the provision of environmental services by helping sustain agricultural production on otherwise unprofitable areas [3]. Provisions aimed at reducing negative externalities or promoting positive externalities are increasingly common as well. Belgium, Finland, Germany and Sweden utilize mandatory or voluntary restrictions on the use of fertilizers to reduce runoff and Belgium, Finland, Sweden and United Kingdom utilize mandatory or voluntary field margin management to promote biodiversity conservation and/or limit runoff (for general overview see e.g. [4]).

Enforcement can be a significant obstacle to effective implementation of these agri-environmental policies (see for example [5], [6], [7], [8], [9], [10], and

[11]. The environmental compliance requirements that accompany agri-environmental subsidies are not self-enforcing. They are costly for farmers because they reduce agricultural productivity (e.g., by lowering fertilizer application or removing land from crop production), giving farmers a clear incentive to cheat by falsely claiming to have implemented them. There is no automatic verification because there is no clearly identified product delivered to the government (in contrast to production contracts, e.g., where output is verified automatically on delivery of the product). Compliance monitoring is often costly, however, in which case it becomes important to devise efficient compliance monitoring schemes to ensure that agri-environmental policy goals are met.

Consider for example the case of fertilizer reduction and riparian buffer strip requirements, which are used in a number of European countries. 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. Similar considerations may apply to riparian buffers 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.

The problem of how governments should design compliance monitoring strategies when environmental compliance requirements are not self-enforcing has not received much attention to date. The most relevant

studies in the literature to date are those of [10] and [11]. [10] studies the optimal responses of risk averse farmers subject to compliance monitoring in the presence of price uncertainty. [10] shows theoretically that returns to cheating are decreasing in the degree of risk aversion; an empirical illustration demonstrates that compliance is optimal when risk aversion and price uncertainty combined are sufficiently great. [11] extends this analysis of optimal farmer response to targeted compliance monitoring schemes in a two period model in which the probability of period 2 inspection is contingent on observed period 1 compliance status. An empirical illustration demonstrates that such a targeted monitoring scheme can make compliance in both periods the dominant strategy when penalties for non-compliance are sufficiently high. Other studies of optimal government strategy have largely focused on second-best agri-environmental subsidies in the presence of hidden information when compliance is costless verifiable, i.e., when self-enforcing contracts are possible (see for example [12], [13], [14], [5], [6], [7], and [8]). As the compliance requirements of agri-environmental policies are rarely self-enforcing, the results of these studies are of only limited applicability.

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. We assume that land quality is perfectly observable at negligible cost and thus that compliance with buffer strip requirements is verifiable at negligible cost. For fertilizer use we consider two cases. In the first, fertilizer application is verifiable through costly monitoring. In the second, it is non-verifiable or verifiable only at excessive cost. In the latter case, buffer strip requirements and associated payments are the only enforceable policy instrument. We extend the conceptual framework of [9], [15], and [16] 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. Details of the theoretical and empirical models are presented in [17].

## II. PRODUCTION AND RUNOFF

In [17] we use as a baseline the Ricardian model of [16] 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. Land quality differs over parcels.

It is assumed for simplicity that there are only two crops grown in this region, both crops produced under constant returns to scale technologies with crop 1 better suited to lower quality land. Output of each crop per unit of land area, is a function of land quality and the fertilizer application rate. Crop production generates negative environmental externalities via nutrient runoff. We assume that runoff for each parcel of land is a function that depends on the crop, the amount of fertilizer applied to the parcel, and the share of the parcel devoted to the buffer strip. Land in agriculture also generates positive externalities in terms of open space, preservation of landscapes of important cultural significance, and similar environmental services. Under certain regularity assumptions (intuitively, that crop 2 is more profitable at land of maximal quality and more responsive to changes in land quality), a unique critical quality, can be defined at which the land allocation switches from one crop to another (see for example [9]). 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. Thus, farmers will not maintain buffer strips in such cases because they receive no compensation for the lost rent. 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 [9] and [16]).

## III. A-E 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. Analytical results (see [17] for details) 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 [9].

In what follows, [17] extends 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).

### *Fertilizer Use Verifiable with Costly Monitoring*

Farmers receive three types of direct payments under existing policy regimes in Europe: a subsidy for planting a buffer strips, an area payment for land allocated to crops and, when applicable, a subsidy for complying with restrictions on fertilizer use.

Suppose that fertilizer use is perfectly verifiable through an annual soil test 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.

The socially optimal allocation of land between the two crops can be attained by restricting total agri-environmental subsidy payments per unit of land to the marginal value of positive environmental services generated by that land. In what follows, we impose this restriction on total subsidy payments. 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.

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.

### *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 that land. Farmers will choose the unregulated level of fertilizer use for each crop on each quality of land, and a buffer strip size.

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. The optimal subsidy in this case is set to induce farmers to allocate more land to buffer strips than is socially optimal.

## IV. EMPIRICAL ANALYSIS

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. For details of the empirical model see [17].

### *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. Details can be found in [17].

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. The marginal cost of nitrogen runoff

damage is assumed to be constant.

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.

*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. 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.

*Base Case Results*

As indicated by the theoretical analysis, fertilizer application rates are increasing in land quality while buffer strip areas are decreasing in land quality for any given crop. 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. 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, 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 that is socially optimal to plant in wheat. 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.

*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.

## V. 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.

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