Costs of controls on farmers' use of nitrogen

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Costs of Controls on Farmers' Use of Nitrogen

A study applied to Gotland

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Stockholm, November 7, 1988

Ing-Marie Andréasson

CONTENTS

INTRODUCTION

Results from an interdisciplinary research study of the Swedish island of Gotland were presented in late 1970s; see Janson and Zucchetto (1978) in Chapter 1. It was found that the content of nitrate in the drinking water from many wells exceeded the level recommended by the Swedish National Social Welfare Board. Warnings were therefore raised to the effects that nitrogen could not continue to be applied in unchanged amounts. Today, high concentrations of nitrate in drinking water is a severe environmental problem, not only in Gotland but also in agricultural districts in the rest of Sweden and in other countries.

There are two main difficulties associated with implementing policy instruments aimed at reducing the application of nitrogen. First, farming is often of considerable importance to the entire region in question. In Gotland, many processing industries, such as slaughterhouses and dairies, rely on supplies from agriculture. Second, policy paramaters open to regional policy-makers are restricted as compared to national decision-making which might place high demands on monitoring capacity. This is a brief background to the main purpose of this study, which is to calculate and compare costs of alternative policies with respect to cost efficiency, income distribution effects and violation incentives. The policy instruments included are the quota, charge and permit market systems.

There are only a few studies which contain empirical calculations of the costs of different policy instruments aimed at reducing farmers' use of nitrogen. To my knowledge, there are three; see Taylor (1974), Horner (1975) and Dubgaard (1986) in Chapter 3. A common feature of these studies is that they compare policy instruments solely with respect to cost efficiency. Thus, an extension in our study is that we include several criteria of comparison. Another difference as compared to the above-mentioned studies is the method used to carry out empirical calculations. We apply econometric methods to estimate a nitrogen demand function which is then used in all of our quantitative calculations. The quantative method applied in the other studies is optimization.

A cornerstone for all of the calculations executed in this study is the contents of Chapter 1. In this chapter we describe how the reduction in nitrogen necessary to obtain satisfactory water quality is determined. We then distinguish between fertilizer and manure. The chapter also contains a brief review of the factors which determine farmers production decisions. Some of the major features found are that farmers' incomes are uncertain due to randomness in yield and that fertilizer accounts for a relatively large share of total costs. Another noteworthy phenomenon is that the use of nitrogen exceeds the quantity which maximizes expected profits.

The observations made in Chapter 1 serve as inputs for Chapter 2, where the farmer's decision-making regarding use of nitrogen is modelled. The farmer is assumed to maximize expected utility of profits owing to randomness in yield. This decision rule is found to be consistent with the observations in Chapter 1 and the estimates of the demand for nitrogen in Chapter 5. If farmers regard the treatment of manure as a disposal problem, their decisions regarding use of nitrogen are characterized by risk aversion according to the theory of expected utility. The assumption that the farmers apply this decision rule is used in the calculations in subsequent chapters.

In Gotland, farming is of substantial economic importance. Policy instruments aimed at reducing farmers' use of nitrogen might therefore affect the economy of the entire island. On the other hand, implementation of nitrogen-abatement technologies might provide a technological advantage, from which the island could make benefits, as compared to the rest of Sweden. The policy instruments are therefore analyzed with respect to cost efficiency, income distribution effects and technological change in Chapter 3.

The results of Chapter 3 show that the charge and permit market systems perform best with respect to cost efficiency. This is a common result of studies which analyze the cost efficiency of alternative policy instruments. A permit market also generates the lowest income effects. The income distribution effects under a quota system are greater than under a charge system for a sufficiently great difference between the distribution of quotas and the efficient allocation under a charge system. All three policy instruments encourage technological change, but the results regarding the instrument which promotes the highest incentives for technological adjustment are ambiguous.

The success of achieving a reduction in the use of nitrogen depends to a large extent on the incentives to violate the policy instruments.

An analytical comparison of these so-called violation incentives is therefore done in Chapter 4. Violation incentives are measured as the potential profit from violation, which is defined as expected utility of violation gains less expected utility of violation costs. The analytical results show that the profits from violating a quota system are lower than those from violating a charge system if the charge is high enough and/or the quotas are not distributed too inefficiently. Under a permit market, the price of permits, i.e., the price of legal use of nitrogen, is reduced by the occurrence of illegal use of nitrogen. This, in turn, reduces the size of violation profits. For a sufficiently large reduction in the price of permits, violation profits under this system are below the profits from violating the other two policy systems.

According to the analytical results of Chapters 3 and 4, quantitative analysis is the only means of determining whether or not a charge system performs better than a quota system with respect to income distribution effects and violation incentives. An unambiguous result was that a permit market yields the lowest income effects. Furthermore, a permit market system in combination with a charge system, perform best with respect to cost efficiency. In order to determine the ranking of the charge and quota systems and to ascertain the degree of superiority of a permit market, quantitative analyses are performed in Chapters 5 and 6.

The empirical calculations are based on estimations of the demand for nitrogen in Chapter 5. In order to estimate costs of a quota system, demand functions for different groups of farmers have to be estimated. According to the results, the average nitrogen-price elasticity is 0.5

in absolute value. The nitrogen-price elasticities for different groups of farmers vary between 0.15 and 1.09 in absolute values.

The results from the estimations of nitrogen-price elasticities in Chapter 5 are used to calculate the performance of policy instruments with respect to cost efficiency, income distribution effects and violation profits in Chapter 6. Two effects of the leakage of nitrogen from manure are considered, which implies that we obtain two results for each criterion of comparison and policy instrument. According to the results, the losses from an inefficient distribution of quotas can amount to 60 percent of the costs under the charge and permit market systems. The income distribution effects of a permit market system are the smallest, regardless of the amount of nitrogen leakage from manure. When the leakage from manure is assumed to be high, the income distribution effects are largest for a charge system. For a low level nitrogen leakage from manure, a quota system has the largest income distribution effects. The policy systems are ranked in the same way when they are compared with respect to violation profits. It turns out that the profits from violating a quota system can exceed the profits from violating a permit market by more than 200 percent. These and other results are summarized in the end of this study.

1. WATER QUALITY AND USE OF NITROGEN – A DESCRIPTION

On the Swedish island of Gotland, the average concentration of nitrate in the drinking water is four times higher then in the rest of Sweden, 40 mg NO_3/l as compared to 10 mg NO_3/l (Spiller, 1978). High concentrations of nitrate are injurious to health, carcinogenic and lower the ability of the blood to absorb oxygen. In this chapter it is shown that the largest single source of nitrogen is farmers' use of fertilizer.

Gotland's farmers are significant not only in an environmental perspective but also in economic terms. Agriculture accounts for a considerable to gross regional product. Much of the processing industry, such as slaughterhouses and dairies, depend on the supply from agriculture. Thus, a improvement in water quality, achieved by decreasing the use of fertilizers, could be costly to the entire society of the island.

Ideally, determination of reductions in the use of fertilizers should be based on associated social costs and benefits. Costs of reducing the use of fertilizer include e.g. farmers' income losses. The main benefit from decreasing the use of fertilizer is improvement in water quality. The process of determining an optimal level for reduction in the use of fertilizer presupposes information on the relation between all sources of pollution and their associated environmental damage. Unfortunately, no such model of the hydrological structure of Gotland is available. Instead, we have to rely on a simulation model of the relationship between total use of nitrogen and concentration of nitrate in the drinking water is simulated; see Spiller (1978). According to this simulation, actual use of nitrogen has to decrease by as much as 60 percent in order to obtain an acceptable quality of drinking water, i.e., less than 30 mg NO_3/l.

Such a large decrease in the use of nitrogen would in all likelihood have a serious economic impact on farmers. The size of the economic effects depends on, among other things, the substitutability between nitrogen and other factors of production. This chapter contains a brief description of the factors which determine farmers' production decisions. This description serves as a basis for the modeling of a nitrogen decision rule in Chapter 2. Salient features are a high cost share for nitrogen and uncertain income due to randomness in the yield outcome. Another noteworthy phenomenon is that the total use of nitrogen, i.e., the sum of chemical nitrogen and manure nitrogen, seems to exceed the quantity which maximizes expected profits.

We begin by briefly describing water pollution and its sources. We then show how necessary reductions in the use of nitrogen are determined and describe the economic conditions which influence farmers' decisions regarding the use of fertilizer.

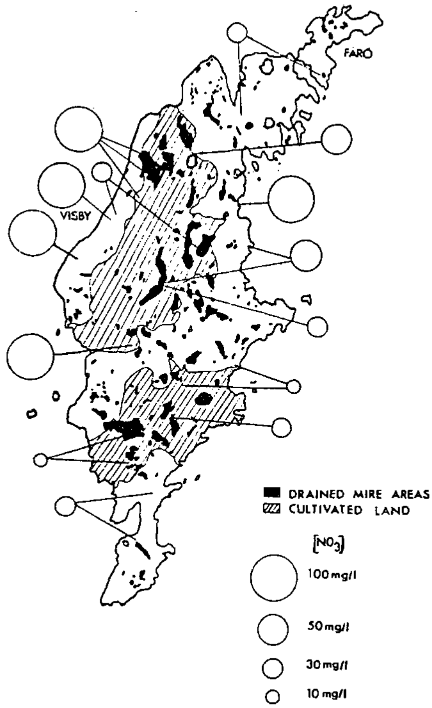
1.1 Water Quality and Nitrogen Pollution.

Gotland is a rather elongated island measuring about 130 km in length and 50 km at its widest point. Its area is approximately 3070 km^2, of which almost 50 percent is covered by forests cf. Jansson (1978). The acreage of arable land amounts to about 30 percent. One third of the arable land consists of drained mires where the leakage of nitrogen is high.

The bedrock of Gotland is mainly limestone. This is advantageous in the sense that acidification does not occur on the island. But limestone is porous, which makes it easy for nitrogen to infiltrate and reach the ground water. The bedrock also contains widespread cracks so that nitrogen is quickly spread from one area to another. This bedrock structure is one important reason why concentrations of nitrate in the drinking water are high in spite of the moderate intensity of fertilization.

The yearly average of nitrate concentration in the drinking water is 40 mg NO_3/l while the corresponding figure for the rest of Sweden is 10 mg; see Spiller (1978). In some wells the nitrate concentration is as high as to 100 mg NO_3/l. Figure 1 shows that there are high concentrations of nitrate in the drinking water throughout the whole island.

Figure 1.1: Nitrate contents in drinking water in Gotland.



Source: Spiller (1978)

High concentrations of nitrate are found in drained mires and arable land. In drained mires nitrogen leaks into the ground water instantaneously. This is due to the fact that drainage of the mires releases nitrogen which was previously bound in large stores. In cultivated land, fertilization causes the high concentrations of nitrate.

Farmers' use of fertilizer is not the only source of nitrogen, however. Other sources might also influence the quality of water, although probably to a lesser extent. These sources are sewage sludge, traffic and combustion installations. All of the sources and their nitrogen emissions are listed in Table 1.1 (see appendix for calculations).

Table 1.1: Sources of nitrogen emissions, in 1984.

Source	Nitrogen, tons
Agriculture	8 510 N
Sewage discharge	170 N
Traffic	1 890 NO_x
Combustion installations	270 NO_x

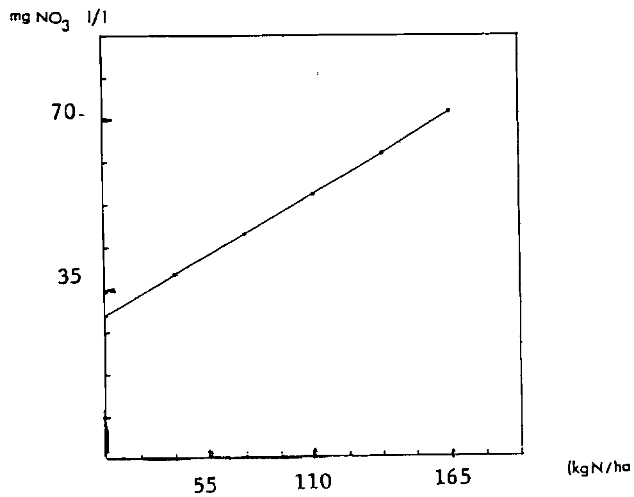
Agriculture is undoubtedly the largest single source of nitrogen. The second largest source, is the traffic. Such air pollution, however, is of minor importance to the quality ground water because it blows away from the island and pollutes the surrounding sea water instead (Jansson, pers. communication). The same holds true for air emissions of the combustion installations.

Thus, there are in principle two ways of improving the quality of the ground water: i) reductions in fertilization and sewage discharge and ii) restoration of the wetlands so as to reduce nitrogen leakage. Unfortunately, very little is known about the effects of such restoration since very few large scale experiments have been carried out. Therefore this alternative is excluded here. Discharge from the sewage system can only be reduced by a small amount since the homes of one- third of the population is already connected to a the sewage-treatment plant which reduces the content of nitrogen by 50 percent. Obviously then, the most important remaining source of nitrogen is the application of fertilizer. Different measures for reducing farmers' use of nitrogen have been considered in many studies at the Swedish University of Agricultural Sciences in Uppsala.

Despite extensive research, not very much is known about fertilizer application and infiltration of nitrogen into the ground water. The amounts which infiltrate and the time required for nitrogen to percolate the soil depend on the crops in question as well as weather and soil conditions. Gotland has been studied in two hydrological projects by Spiller (1978) and Nilsson (1983). Spiller constructed a model for the whole island, while Nilsson focused on one heavily polluted basin, Lummelunda stream (608 km^2). Both studies found chemical nitrogen and manure to be important sources of nitrogen pollution. The application of chemical nitrogen increases the overall concentration of nitrate. According to Nilsson's study, the treatment of manure produces high local concentrations of nitrate. Application of manure in the autumn is particularly damaging to water quality because crops do not make use of the nutrients at this time of year.

Spiller's hydrological model is the point of departure for this study. The model determinates the reduction in nitrogen application required to obtain water quality with nitrate concentrations of less than 30 mg NO_3/l, which is classified as a satisfactory level by the National Swedish Social Welfare Board. The results of Spiller's simulations shows a linear relation between the concentration of nitrate and application of nitrogen; see Figure 1.2.

Figure 1.2: Nitrogen application and concentrations of nitrate in ground water in Gotland.



Source: Spiller (1978)

Currently 100 kg N/ha is applied to the cropland, of which 70 kg N/ha is chemical nitrogen and 30 kg N/ha is manure. In order to achieve a level 30 mg NO_3/l, the nitrogen dose should not exceed 40 kg N/ha. Satisfactory quality is then obtained if the total application of nitrogen is reduced by 60 percent. It is interesting to note that the Environmental Protection Agency recommends a 50 percent reduction in the total deposition of nitrogen in Sweden; see SNV (1987). Similar results were arrived at in studies of the Laholm Bay on the West coast of Sweden, where it is found that the application of nitrogen should be decreased by 50 percent in order to restore the bay; cf. Fleisher (1987).

An average of 8520 tons of nitrogen is applied to the cropland in Gotland, i.e., which implies 100 kg N/ha. Chemical nitrogen account for 5830 tons and manure 2690 tons. According to Spiller's model, the necessary reduction in the use of nitrogen amounts 5100 tons (0.6 x 8520), which could theoretically be obtained solely by reducing the use of chemical nitrogen. In practice, this might be a difficult task because farmers do not regard chemical nitrogen and manure as perfect substitutes. The quality of nitrogen in fertilizer and manure is not indicated. It is inorganic in fertilizer, which implies that it is easily available to crops. Some qualities are immediately available through sprinkling. Manure nitrogen is organic and microbes are required to make it available to crops. This makes it difficult to forecast when and how much nitrogen has an effect on crops. Some of the nitrogen can be used immediately, some is accessible 30 years later. In general, half of manure nitrogen is available to crops during the season it is applied (Medhammar, personal communication). Therefore, reductions in the use of both chemical nitrogen and manure have to be taken into consideration

The damaging effects of fertilization on the quality of water can, in principle, be alleviated in two ways. As indicated in Figure 1.2, water quality can be improved either by reducing the use of fertilizer or by shifting the curve downwards. A shift in the curve implies that less nitrogen leaks into the ground water for a given dose of fertilizer. We move along the curve by reducing the application of chemical nitrogen and manure we move along the curve. A downward shift in the curve is obtained through measures directed towards the use of manure.

The application of chemical nitrogen can be reduced simply by buying lower quantities. It is more difficult to decrease the application of manure since it is a waste product from livestock. One way to reduce application is to decrease holdings of livestock, which is one of the measures considered in this study. Other possibilities include devising an alternative use for manure in Gotland, or finding potential users of manure outside the island.

Experiments have been carried out where manure is used as fuel to heat private homes (Rundquist, personal communication). Using combustion technology was not found to be an appropriate fuel. This possibility is therefore excluded in this study. Experiments have also been conducted where manure is dried in order to make the nutrients more easy to handle (Rodhe, personal communication). This means that Gotland could export manure in a dried form to potential buyers outside the region. At present, chicken and cattle manure are the only animal waste dried in this way, and are thus only drying alternatives considered in this study.

Nitrogen leakage can be reduced, i.e., a downward shift in the curve in Figure 1.2, by applying manure to land which is cowered by crops. As was mentioned above, the quality of water is especially sensitive to application of manure in the autumn when there are no crops to make use of the nitrogen. Leakage may then be decreased by spreading manure in spring instead of autumn, and/or by cowering the land with crops in the autumn. Crops appropriate for this purpose are cover crops, grass and energy forest, see Kindt (1987). Other alternative are crops which are used as fibers for pulp manufacturing (Andersson, personal communication). Such crops are not included in this study because they are not currently available for large-scale cultivation.

The measures under consideration may be compared by calculating them in terms of reductions in the application of nitrogen, i.e., movements along the curve in Figure 1.2. For example, cultivation of cover crops reduces the nitrogen leakage corresponding to some quantity of applied nitrogen. Table 1.2 shows the reduction in application of nitrogen from implementing the above-mentioned measures. Note that these figures are based on experiments from other parts of Sweden since no similar experiments have been carried out for Gotland (see appendix for calculations).

Table 1.2: Effects of different measures on the reduction in nitrogen application, tons of nitrogen/year.

1. Reduced livestock holdings	583
2. Drying of manure	2 185
3. Change in spread-ding time	1 343
4. Cover crops	950
5. Grassland	650
4+5	1 150
6. Energy forestry	960

All measures are assumed to be mutually exclusive except for 4 and 5. A change in spreading time will not have the effect given in the table if farmland is covered by crops in autumn and winter. Implementation of measures 4 and 5 compete with measure 6 for the same land. Thus, a maximum of 2 185 tons of nitrogen application can be reduced by measures involving manure. This means that chemical nitrogen has to be decreased by at least 50 percent.

The calculations which underlie the figures in Table 1.2 rely on the assumption that leakage is the same regardless of whether manure or fertilizer is applied. For different soils, the leakage of nitrogen averages 25 percent of the amount of nitrogen applied. However, there are findings which show that the leakage from manure is much higher, corresponding to 50 percent of the application rate (Medhammar personal communication). If this is correct, then the application of chemical nitrogen would only have to be reduced by only 13 percent if manure is reduced by 2185 tons. In Chapter 6, where costs for different measures are compared, we consider both types of nitrogen leakage.

1.2 Nitrogen Costs and Risk Management

Agriculture has been of considerable importance to the economy of Gotland for a long time. Today, farmers constitute about 13 percent of the household population. Farmers' contribution to total value added in production is about 20 percent; see Andréasson (1984). This includes incomes from both livestock holdings and crop production. On the average, income from crop production corresponds to 40 percent of total agricultural income; see Yearbook of Agricultural Statistics (1984)

Fertilizer costs account for 28 percent of the total variable costs for production of crops. This cost share is not constant but depends on soil conditions and which crops are cultivated. Nevertheless, according to Table 1.2 there are only small variations in fertilizer cost shares between different groups of farmers. The farmers are divided into three groups according to their holdings of arable land.

Table 1.3: Fertilizer cost shares for different groups of farmers.

Ha of arable land/farmer	< 30	30 - 50	> 50
Share of total variable cost	0.25	0.26	0.33

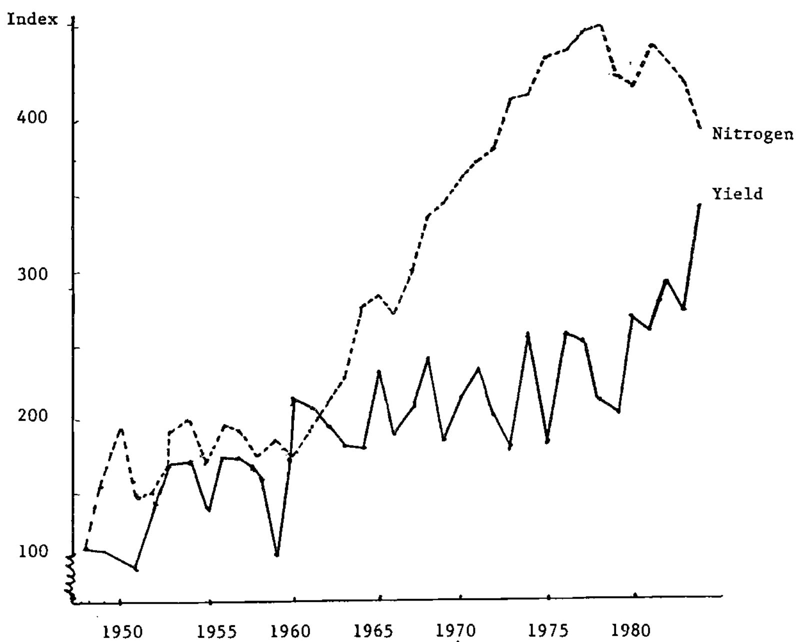
According to theses figures, fertilizer costs are significant. A cost increase might therefore have serious economic consequences. On the basis of the figures in Table 1.3, we would expect a high price elasticity. On the other hand, if there are no good substitutes for chemical fertilizer, a low elasticity would be expected. As the availability of manure might have an impact on price elasticities of nitrogen, it would be relevant to compare the figures in Table 1.2 with measures of the livestock holdings of different groups of farmers. Unfortunately, the data set did not permit such comparisons. A positive correlation between livestock and land holdings could be expected, however, since land is required for the production of forage.

The data in Table 1.3 includes not only nitrogen but all kinds of nutrients. Data on expenses for different nutrients are unavailable, but the cost of nitrogen cost can be related to total variable costs for different crops. The nitrogen share of total variable costs varies between 5 and 35 percent (Medhammar, personal communication). The profit margin (sales income less variable costs as a percent of sales income) amounts to 50 percent for the most crops. Thus, nitrogen costs, as a share of sales income, vary between 2.5 and 17.5 percent for different crops.

Handling of manure gives rise to two kinds of costs, one for applying it to the fields and the other for storing it. Labour costs account for most of the application cost, although the value of the marginal product of labour differs with respect to the season. This value is much less in autumn than in spring because a great deal of labour is needed for sowing in the spring time. The alternative cost of applying manure is high in spring and it is lower in autumn (Medhammar personal communication). The cost of storing manure depends on the composition of livestock, being higher for cattle manure than for chicken manure (see Chapter 6)

Farmers' decisions regarding the amount of fertilizer to use are based not only on its cost and contribution to yield, but also on the uncertainty with respect to yield. For a given fertilizer dose, the yield varies substantially depending on the weather. Experiments show that the highest yield can be 50 percent above the lowest; see Kumm (1975 and Mattson & Biärsjö (1981). Figure 1.3 reveals that total yield fluctuated considerably during the period 1948-1984. A curve of the use of chemical nitrogen is also drawn in Figure 1.3, which shows a relatively steady increase (see Chapter 5 for a description of the data).

Figure 1.3: Yield and use of nitrogen, 1948-84.



In Sweden, an insurance system has been set up to cover yield losses caused by poor weather conditions. This system has to be taken into account because it to some extent determines the specification of uncertainty; see Chapter 2. According to this system, th farmer receives insurance compensation when the value of yield is below a certain level. The payment is based on a so called "yield norm" which is calculated as the average yield per ha over a period of 50 years. Such yield norms are estimated for nine different agricultural districts in Gotland. The excess is 16 percent of the value of the norm yield. The farmer thus receives 84 percent of the yield norm value plus/minus 2 percent depending on in which of the nine districts he lives.

It is difficult to evaluate the economic importance of the insurance system because we have no information on the variations in yield incomes. But the insurance system seems to be of limited value as compared to total incomes from crop production. During the period 1964-1984, insurance payments never exceeded one percent of total income from crops.

The farmers in Gotland are in fact not satisfied with the way the insurance system functions. A central authority determines who has the right to receive money. The farmers do not claim any payments themselves and hence have no influence on the system. Those with heavy losses do not always receive insurance payments (Nyberg, personal communication).

Thus, in spite of the insurance system, farmers' decisions on output and factor use are most probably influenced by randomness in yield. Fluctuating yield is the most important but not the only source of uncertainty. There is also a random element in the determination of input and output prices.

As in many other countries, prices of agricultural inputs and outputs are determined on a national level by negotiations. The frequency of these negotiations in Sweden is once a year. This annual process gives rise to price stability. The price of fertilizer is known to the farmer in July and nine months later, in April, he knows output prices with certainty. However, due to sellers' storage costs, an incentive scheme has been set up to induce farmers to buy fertilizer earlier. The price of fertilizer increases steadily by 20 percent from July to April (Eriksson, personal communication). When a farmer makes a decision about fertilizer purchases, he has to weigh increased fertilizer costs against certainty in crop prices.

Another source of uncertainty is the interest rate. In the last few years, farmers have become more sensitive to changes in the interest rate. One reason is that a few years ago there was an unusually sharp increase in the interest rate. Many farmers then complained about the high debt burdens. Therefore, a special insurance against losses due to changes in the interest rate was introduced in 1984.

In other words, farmers have to cope with three kinds of uncertainties: the weather, input and output prices and the interest rate. Random weather certainly has the greatest impact on farmers' incomes. However, as a guideline, annual recommendations are given for accurate nitrogen dosages for different crops. These recommendations take into account for differences in soil conditions and are distributed to all farmers in Sweden. Dosages are based on field experiments and correspond to the level which maximizes expected profit for each crop. Recommended and actual nitrogen doses are compared in Table 1.3. The figures for actual doses refer only to chemical nitrogen.

Table 1.4: Recommended and actual nitrogen dosages, kg/ha 1978.

	Wheat	Barley	Oats	Rye	Potatoes
Recommended	100	62	90	65	100
Actual	99	74	73	67	117

Source: Yearbook of Agricultural Statistics (1984) and Gotlands Lantmän.

Actual doses exceed the recommended levels for barley and potatoes and are below the levels for oats. When manure nitrogen is added to the actual dosages, they increase by 30 kg. Then all actual dosages exceed the recommended levels by with between 13 and 68 percent depending on the crop. Unfortunately, no other studies have been carried out in regard to actual nitrogen dosages for different crops in Gotland. However, recent studies of the West coast of Sweden show however that actual application of nitrogen highly exceeds the recommended dosage (Kindt, personal communication)

1.3 Summary

The total application of nitrogen in Gotland has to decrease by 60 percent in order to achieve satisfactory water quality, less than 30 mg NO_3/l. This reduction in nitrogen can be accomplished by measures directed towards the application of both chemical nitrogen and manure. When manure is spread in the autumn, it has particularly damaging affects on water quality. Thus, some measures for reducing autumn leakage are considered i.e., a change in the spreading time from autumn to spring, cultivation of cover crops, an increase in grass production and energy forestry. Other measures which reduce the overall application include a decrease in the size of livestock holdings and drying of chicken manure. (The costs of these measures will be compared with the costs of reducing the use of commercial fertilizer in Chapter 6.)

The costs of reducing nitrogen application depend, among other things, on the factors which influence farmers' production decisions. Expected profit is one such factor. Another is uncertainty in actual yield. Farmers are not very satisfied with the Swedish insurance system aimed at compensating them for poor harvests. They are, however, provided with recommendations regarding the nitrogen dosages which maximize expected profits. But a comparison of actual and recommended doses shows that actual application exceeds the recommended level. It is noteworthy that this phenomenon occurs not only in Gotland but also in other agricultural districts in southern of Sweden.

APPENDIX

A.1. Sources of Nitrogen Emissions

Agriculture

The total amount of chemical nitrogen used in Gotland was 5820 tons in 1983. According to Table A1, the nitrogen content of manure is 2686 tons for 8 months' production. The application of nitrogen attributable to agriculture is then 8506 tons.

Table A1: Nitrogen in manure for 8 and 12 months' production, 1984.

	Number	Nitrogen/animal, solid+liquid, kg N/year	Total nitrogen, tons of N/year
Cattle:			
Milk cows	21,323	35.7	761
Calves	19,585	15.8	309
Heifers	23,317	35.7	832
Pigs:			
Sows and piglets	7,883	15.1	118
Others	32,904	4.1	135
Sheep	68,835	3.6	248
Poultry	353,486	0.8	283
Total 8 months			2686
Total 12 months			4029

Source: Spiller (1978), Yearbook of Agricultural Statistics (1985)

Sewage sludge

Nitrogen discharge/person/day is 11 g; Environmental Statistics (1983-84). The population of Gotland is 56 000, thereby implying 225 tons of nitrogen discharge per year. But the homes of 26 000 people are connected to a sewage treatment plant, which reduces the nitrogen content by 50 percent. Thus, 170 tons of nitrogen are emitted from the sewage sludge.

Traffic and Combustion Installations

The emission of nitrogen from traffic and combustion installations are derived from the consumption of fuel. The distribution of consumption of gasoline and fuel oils in 1983 is shown in Table A2.

Table A2: Consumption of gasoline and fuel oils, 1000 m^3

Gas	Diesel	Fuel oils: No. 1	No. 2-5
38.2	27.0	33.4	13.6

Source: Statistics Sweden, 1985

It is assumed that the composition of cars and trucks is the same in Gotland as in Sweden as a whole. Thus, nitrogen emission from gas is 29.3 kg/m^3 and from diesel 28.7 kg/m^3 (Ministry of transport, 1987). Total emission from traffic then amounts to 1894 tons.

The emission of nitrogen from fuel oils is assumed to be 1.1 kg/MJ; see Ahlbom (1983). The two kinds of fuel oils in Table A2 are converted into MJ as follows; cf. Jansson et. al. (1978)

Fuel oil 1: 0.035 MJ/m^3
Fuel oils 2-5: 0.039 MJ/m^3

Emissions of nitrogen from the combustion installations are then 270 tons.

A.2. Calculations of Potential Reductions in Nitrogen due to Different Measures.

Reduction in livestock holdings and drying of manure

According to a Government proposal, one way of handling the surplus of animal waste is to reduce the intensity of livestock holdings. livestock to 1 unit/ha (1 unit = 1 cow = 2 calves = 3 sows = 10 porkers = 100 chickens). The intensity in Gotland is already below this level, 0.9 units/ha. But in Gotland there are high concentrations of nitrate in wells located close to tanks where manure is stored. One proposal would therefore be to reduce the number of livestock which is not sent out to pasture. This means that the application of manure could be reduced by an amount corresponding to the manure of pigs and poultry, i.e., 583 tons of nitrogen according to Table A1.

By drying cattle and chicken manure, the application of nitrogen could be reduced by 1902 tons according to Table A1.

Changing the season when manure is applied from autumn to spring.

Current legislation stipulates that farmers store manure for a period of six months. Manure is then deposited on cropland twice a year. It is assumed that half of the production of manure nitrogen in Table A1 is spread in the autumn/wintertime, which implies 1343 tons.

Cover Crops

It is assumed that the area available for cover crops corresponds to used for spring crops less the land where grass is sown. The grassy area is about 25,000 ha, one-fifth of that is sown every year. The spring crops area amounts to 24000 ha. Thus the potential area for cover crops is 19,000 ha. Experiments show that cover crop reduce nitrogen leakage by 25 kg/ha; see Kindt (1988). The total potential reduction is then 25 x 19000 = 475 tones. It is further assumed that nitrogen leaching corresponds to 50 percent of the nitrogen application (Fleischer, personal communication). Thus the reduction in leakage corresponds to 2 x 475 = 950 tons.

Grassland

The potential increase in the acreage of grassland is assumed to amount to 30 percent of the grain area; see Andersson (1982). This means that 0.3 x 24000 = 8000 ha can be used for grassland. The reduction in leaching is 75 percent when barley is replaced by grassland; cf. Kindt (1988). Leaching from barley amounts to 50 kg/ha; cf. Kindt (1988). The total reduction in nitrogen leakage from increasing the acreage of grassland is then 8000 x 50 x 0.75 = 300 tons. This corresponds to a reduction of nitrogen application by 600 tones (see cover crops).

Energy Forestry

The maximum acreage is assumed to be the total grain area, i.e., 24,000 ha. The reduction in nitrogen leaching is 20 kg/ha; cf. Kindt

(1988). Thus the reduction in nitrogen leaching is 24000 x 20 = 480 tons which corresponds to 960 tons of nitrogen application.

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2. USE OF NITROGEN UNDER CONDITIONS OF UNCERTAINTY

Knowledge about the farmer's decision rule regarding the use of fertilizer is crucial for calculating the effects of a policy instrument. In the preceding chapter, we indicated that uncertainty with respect to yield plays a role. But how? It is known that the actual chemical nitrogen demand curve is downward sloping; cf. Chapter 5. Our description of farmers' situation for the conditions which farmers have to consider in their decision-making showed that the total use of nitrogen can exceed the level which maximizes expected profits; cf. Chapter 1. Thus, the purpose of this chapter is to model a nitrogen decision rule which takes into account a chemical nitrogen function that is decreasing in price and an "overoptimal" use of total nitrogen.

It is shown in this chapter that a risk averse behavior generates a downward-sloping nitrogen demand curve under certain conditions but is not consistent with the "overoptimal" nitrogen doses in the framework of the expected utility model. However, this inconsistency disappears if manure nitrogen is regarded as a by-product of animal production which creates a disposal problem. The only assumptions required for a downward-sloping chemical nitrogen demand curve is separability between chemical nitrogen and manure and that absolute risk aversion is nonincreasing in income.

This chapter is divided into four sections. We begin by describing the basic model. In Section 2.2 we analyze how the existence of risk aversion affects the use of nitrogen. Thereafter, conditions are derived for a downward sloping nitrogen demand curve. Cross-price effects are also analyzed in this section. The final section contains our main conclusions and a discussion of the results with references to experiments in the behavioral sciences.

2.1 The Basic Model.

Our model relies on following assumptions (maintained throughout the study unless specified otherwise):

- The farmers are price takers. This is quite realistic since the prices of both inputs and outputs are determined by national negotiations. In addition, the factor demand and production in Gotland constitute a very small part of the total factor demand and output.

- Decisions concerning output quantity and input use are made prior to knowledge about weather conditions. This is not completely true in the sense that a small fraction of fertilizer is bought during the growing season. In addition, fertilizers applied to autumn crops could also be adjusted to the yield achieved before that point in time. But since most of the chemical fertilizer, 75 - 80 percent, is applied in springtime, we believe the assumption to be plausible.

- The farmers' behavior towards risk can be described by a von Neuman-Morgenstern utility function.

In Chapter 1 we identified six different ways of reducing the application of manure. These measures are reducing the size of livestock holdings, drying of manure, spreading manure in the spring, cover crops, grassland and energy forestry. The first two measures reduce the overall application of manure, while the others are directed towards the autumn application. All of these measures are converted into equivalents for a decrease in the overall application as described in Chapter 1. The costs for reducing the application of manure by any of these measures are regarded as the costs of switching from current production technology to a new technology. It is assumed that the cost per unit of reduction, d^k where $k=1,...,6$, is constant for each measure which decreases the application of manure (see Chapter 6 for calculations of these costs).

The farmer is assumed to choose the quantities of chemical nitrogen, X, and application of manure, M, which maximize expected utility. The supply of manure is MT. The farmer incurs two types of costs for MT. One is the unit cost of applying manure to arable land, denoted by m. The other is the cost of not applying manure or reducing the leakage effects of manure application which, as described above, is denoted by d^k. The quantity of manure not applied to the land, or decreased leakage effects, are calculated as (MT-M). Throughout this chapter, the model refers to a single farmer so that index to indicate an individual is omitted.

Let $U(\pi)$ be the farmer's preference function and

(2.1) $$\pi = pQ - gX - mM - d^k(MT - M)$$

where

Q: output

p: output price

g: price of chemical nitrogen

X: chemical nitrogen

m: manure application cost

M: applied manure

d^k: cost for not applying manure, or reduce the leakage effects

MT: supply of manure

It is assumed that $U'>0$ and $U''<0$. The argument (π) of $U'=\delta U/\delta\pi$ and $U''=\delta^2U/\delta\pi^2$ is suppressed. This practice is frequently used in this and subsequent chapters.

In specifying the stochastic yield function, $Q=Q(X,M,\theta)$, where θ is the disturbance term, we have to know something about the effect of θ on yield. From studies based on field experiments the disturbance seems to have a multiplicative effect; see e.g. (Kumm 1975). In the event of a poor harvest, insurance compensation is paid in proportion to a statistically expected yield; cf. Chapter 1. However, it is not clear to the farmers who will receive payments and who will not. Therefore, following Pope (1979) a general specification of the effect of uncertainty is therefore given which includes the multiplicative effect as a special case. The stochastic production function $Q(X,M,\theta)$, where θ is the disturbance term, is thus formulated as

$$(2.2) \qquad Q = f(X,M,\theta) = f(X,M) + h(X,M)\theta$$

It is assumed that θ is normally distributed with $E(\theta)=0$ and $Var(\theta)=\sigma^2$. Note that we have the multiplicative case when $f(X,M)$ is equal to h(X,M). The following conditions are assumed to hold for the stochastic production function $Q_X, Q_M > 0$ and $Q_{XX}, Q_{MM} < 0$. It is also assumed that $f_X, f_M, h_X, h_M > 0$ and $f_{XX}, f_{MM} < 0$.

The conditions $h_X, h_M > 0$ might need some further explanation. Following Pope (1979), a production factor, F, is defined as risk increasing when $\delta Var(Q)/\delta F > 0$ and as risk decreasing when $\delta Var(Q)/\delta F < 0$. When differentiating the variance of (2.2) with respect to a production factor, a factor is found to be risk increasing (decreasing) if $h_F > 0$ ($h_F < 0$). Several field experiments find that higher dosages of fertilizer or manure increases the variance of output; see e.g. Kumm (1975). We therefore assume that $h_X, h_M > 0$ throughout the study.

When manure is viewed as a disposal problem, the above conditions are slightly changed. It is then assumed that $Q_M = Q_{XM} = 0$ (cf. Section 2.3 for a discussion of the condition $Q_{XM} = 0$).

The first order conditions for utility maximization are given by

$$(2.3) \quad \delta E(U)/\delta X = E[U'(pQ_X - g)] = 0$$

$$(2.4) \quad \delta E(U)/\delta M = E[U'(pQ_M - m + d)] = 0$$

where subscripts denote partial derivatives. Equations (2.3) and (2.4) can be written as

$$(2.3^*) \quad \delta E(U)/\delta X = pCov(U',\theta)h_X + pE(U')f_X - E(U')g = 0$$

$$= E(U')ph_X t + pf_X - g = 0$$

(2.4*) $\delta E(U)/\delta M = pCov(U',\theta)h_M + pE(U')f_X - E(U')(m-d) = 0$

$= E(U')ph_M t + pf_M - (m-d) = 0$

where $t = Cov(U',\theta)/E(U')$. Equations (2.3*) and (2.4*) indicate that at optimum we have

(2.5) $(pf_X - g)/ph_M = -E(U')t = (pf_M - m + d)/ph_M$

which implies that $pf_M - m + d = h_M/h_X(pf_X - g)$ and hence,

(2.6) $\pi_M = \omega\pi_X$

where $\omega = h_M/h_X$, $\pi_M = \delta\pi/\delta M$ and $\pi_X = \delta\pi/\delta X$. Equation (2.6) is used frequently in the analysis of the effects of a change in factor prices; cf. Section 2.1.3.

The second order conditions for a maximum are

(2.7) $\delta^2 E(U)/\delta X^2 = E[U''(pQ_X - g)^2 + U'pQ_{XX}] \equiv A < 0$

(2.8) $\delta^2 E(U)/\delta M^2 = E[U''(pQ_M - m + d)^2 + U'pQ_{MM}] \equiv B < 0$

(2.9) $\delta^2 E(U)/\delta X\delta M = E[U''(pQ_X - g)(pQ_M - m + d) + U'pQ_{XM}] \equiv C$

(2.10) $AB - C^2 \equiv [H] > 0$

2.2 Input Demand and Risk Aversion

Several empirical studies have tested the hypothesis that farmers maximize expected profits. In most instances, the major result was that they do not; see Lau & Yotopolous (1971), Dillon & Andersson (1971) and Wolgin (1975). However, the opposite result was obtained by Sidhu & Baanante (1979). But, if farmers do not maximize profits, what do they do instead? Lean, Dean & Moore (1974) and Schluter & Mount (1976) found that maximization of expected utility under risk aversion is a good description of revealed production decisions. The degree of risk aversion and the effect on input and output decisions have also been estimated; cf. Wiens (1976), Moscardi & de Janvrey (197)7, and Collender & Chalfant (1986). The existence of risk aversion could reduce the use of nitrogen by 30 percent as compared to the level when expected profit is maximized; see Moscardi et al. (1977).

The empirical result that the existence of risk aversion reduces the demand for inputs was expected from many theoretical studies; cf. Sandmo (197)1, Leland (1972), Batra & Ullah (1974), Ratti & Ullah (1976) and Pope & Kramer (1979). Most of these studies analyzed the effects of uncertainty in input and output prices and can be traced back to Sandmo (1971). Our purpose is somewhat different since we deal with uncertainty in output. We may nevertheless apply Sandmo's method when comparing factor use under risk aversion with factor use when expected profits are maximized.

In the following we show that, when output is stochastic, the demand for nitrogen under risk aversion is below the level which maximizes expected profits. We follow Sandmo (1971). The first order conditions (2.3) and (2.4) can be written as

(2.3') $E[U'pQ_X] = E[U'g]$

(2.4') $E[U'pQ_M] = E[U'(m-d^k)]$

Subtracting $E[U'pf_X]$ from both sides of equation (2.3') yields

(2.11) $E[U'p(Q_X-f_X)] = E[U'(g-pf_X)]$

We apply the expectation operator to both sides of the profit function which gives $E[\pi]=pf-gX-mM-d(MT-M)$ or $E[\pi]-pf= -gX-mM-d(MT-M)$. We know that for a concave utility function, $U'\leqslant U'(E[\pi])$ when $Q\geqslant f$. Given that $Q_{XX},f_{XX}<0$ and $h_X>0$, it is also known that $Q_X<f_X$ when $Q>f$. Multiplying $U'\leqslant U(E[\pi])$ through by $-p(Q_X-f_X)$ and taking expectations gives

(2.12) $E[U'(\pi)p(Q_X-f_X)] \leqslant U'(E[\pi])E[p(Q_X-f_X)]$

When $Q<f$ we get the same result as in (2.12). Then $U'>U'(E[\pi])$ and $Q_X>f_X$ given that $U'',Q_{XX},f_{XX}<0$ and $h_X>0$. Multiplying $U'>U'(E[\pi])$ through by $-p(Q_X-f_X)$ yields equation (2.12)

Since p is nonrandom, the right-hand expression in (2.12) is zero which, from the first-order conditions (2.3) and (2.11), implies

(2.13) $E[U'(\pi)p(Q_X-f_X)] = E[U'(\pi)(g-pf_X)] \leqslant 0$

Equation (2.13) says that the risk-averse farmer maximizes utility where $g \leq p\mu_X$. The profit maximizing condition under certainty is $g = pf_X$. Thus, input demand under uncertainty must be less then input demand under certainty.

In a similar way, we can derive the utility-maximizing use of manure which is

$$(2.14) \qquad E[U'(\pi)(m-d^k-pf_M)] \leq 0$$

We see from equation (2.14) that manure might very well be applied to arable land, although its expected value of marginal product, pf_M, is nonpositive. This occurs when the disposal cost, d^k, exceeds the application cost, m. If the expected marginal product is zero all manure will be applied if the disposal cost is greater than the application cost. In the opposite case, all manure will be disposed of in other ways. If some disposal costs are below the application cost, part of the supply of manure is applied to arable land.

In summary, according to the theory of expected utility, the demand for nitrogen is less under risk aversion than when expected profits are maximized. We concluded in Chapter 1 that farmers are risk averse. This means that "overoptimal" nitrogen dosages are inconsistent with the theory of expected utility. "Overoptimal" dosages occur only if farmers are risk seekers. However, if we view the application of manure as a way of disposing of a waste product of animal holdings, actual use of nitrogen is consistent with risk-averse behavior. Manure is then regarded, not as an ordinary input, but as a disposal problem. The use of chemical nitrogen is below the level where expected profits are maximized, which is in accordance with risk-averse behavior as shown in this section.

2.3 Effects of Changes in Factor Prices

The effects of changes in factor prices for several production factors have been analyzed in a number of studies; cf. Batra & Ullah (197)4, Hartman (1975) and Pope & Kramer (1979). A unanimous result is that the degree of risk aversion and factor complementarity determine the sign of the own-price effects. The degree of risk aversion is ascertained by the Arrow-Pratt measure of absolute risk aversion, $Ra(\pi)=-U''(\pi)/U'(\pi)$. In this section it is shown that the nitrogen demand curves are downward sloping when absolute risk aversion is nonincreasing in income and complementarity holds.

In deriving the fertilizer demand function we differentiate the first order conditions (2.3) and (2.4) with respect to g. Using the symbols for the second-order conditions (2.7-10) the differentiation gives us the following system of equations

$$(2.15)\quad \begin{pmatrix} A & C \\ C & B \end{pmatrix} \begin{pmatrix} \delta X/\delta g \\ \delta M/\delta g \end{pmatrix} = \begin{pmatrix} E[XU''(pQ_X-g) + U'] \\ E[XU''(pQ_M-m+d)] \end{pmatrix}$$

In order to solve for $\delta X/\delta g$ we use Cramer's rule which yields

$$(2.16)\quad \frac{\delta X}{\delta g} = \frac{1}{[H]}\, E[XU''(pQ_X-g)+U']B - CE[XU''(pQ_M-m+d)]$$

Written out fully, by substituting for B and C, the expression is difficult to interpret. But, by making use of equation (2.6) and rearranging, we get an interpretable expression for the input demand function

$$(2.16^*)\quad \frac{\delta X}{\delta g} = \frac{1}{[H]} E[U''\omega^2\pi_X^2 + U'pQ_{MM}]E[U'] + E[U''\pi_X]Xp[E[U'Q_{MM}] - \omega E[U'Q_{XM}]]$$

The first term in (2.16*) is negative due to concavity of the utility function and the production function, i.e., $U'', Q_{XX} < 0$. The second term is negative if $E[U'\pi_X] > 0$ and $Q_{XM} > 0$. In the following it is shown that $E[U'\pi_X]$ is nonnegative when absolute risk aversion is nonincreasing in income.

Let π^* be the profit where $pQ'(X) = g$ and $Ra(\pi^*) = -U''(\pi^*)/U'(\pi^*)$. When $pQ_X \geq g$ we know that $\pi < \pi^*$, which implies that $Ra(\pi) \leq Ra(\pi^*)$ when absolute risk aversion is decreasing or constant in income. This implies that

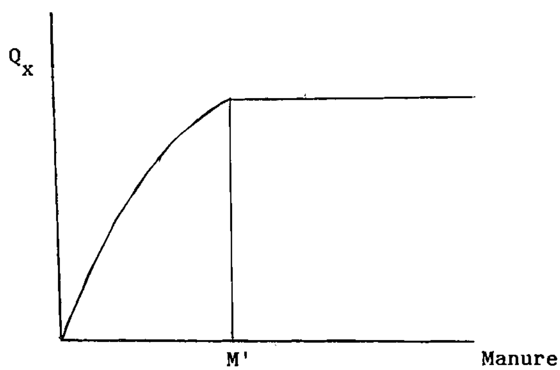
$$(2.17)\qquad -U''/U' \leq Ra(\pi^*) \quad \text{for} \quad pQ_X > g$$

Multiplying (2.17) by $-U'(pQ_X - g)$ and taking expectations yields

$$(2.18)\qquad E[U''(pQ_X - g)] \geq -Ra(\pi^*)E[U'(pQ_X - g)]$$

The right-hand side is zero according to the first-order condition (2.3). Strict inequality holds when absolute risk aversion is decreasing in income. For constant absolute risk aversion, the left-hand side is zero. It then follows that $E[U''(pQ_X - g)] \geq 0$. This means that $\partial X/\delta g < 0$ if $Q_{XM} \geq 0$. If strict inequality holds, an increase in the use of manure raises the marginal product of chemical nitrogen. This could be true for small quantities of manure. But if there is a surplus of manure, it is more likely that $Q_{XM}=0$ which implies separability between chemical nitrogen and manure. The function Q_{XM} can then have the shape which is illustrated in Figure 2.1.

Figure 2.1: Complementarity and separability in chemical nitrogen and manure



Below the quantity M', further use of manure adds to the marginal product of chemical nitrogen. Several common production functions have this property. To the right of M' the use of manure has no impact on Q_X. This is certainly true for the manure applied in the autumn to land without crops. The nitrogen applied at this time of the year is lost through either evapotranspiration or leakage into ground and surface water.

We thus conclude that it is plausible to assume complementarity or separability. When $Q_{XM}=0$ manure is regarded as a disposal problem, it then follows that $\delta X/\delta g<0$ according to equation (2.16*).

It could, however, be the case that $Q_{XM}<0$. The curve in Figure 2.1 would then have a negative slope. This occurs when the use of manure reduces the marginal product of chemical nitrogen and might very well happen for high dosages of manure. The sign of $\delta X/\delta g$ is then indeterminate. But, if either manure or chemical nitrogen were risk reducing production factors, i.e., $h_X<0$ or $h_M<0$, then $\delta X/\delta g<0$. This possibility is excluded, however, according to the discussion in Section 2.1. It is therefore assumed that $Q_{XM}\geq 0$ throughout the study.

If manure and chemical nitrogen were substitutes, we would expect an increase in the price of X to raise the demand for manure, i.e., $\delta M/\delta g>0$. In the following it is shown that the sign of $\delta M/\delta g$ is positive when absolute risk aversion is constant in income. For decreasing absolute risk aversion, the sign is ambiguous. These results are independent of whether manure is perceived as an ordinary input or a disposal problem.

We solve for $\delta M/\delta g$ from (2.15) which yields

$$(2.19)\quad \delta M/\delta g = \frac{AE[XU''(pQ_M-m+d^k)] - E[XU''(pQ_X-g)+U']C}{[H]}$$

Applying (2.6) to (2.19) and rearranging gives

$$(2.20)\quad \delta M/\delta g = \frac{E[XU''\pi_X]pX(\omega E[U'Q_{XX}]-E[U'Q_{XM}]) - E[U'](E[U''\pi^2\omega+E[U'pQ_{XM}])}{[H]}$$

The first term in (2.20) is negative when absolute risk aversion is decreasing in income and $Q_{XM}>0$. The second term is positive since $U''<0$

and $Q_{XM}>0$. Hence, the sign of $\delta M/\delta g$ is ambiguous. When absolute risk aversion is constant in income, the first term becomes zero which implies $\delta M/\delta g>0$.

We now turn to the effects of a change in the application cost, m. We expect m to be negatively related to manure application. In the following we show that this turns out to be the case if absolute risk aversion is nonincreasing in income and complementarity prevails.

We begin by calculating the effects of a change in m we obtain the following system of equations

$$(2.20) \qquad \begin{pmatrix} A & C \\ C & B \end{pmatrix} \begin{pmatrix} \delta X/\delta m \\ \delta M/\delta m \end{pmatrix} = \begin{pmatrix} E[U''(pQ_X-g)M] \\ E[U''(pQ_M-m+d^k)M + U'] \end{pmatrix}$$

Applying Cramer's rule yields

$$(2.23) \qquad \delta M/\delta m = \frac{AE[U''(pQ_M-m+d)M+U'] - CE[U''(pQ_X-g)M]}{[H]}$$

which, after applying (2.6) and rearranging, gives

$$(2.23) \qquad \delta M/\delta m = \frac{E[U''\pi_X^2+U'pQ_{XX}]E[U'] + E[U''\pi_X]Mp[\omega E[U'Q_{XX}]-E[U'pQ_{XM}]]}{[H]}$$

Equation (2.23) looks very similar to (2.16*), i.e., for $\delta X/\delta g$. As before, due to concavity and $Q_{XM}\geqslant 0$, application cost is negatively related to manure application if $E[U''\pi_X]\geqslant 0$. As has been shown above, this occurs for nonincreasing absolute risk aversion and a well-behaved production function.

When manure is viewed as a disposal problem, i.e., $Q_M = Q_{XM} = 0$, the assumption of separability in chemical fertilizer and manure ensures the negative sign.

The system of equations when searching for $\delta M/\delta d^k$ will look like

$$(2.24) \quad \begin{pmatrix} A & C \\ C & B \end{pmatrix} \begin{pmatrix} \delta X/\delta d^k \\ \delta M/\delta d^k \end{pmatrix} = \begin{pmatrix} E[U''(pQ_X - g)(MT-M)] \\ E[U''(pQ_M - m + d^k)(MT-M) - U'] \end{pmatrix}$$

The final result, after using Cramer's rule, equation (2.6) and rearranging, is

$$(2.25) \quad \delta M/\delta d^k = \frac{-E[U''\pi_X^2 + U'pQ_{XX}]E[U'] + E[U''\pi_X]p(MT-M)[\omega E[U'Q_{XX}] - E[U'Q_{XM}]]}{[H]}$$

This expression is also similar to what equations (2.20) and (2.23). The difference is a change in sign. The whole expression (2.25) becomes positive when $E[U''\pi_X]=0$, regardless of how the application of manure is perceived. The sign is indeterminate when absolute risk-aversion is decreasing in income.

In this section, we derived different conditions for the effects of changes in factor prices which depend on how the application of manure is perceived. All conditions are summarized in Table 2.1. The basic assumptions underlying all results are $U'', Q_{XX}, Q_{MM} \leq 0$.

Table 2.1: Conditions for some results when manure is regarded as an ordinary input or a disposal problem

	Manure is: Ordinary input	Disposal problem, $Q_M=0$
$\delta X/\delta g<0$	$\delta Ra/\delta\pi<0$ $Q_{XM}>0$	$Q_{XM}=0$
$\delta M/\delta m<0$	$\delta Ra/\delta\pi<0$ $Q_{XM}>0$	$Q_{XM}=0$
$\delta M/\delta g>0$	$\delta Ra/\delta\pi=0$	$\delta Ra/\delta\pi=0$
$\delta M/\delta d>0$	$\delta Ra/\delta\pi=0$	$\delta Ra/\delta\pi=0$

When manure is regarded as an ordinary input, the own-price effects are negative if absolute risk aversion is decreasing in income and complementarity holds. The sign of the cross-price effects are indeterminate under these conditions. The cross-price effects are positive only if absolute risk aversion is constant in income.

According to our assumptions in Section 2.1, $Q_M=0$ when manure is regarded as a disposal problem. We then obtain expected signs of own-price and cross-price effects if $Q_{XM}=0$, i.e., the production function is separable in chemical nitrogen and manure.

2.4 Discussion and Conclusions

The purpose of this chapter was to model the farmer's decision on the use of nitrogen. The model should account for two phenomena; a downward-sloping nitrogen demand curve and use of nitrogen in excess of the expected profit-maximizing level. It was found that risk-averse behavior implies use of nitrogen which is lower than the level which maximizes expected profits. The expected utility theory does not generate any counterintuitive results when only commercial fertilizer is regarded as an ordinary input. The application of manure is then looked upon as a way of disposing of by-products of animal production. But if we regard manure as an ordinary input and consider total use of nitrogen, there is an inconsistency. According to the expected utility model use of nitrogen in excess of the expected profit maximizing level is a result of a risk seeking attitude.

We analyzed the own-price and cross-price effects. It turned out that the conditions for a downward-sloping nitrogen demand curve differ depending on how the use of manure is perceived. We obtain the most relaxed assumption for negative own-price effects when manure is regarded as a disposal problem which is defined as having a marginal product of zero. The relation between the use and price of nitrogen is then negative for both chemical nitrogen and manure. The only assumption required is separability between chemical nitrogen and manure. When manure is regarded as an ordinary input, the own-price effects are negative if risk aversion is nonincreasing in income and complementarity holds. The cross-price effects are positive if absolute risk aversion is constant in income.

We regard the case to be where manure application in autumn is perceived as a disposal problem as the most promising. Only a very few crops need to be fertilized this time of the year. It seems likely that the effect of applying manure is then neither positive nor negative. Thus, we conclude that the farmers are risk averse which reduce their use of chemical fertilizer as compared to the level when expected profits are maximized. The only additional assumption we require to guarantee a downward sloping chemical nitrogen demand curve is separability between chemical nitrogen and manure.

But if we consider manure as an ordinary input and accept the inconsistency generated by the expected utility model, some explanations can be found in other theories of economic behavior. Behavioral scientists have observed irrationality in laboratory experiments for a long time. One such observation concerns the preference reversals; see Lindman (197)1, Lichtenstein & Slovic (1971) and Grether & Plott (1979). The subjects' choices of projects do not seem to coincide with their evaluations of the same projects. Farmers might behave in the same they; they know which nitrogen dose maximizes expected profit but they choose a higher dose. There are some explanations as to why this phenomenon occurs. One is that the decision-making context is important and violates the independence axiom of the expected utility model; cf. Holt (1986). Another explanation is that people overestimate low probabilities and underestimate high probabilities.

A theory known as the prospect theory was developed in order to account for these phenomena (Kahneman & Tversky, 1979 and 1984). However, it does not seem applicable to the decisions of farmers in Gotland. However, another decision-behavior feature also captured in the prospect theory might be applicable. It involves defining utility in terms of changes in wealth instead of states of wealth as in expected utility theory. Then risk aversion is consistent with "overoptimal" nitrogen doses and the farmers are risk averse against losses. But such a formulation creates analytical problems since the utility function becomes partly convex.

Another psychological theory which has been applied to economic behavior deals with the question of what information is allowed in the decision-making process; see Akerlof & Dickens (1983). According to the theory of cognitive dissonance, people "filter" out information which does not confirm their perception of themselves as being "nice and smart" - at least for a while. Once a certain threshold level of dissonance is reached, the individual tends to accept the new information and change his initial decision; cf. Frey (1982). In our problem, it could be argued that "overoptimal" nitrogen doses are based on the farmers' own judgments and traditions. Information recommending lower doses creates dissonance since the farmer's own judgment is questioned. Behavior which originates from cognitive dissonance, however, is not necessarily inconsistent with the theory of expected utility. Attempts have been made to formulate the "filtering" mechanism as a choice variable in the utility function; Gilad et. al. (1987).

The above-mentioned observations from laboratory experiments in the behavioral sciences do in fact elucidate the farmers' decision-making process. But in our case, we believe it is most accurate to model the farmers' nitrogen decisions within the framework of the expected utility model. The most convincing explanation for the use of manure is that its application is the result of a disposal problem. Revealed behavior is then quite consistent with a risk-averse attitude and maximization of expected utility. Theories from the behavioral sciences are also of great value in considering how to implement different policy devices. Cognitive dissonance theory tells us that a successful implementation depends to some degree on whether or not dissonant reactions are created.

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3. COST EFFICIENCY, INCOME DISTRIBUTION EFFECTS AND TECHNOLOGICAL CHANGE OF POLICIES

In this chapter, the quota, charge and permit market systems are compared with respect to cost efficiency, income distribution effects and technological change in a model where farmers maximize expected utility. The purpose of the comparisons of cost efficiency and income distribution effects is to find formulas which can serve as a basis for the empirical calculations in Chapter 6. Unfortunately, the performance of the policy instruments with respect to technological change cannot be calculated empirically. These aspects are nevertheless compared in analytical terms, since it is of interest to ascertain which policy has the greatest impact on making Gotland a leading adopter of nitrogen-abatement technologies.

Our results show that no policy device is always better than any of the others. However, according to most of the criteria, a permit market is preferred to or as good as the other schemes. When the policies are compared with respect to cost efficiency and income distribution effects, a permit market is always the best instrument. On the other hand, for certain reductions in the price of permits, a permit market could be the least attractive instrument when technological change is used as a criterion of comparison.

The chapter is organized as follows. We begin by describing how the instruments are defined and how they are supposed to function. In Section 3.2, the devices are compared with respect to cost efficiency and income distribution effects. After this, we study the performance of the policy devices with respect to technological change. Our tentative conclusions are summarized in a concluding section.

3.1 Description of the Policy Devices and Basic Approach.

Ideally, we would prefer a policy device based on the quality of water quality. But, as discussed in Chapter 1, there is no hydrological model which enables us to specify such an ambient standard. Instead, the necessary reduction in the application of nitrogen is instead determined by means of a hydrological model where the relation between total application of nitrogen and average water quality is simulated. All policies are therefore constructed to obtain a single standard of water quality for the entire island of Gotland.

In Chapter 1 it was also mentioned that the simulation results of the hydrological model are sensitive to assumptions regarding leakage of nitrogen into the ground water. The effect of a given dose of nitrogen on the concentration of nitrate of a given dose of nitrogen is therefore uncertain. Because of this uncertainty, the standard of nitrogen use is valid for a limited period of time, so that adjustments can be made to unexpectedly low or high concentrations of nitrate.

As for a permit market, we still have two aspects to consider; the initial allocation of permits and the functioning of the market. There are in principle two different distribution systems for the allocation of permits; see Tietenberg (1984). One is when permits are sold in an auction. The farmers' bids determine an equilibrating permit price at which they can buy the amount of permits they wish to hold. The farmers are then responsible for all costs associated with pollution abatement. According to the other allocation approach, farmers are given an initial amount of permits and only have to pay for permits in excess of this level. In other words, the costs of nitrogen abatement are shared between the authorities and the farmers. In Sweden, there is no tradition of auctions through which permits can be initially distributed. Moreover, this approach appears to be more difficult to enforce. We therefore advocate the system whereby initial permits are given to the farmers free of charge.

We assume the permit market to be competitive. However, the initial distribution of permits could influence the market's ability to generate an efficient permit price. Hahn (1985) showed that when a firm can excise market power, only a specific initial distribution will lead to a competitive outcome. A firm with monopoly power could make profits from regulating the supply of permits such that the price of permits is increased. This implies that the total use of nitrogen is reduced as compared to a competitive market for permits. But since there are 2400 farmers in Gotland, we do not expect any single farmer or group of farmers to be able to influence the price of permits. Our assumption of a competitive market thus becomes plausible. Any initial distribution of permits will then give an efficient outcome; cf. Montgomery (1972).

Thus, all policy devices are undifferentiated with respect to time and space and are valid for a limited period of time. A permit market is further assumed to give an efficient outcome and the initial permits are distributed free of charge. Given these definitions and assumptions, the policy-maker finds the optimal nitrogen quotas and charges by maximizing farmers' total expected utility, subject to a restriction on the total use of nitrogen, N*. One unit of chemical nitrogen, X, is assumed to be equal to one unit of manure nitrogen, M. Ideally, if the policy-maker had perfect information, optimal quotas and charges for chemical nitrogen and manure would be derived from the following maximization problem:

$$(3.1) \qquad \max_{X^i, M^i} \sum_{i=1}^{n} E[U^i(pQ^i - gX^i - aM^i - d(MT^i - M^i))]$$

$$\text{s.t.} \qquad \sum_{i=1}^{n} X^i + \sum_{i=1}^{n} M^i \leqslant N^*$$

i=1,...,n farmers
p: output price
Q: output
g: price of chemical fertilizer
X: chemical fertilizer
a: manure application cost
M: manure applied in the fields
d: manure disposal cost
MT: total amount of manure

The formulation of the disposal cost, d, is changed as compared to equation (2.1) in Chapter 2, where d was discontinuous with respect to (MT-M). In order to simplify calculations, d is formulated as a continuous function of (MT-M). It is assumed that $d_M, d_{MM} < 0$.

5

The Lagrangian for the policy-maker is

$$(3.2) \qquad L = \sum_{i=1}^{n} E[U^i(pQ^i - gX^i - mM^i - d^i(MT^i - M^i))] + \lambda(N^* - \sum_{i=1}^{n} X^i - \sum_{i=1}^{n} M^i)$$

where λ is the shadow price of the constraint on the total use of nitrogen. The first order conditions are

$$(3.3) \qquad \delta L/\delta X = \sum_{i=1}^{n} E[(U_\pi^i(pQ_X^i - g)] - \lambda = 0$$

$$(3.4) \qquad \delta L/\delta M = \sum_{i=1}^{n} E[U_\pi^i(pQ_M^i - m + d_m^i)] - \lambda = 0$$

In Chapter 2 we selected to treat manur as a disposal problem, which implies that $Q_m=0$. Condition (3.4) is then reduced to

$$(3.4^*) \qquad \delta L/\delta M = \sum_{i=1}^{n} E[U_\pi^i(d_M^i - m)] - \lambda = 0$$

The optimal allocation of the use of chemical nitrogen and manure respectively is determined by the shadow price λ, which implies

$$(3.5) \qquad \sum_{i=1}^{n} E[U_\pi^i(pQ_X^i - g)] = \lambda = \sum_{i=1}^{n} E[U_\pi^i(d_M^i - m)]$$

According to (3.5) the optimal allocation of the use of chemical nitrogen and manure occurs when the expected utility of the marginal product of chemical nitrogen less the price equals the marginal cost of reducing the application of manure less the application cost. The optimal allocation of quotas to the farmers is also determined by (3.5), i.e., when the marginal abatement costs are equal for all farmers. The optimal charge, $t=\lambda$, generates this distribution of the use of nitrogen among farmers. The outcome of a permit market is an optimal price of permits, $z=\lambda$.

In this study, however, it is assumed that the policy-maker does not have perfect information on the production technologies of each farmer. Instead, the aggregated demand for chemical nitrogen is known. The reason for this assumption is based on the actual availability of data. Regional data are available which can be used to estimate the total demand for chemical nitrogen (see Chapter 5). Observations regarding a single farmer cannot be obtained due to Swedish legislation which protects individual integrity. Thus, in the case of manure, the only measures of costs which are available have been calculated by means of a few field experiments (see Chapter 6).

When perfect information is not available, the optimal quotas on the use of nitrogen cannot be determined, since this requires information on each farmer. It is possible, however, to find the optimal charge, which only requires information on total demand for chemical nitrogen and total marginal costs for reducing the use of manure. It is shown below that the existence of this kind of imperfect information is important in explaining to why the performance of the policy instruments differs when compared with respect to cost efficiency, income distribution effects and technological change.

3.2 Cost Efficiency and Income Distribution Effects.

Since the mid-1960s, considerable research in environmental economics has focused on the comparison of costs of alternative policies. The objective was to find the policy instrument which achieves a certain environmental standard at minimum cost. A unanimous result was that charges are superior to quotas; see e.g. Baumol & Oates (1971) and Kneese (1964 and 1968). It turned out, however, that policy-makers were not as convinced as economists about the superiority of charges. Their resistance was to a large extent due to income policy constraints; cf. OECD (1980). This is one important reason why we analyze both cost efficiency and income distribution effects of a given reduction in the use of nitrogen.

Very few studies have analyzed abatement costs for policy devices directed towards the use of fertilizers. In fact, to my knowledge, there are only three such studies, all of which show that charges and permit markets are less costly than quotas; see Horner (1975), Taylor (1974) and Dubgaard (1986). In the following subsection it is shown that these results also hold true for the use of commercial fertilizer and manure. In addition, we show that the income distribution effects are of the smallest magnitude for a permit market, given that farmers receive the initial permit at no extra cost.

3.2.1 Cost Efficiency

Cost efficiency implies that no changes can be made in the allocation of nitrogen abatement without increasing the total costs of abatement. The condition for a cost efficient allocation is that the marginal abatement costs are equal for all farmers. We now show that this condition is met under the charge and permit market systems. When the policy-maker has information only on total demand for chemical fertilizer and total costs for reducing the application of manure, implementation of a quota system gives rise to losses due to an inefficient distribution of quotas.

When the farmer incurs a charge on chemical nitrogen and manure, his optimal choice of X^i and M^i is derived from

$$(3.6)\qquad \max_{X^i, M^i} E[U^i(pQ^i - (g+t)X^i - (m+t)M^i - d^i(MT^i - M^i)]$$

The first-order necessary conditions are

$$(3.7)\qquad \delta E[U^i]/\delta X^i = E[U^i_\pi(pQ^i_X - g - t)] = 0$$

$$(3.8)\qquad \delta E[U^i]/\delta M^i = E[U^i_\pi(pQ^i_M - m - t + d^i_m)] = 0$$

Equations (3.7) and (3.8) can be written as

$$(3.7^*)\quad E[U^i_\pi(pQ^i_X - g)] = t$$

$$(3.8^*)\quad E[U^i_\pi(pQ^i_M - a + d^i_M)] = t$$

Recall that manure is regarded as a disposal problem, which implies Q_m=0. Rearranging equations (3.7*) and (3.8*) then gives

$$(3.9)\qquad E[U^i_\pi(pQ^i_X - g)] = t = E[U^i_\pi(d^i_M - m)]$$

When the farmer incurs the charge t on nitrogen, he responds by choosing X and M such that the marginal costs of abatement are equal. Since the level of t is the same for all farmers, the marginal costs of abatement are also equal for all farmers. Thus, the criterion for cost efficiency is met under a charge system.

Under a permit market, the policy-marker issues permits corresponding to the standard N* in equation (3.1). When the market for permits is competitive, the equilibrating price of permits is equal to the market demand for permits at the constant supply N*. The price of permits, z, is then equal to the shadow price of nitrogen, which implies that t=z. Thus, the condition for cost efficiency is met for a permit market system in the same way as for a charge system. The only difference is that we have to replace t with z in equation (3.9).

When the farmer is subjected to a rationing scheme for nitrogen, he chooses X and M according to

$$(3.10) \quad \max_{X^i, M^i} \; E[U^i_\pi(pQ^i - gX^i - mM^i - d^i(MT^i - M^i)]$$

$$\text{s.t.} \quad X^i + M^i \leq N^{i*}$$

where N^{i*} is the amount of nitrogen the farmer is allowed to use. We can now solve the Lagrangian which yields the following first-order conditions

$$(3.11) \quad \delta L/\delta X^i = E[U^i_\pi(pQ^i_X - g)] - \xi^i = 0$$

$$(3.12) \quad \delta L/\delta M^i = E[U^i_\pi(d^i_M - m)] - \xi^i = 0$$

where ξ is the farmer's shadow price for his ration of nitrogen. The farmer sets ξ equal to the marginal abatement costs of chemical nitrogen and manure. This means that each farmer allocates the use of chemical nitrogen and manure in a cost efficient way. But the shadow prices ξ^i differ among farmers and, hence, there is no cost efficient allocation of nitrogen rations.

When the allocation of quotas is not optimal, gains can be made by reallocating quotas as long as marginal abatement costs differ among farmers. The size of the gain foregone under a quota scheme, which we call the efficiency loss, depends on the differences in marginal abatement costs among farmers. The greater the differences, the larger the efficiency loss. This is shown by calculating the reduction in abatement costs caused by a transition from a quota to a charge system.

In order to find a measure of the efficiency loss, we distinguish between the farmers who gain from a transition from a quota to a charge system, i=1,...,h, and those who loose, i=h+1,...,n when the use of chemical nitrogen is regulated. The efficiency loss of a quota system is then found by subtracting the losers' total loss from the winners' total gain. Losses and gains are calculated as integrals of the nitrogen demand functions, D^i. The efficiency loss, E, is then defined according to

$$E = \sum_{i=1}^{h} \int_{X^{i*}}^{X^{ic}} D^i dX - \sum_{i=h+1}^{n} \int_{X^{ic}}^{X^{i*}} D^i dX \tag{3.13}$$

Where D^i: nitrogen demand function

X^{ic}: nitrogen use under a charge system

X^{i*}: distributed rations under a quota system

The demand functions, $D^i(X)$, are assumed to be linear, $g=a^i-b^iX^i$. In fact, the results of regression estimates in Chapter 5 show that a linear function is a good approximation of observed data. Any shift in the demand function, brought about by a change either in the intercept a^i or in the slope b^i, yields one of two outcomes;

$$(3.14) \quad \delta E/\delta a^i \begin{cases} > 0 \text{ when } i=1,\ldots.,h \\ < 0 \text{ when } i=h+1,\ldots,n \end{cases}$$

$$\delta E/\delta b^i \begin{cases} < 0 \text{ when } i=1,\ldots.,h \\ > 0 \text{ when } i=h+1,\ldots,n \end{cases}$$

From (3.14) it is clear that a positive shift in and/or an increase in the slope of a gainer's demand function increases E. This also occurs for a negative shift in or a decrease in the slope of a loser's function.

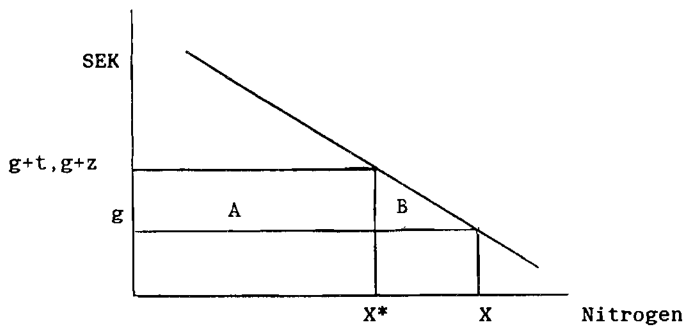
3.2.2 Income Distribution Effects

We define the income distribution effect as the total change in a farmer's income caused by implementation of a regulation scheme. The farmer's total reduction in income is twofold; nitrogen abatement costs and increased payments for actual nitrogen use. The analysis of cost efficiency in the preceding section considered only abatement costs and it was shown that a quota system gives the highest total abatement costs. However, when the income distribution effects of an increase in the price of nitrogen are considered, a quota system has a relative advantage.

Under a quota system, the price of nitrogen does not increase and we would therefore expect the farmer's reduction in income to be smaller for this scheme than for the other two. On the other hand, total abatement costs are higher for a quota system due to the efficiency loss created by this system. Such an efficiency loss does not occur for either a permit market or a charge system. Since the initial permits are distributed free of charge, the income distribution effects are expected to be lowest for this policy instrument. It is shown below that this is in fact the result for both chemical nitrogen and manure. At an aggregated level, a permit market creates lower income distribution effects than both the quota and charge systems. Whether or not a charge system yields larger reductions in income than a quota system depends on the relationship between payments of charges and efficiency loss. All income distribution effects are measured as the sum of all farmers' reductions in income.

The farmers' reductions in income due to different policy alternatives are illustrated in Figure 3.2. The actual total use of nitrogen X is to be reduced to X* through either a charge t, a permit market with the equilibrating permit price z, or a quota system.

Figure 3.1: Comparison of income distribution effects for different schemes.



Under a charge system the farmers have to pay a higher price for actual use of nitrogen corresponding to area A. They also lose income owing to reduced yield, area B. Total reductions in income under a charge system, IX^c, are then measured as

$$(3.15) \qquad IX^c = \int_{X^*}^{X} (D-g)dX + tX^*$$

Under a quota system, the farmers do not have to pay a charge and the minimum income distribution effects, IX^q, thus correspond to area B. This happens only when the quotas are distributed efficiently. It is more likely that the income distribution effects are higher due to the efficiency loss, E, created by this system. The income distribution effects of a quota system, IX^q, are then measured as

$$(3.16) \qquad IX^q = \int_{X^*}^{X} (D-g)dX + E$$

For a permit market, the initial permits, corresponding to X*, are distributed without any additional costs to the farmers. Transactions then take place whereby some buy and some sell permits. But at an aggregated level, incomes and expenses for permits cancel out. Total income distribution effects, IX^{pm}, then correspond to the area B which is written

$$(3.17) \qquad IX^{pm} = \int_{X*}^{X} (D-g)dX$$

From equations (3.15-3.17) we see that IX^{pm} is smaller than both IX^{q} and IX^{c}. Whether $IX^{c}>IX^{q}$ or vice versa depends on the relation between tX* and E. The size of tX* is related to the shape of the total nitrogen demand function and that of E to differences in individual demand functions. Later on, it is shown empirically that E in fact exceeds tX* for large reductions in the use of chemical nitrogen; see Chapter 6.

The analysis of effects of different controls on the application of manure is the same as for chemical nitrogen. The demand for applied manure is measured as the marginal cost for reducing the application of manure, i.e., d_M in equation (3.4). This function is decreasing in the application of manure and thus has the same shape as D in Figures 3.1-3.3. The price of chemical nitrogen, g, is replaced by the cost of applying manure, m. Hence, the analysis as well as the results of comparing policies with respect to income effects are the same for applied manure as for chemical nitrogen.

3.3 Technological Change

Implementation of environmental policies in one region of a country might make that region a pioneer in adopting new pollution abatement technologies. In this respect Gotland could become a leading region in regard to technological change in nitrogen abatement. Effects of different controls on technological change have been dealt within several studies; see e.g. Kneese and Bower (1968), Magat (1978), Mendelsohn (1984), Spulber (1985) and Wenders (1975). The result of most of these studies is that a policy based on economic incentives is more advantageous than a policy with quantity rules. In this section, it is shown that this result is also valid for the effects of controls on changes in nitrogen-abatement technologies in Gotland.

The effects of the new technology are assumed to result in a proportional reduction in the cost of current abatement technology; cf. Wenders (1975). Incentives to change to a new technology for different controls are then measured as the difference in the abatement costs of the old and new technology. These incentives are calculated in the same way for chemical nitrogen and manure. Therefore, in the following, incentives for technological adjustment are derived only for chemical nitrogen. It is then shown that a farmer can make the largest gains from switching technologies under a charge system. Whether or not the incentives of a permit market are stronger than those of a quota system depends on the change in the price of permits.

Let the new technology be described as a proportional change, τ, in the old technology, where $0<\tau<1$. When chemical fertilizer is regulated, the new technology is written as τD^i. For manure, the new technology implies a shift in the marginal cost of reducing the application of manure, τd. We start by calculating a farmer's reduction in income caused by the introduction of different policies under the old technology. The formulas for these losses in income are similar to those for total income effects derived in Section 3.2.1.

When the farmer is subjected to a quota system, his loss in income under the old technology, IX^{iq}, is

$$(3.18) \qquad IX^{iq} \equiv \int_{X^{i*}}^{X^i} (D^i - g)dX$$

where D^i is the farmer's derived demand for chemical nitrogen and X* is the amount of chemical nitrogen he is allowed to use. The loss in income when a quota system is implemented consists of the reduction in the value of yield.

Under a charge system, the farmer also loses income from reduced yield. In addition, he has to pay a higher price for his actual use of nitrogen. At the price g+t, his optimal use of nitrogen is denoted by X^{ic}. The farmer's total loss in income from a charge system is then

$$(3.19) \qquad IX^{ic} \equiv \int_{X^{ic}}^{X^i} (D^i - g)dX + tX^{ic}$$

When a permit market is implemented, the farmer receives permits which allow him to use X^{i*} at the price g. At the equilibrating price of permits, z, he can either sell or buy permits depending on the value of

D^i at X^{i*}. We assume that z=t, which means that the farmer uses permits corresponding to X^{ic}. His loss in income under a permit market is then

$$(3.20) \qquad IX^{ipm} \equiv \int_{X^{ic}}^{X^i} (D^i - g)dX + z(X^{ic} - X^{i*})$$

The farmer sells permits when $z>D^i$ at X^{i*}, which implies that $X^{i*}>X^{ic}$. He is thus partly compensated for his loss in yield due to the reduced use of chemical nitrogen. When $z<D^i$ at X^{i*}, i.e., $X^{i*}<X^{ic}$, he buys permits, which add to his loss in income caused by a reduction in yield.

The new technology is assumed to reduce the value of the marginal product of nitrogen by the same proportion for every farmer. The derived demand for nitrogen under the new technology is, as mentioned above, described as τD^i. The optimal use of chemical fertilizer in the absence of any regulation is then changed from X^i to $X^{i\prime}$.

The loss in income for a farmer subjected to a rationing scheme under the new technology, $IX^{iq\tau}$ is then written as

$$(3.21) \qquad IX^{iq\tau} \equiv \int_{X^{i*}}^{X^{i\prime}} (\tau D^i - g)dX$$

When a charge system is implemented, the new technology will change the use of chemical nitrogen from X^{ic} to $X^{i\prime\prime}$. The loss in income under a charge system, $IX^{ic\tau}$, is then

$$(3.22) \qquad IX^{ic\tau} \equiv \int_{X^{i''}}^{X^{i'}} (\tau D^{i} - g)dX + tX^{i''}$$

At the permit price z=t, the farmer's reduction in income from using the new technology, $IX^{ipm\tau}$, is

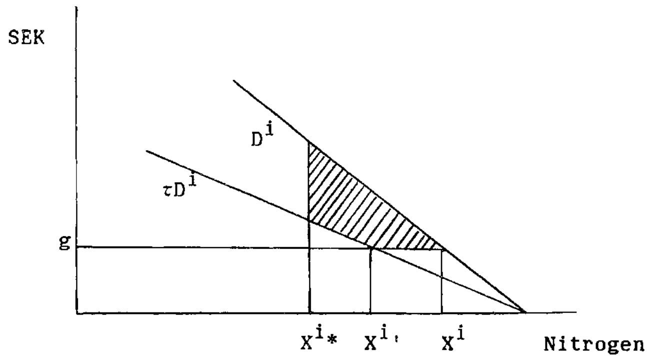
$$(3.23) \qquad IX^{ipm\tau} \equiv \int_{X^{i''}}^{X^{i'}} (\tau D^{i} - g)dX + z(X^{i''} - X^{i*})$$

The incentives to adjust from the old to the new technology are calculated by subtracting the reduction in income due to implementation of a policy under the old technology from the corresponding loss in income under the new technology. The technological adjustment incentive of a quota system, ΔIX^{ig}, is then calculated as

$$(3.24) \quad \Delta IX^{iq} \equiv IX^{iq} - IX^{iq\tau} = \int_{X^{i*}}^{X^{i}} (D^{i}-g)dX - \int_{X^{i*}}^{X^{i'}} (D^{i}\tau-g)dX$$

The profits from switching to the new technology under a quota system are illustrated in Figure 3.2. The curve D^{i} represents the old technology and the curve τD^{i} the new technology. The incentives to adjust to the new technology correspond to the shaded area.

Figure 3.2: Incentives to change technology under a quota system.

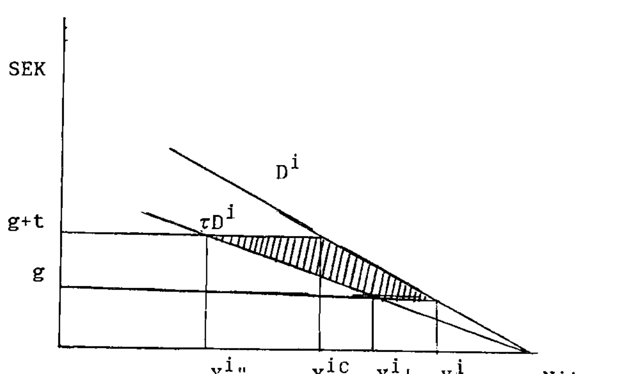


Profits made by changing from the old to the new technology under a charge system, ΔIX^{ic}, are calculated in the same way, which gives

$$(3.25)\quad \Delta IX^{ic} \equiv IX^{ic} - IX^{ic\tau} = \int_{X^{ic}}^{X^i} (D^i - g)dX + tX^{ic} - \int_{X^{i''}}^{X^{i'}} (D^i\tau - g)dX - tX^{i''}$$

The profits ΔIX^c correspond to the shaded area in Figure 3.3.

Figure 3.3: Incentives to change technology under a charge system.

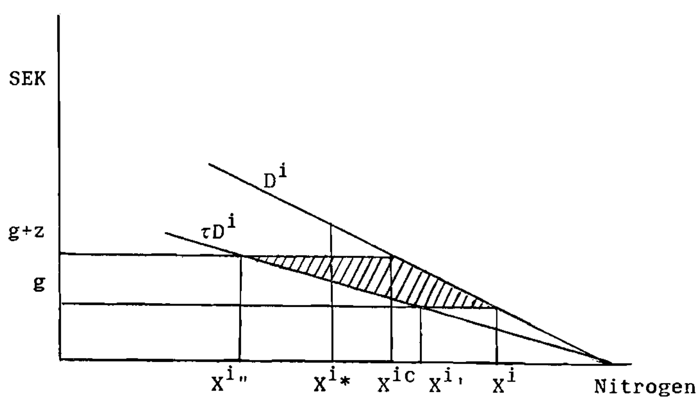


Under a permit market, the saving in costs from switching technologies, ΔIX^{ipm}, is written as

$$(3.26)\ \Delta IX^{ipm} \equiv IX^{ipm} - IX^{ipm} = \int_{X^{ic}}^{X^{i}} (D^i - g)dX + z(X^{ic} - X^{i*}) - \\ - \int_{X^{i''}}^{X^{i'}} (D^i\tau - g)dX - z(X^{i''} - X^{i*})$$

which corresponds to the shaded area in Figure 3.4.

Figure 3.4: Incentives to change technology under a permit market.



In order to compare the incentives to switching technologies between the different policy alternatives, let

$$\int_{X^{ic}}^{X^{i}} (D^i - g)dX = \int_{X^{i*}}^{X^{i}} (D^i - g)dX + \int_{X^{ic}}^{X^{i*}} (D^i - g)dX$$

$$\int_{X^{i''}}^{X^{i'}} (D^i\tau - g)dX = \int_{X^{i*}}^{X^{i'}} (D^i\tau - g)dX + \int_{X^{i''}}^{X^{i*}} (D^i\tau - g)dX$$

Equations (3.25) and (3.26) can then be written as

$$(3.27)\quad \Delta IX^{ic} = \Delta IX^{iq} + \int_{X^{ic}}^{X^{i*}} (D^i - g)dX - \int_{X^{i''}}^{X^{i*}} (D^i\tau - g)dX + t(X^{ic} - X^{i''})$$

$$(3.28)\quad \Delta IX^{pm} = \Delta IX^{iq} + \int_{X^{ic}}^{X^{i*}} (D^i - g)dX - \int_{X^{i''}}^{X^{i*}} (D^i\tau - g)dX + z(X^{ic} - X^{i''})$$

From (3.27) and (3.28) it is obvious that the size of incentives to change technology are exactly the same for the charge and permit market systems, given that z=t. These adjustment incentives exceed those of a quota system if

$$(3.29)\quad \int_{X^{ic}}^{X^{i*}} (D^i - g)dX - \int_{X^{i''}}^{X^{i*}} (D^i\tau - g)dX + t(X^{ic} + X^{i''}) > 0$$

In the following it is shown that this expression is positive when $X^{i*} \geqslant X^{ic}$. Let

$$\int_{X^{i''}}^{X^{i*}} (D^i\tau - g)dX = \int_{X^{ic}}^{X^{i*}} (D^i\tau - g)dX + \int_{X^{i''}}^{X^{ic}} (D^i\tau - g)dX$$

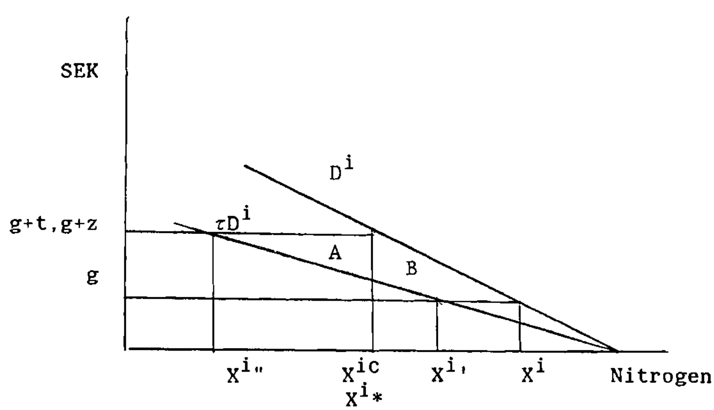
and substitute into (3.29), which yields

$$(3.30)\quad \int_{X^{ic}}^{X^{i*}} (D^i - g)dX - \int_{X^{ic}}^{X^{i*}} (D^i\tau - g)dX - \int_{X^{i''}}^{X^{ic}} (D^i\tau - g)dX + t(X^{ic} - X^{i''}) > 0$$

When $X^{i*} \geqslant X^{ic}$, the difference between the first two terms is nonnegative since $D^i > D^i\tau$. We know that $t = D^i\tau$ at $X^{i''}$, and that D^i is decreasing in X, which imply that $t(X^{ic} - X^{i''}) > \int_{X^{i''}}^{X^{ic}} (D^i\tau - g)dX$. Thus expression (3.30) is positive when $X^{i*} \geqslant X^{ic}$.

In order to illustrate the incentives to adjust to a new technology for the policy alternatives, we assume that $X^{i*} = X^{ic}$. This means that optimal quotas of nitrogen use are distributed to the farmers. The profits gained from changing technology under the economic incentive and quota systems can then be illustrated as in Figure 3.5.

Figure 3.5: Incentives to change technology under the charge, permit market and quota systems.



The abatement cost is lower under the new technology since the value of the marginal product of chemical nitrogen is reduced. This gain from switching technology is common to all policies and corresponds to the area A. Under the charge and permit market systems, additional gains are made from using less nitrogen and, hence, payments for nitrogen are reduced, which correspond to area B. Thus total profit due to a switch from technology D^i to $D^i\tau$ under a quota system corresponds to area A and profits of the charge and permit market systems are represented by the area A+B.

However, the profits made from changing technology under a permit market could be less than the amount corresponding to A+B. The reason is that the new technology reduces the value of the marginal product of chemical nitrogen, which decreases the demand for chemical nitrogen. This implies that the price of permits decreases as well.

The permit price, which ensures that $\Delta IX^{ipm} > \Delta IX^{iq}$, can be derived from equation (3.29). When $X^{i*} = X^{ic}$ the following condition must hold

$$(3.31) \qquad z(X^{ic} - X^{i''}) \geq \int_{X^{i''}}^{X^{ic}} (D^{i}\tau - g)dX$$

Let us assume that D^i is a linear function, i.e., $g = a^i - b^i X^i$. We can then solve for z in the following way

$$(3.32) \qquad z(X^C - X'') \geq a(X^C - X'') - b((X^C)^2 - (X'')^2)/2$$

which, after rearranging, gives

$$(3.33) \qquad z \geq a - b(X^C + X'')/2$$

The supply of permits must decrease at a rate such that z never falls below D at $(X^C + X'')/2$ if $\Delta IX^{pm} > \Delta IX^{q}$. If the incentives to adjust to new technologies should remain, the supply of permits must be further reduced to levels where t=z.

We summarize this section by concluding that all three policy instruments encourage technological change. Under the charge and permit market systems, the farmer incurs two types of reductions in costs. First, abatement costs are reduced and, second, payments for actual use of nitrogen are reduced. At a given charge or price of permits, the farmer uses less quantities of nitrogen since the value of the marginal product decreases. Whether or not the incentives for adjustment are lowest for a quota system depends on the relation between the ration of nitrogen and optimal use of nitrogen at a given charge or price of permits. It was shown that the reduction in income from adopting a new technology is always higher for the charge and permit market systems if the ration of nitrogen exceeds the optimal use of nitrogen. We also showed that, for a permit market, the policy-maker has to intervene and reduce the supply of permits at a certain rate in order to ensure that the incentives to switch technologies remain unchanged.

3.4 Summary and Conclusions

The purpose of this chapter has been to compare the systems of quotas, charges and permit markets with respect to cost efficiency, income distribution effects and technological change. All policy devices are directed towards the farmers' use of chemical nitrogen and manure and no distinction is made between different sources of pollution.

The calculations of all effects are based on the farmers' maximization of expected utility, from which the demand for nitrogen is derived. Costs and effects are then measured as integrals of the demand functions. Chemical nitrogen is treated as an ordinary input while manure is regarded as disposal problem.

However, we do not obtain any unambiguous results in the sense that one policy instrument is always better than another. What can be said is that a permit market is the best instrument, or shares the highest ranking, most of the time. This is true for all criteria, except under certain conditions when incentives are compared to change technologies. As an overview, all of these results are summarized in Table 3.1. The policy devices are ranked according to each criterion. The symbols >,=, and ⩾ should be interpreted as "better than", "as good as" and "better than or as good as".

Table 3.1: Criteria of comparison and rankings of quotas, Q, charges, C, and permit market, PM.

Cost efficiency	C = PM > Q
Income distribution effects	PM > Q > C or PM > C > Q
Technological change	C ⩾ PM ⩾ Q or Q ⩾ C ⩾ PM

Cost efficiency is defined as achieving a certain reduction in the use of nitrogen at minimum costs, i.e., with minimum reductions in the value of output. Both the charge and permit market systems yield such a solution, given that the optimal charge is found and that the market for permits is competitive. For a quota system, where each farmer is told how much nitrogen to use, cost efficiency is not likely to occur because such an outcome would require information on every farmer's production technology. Implementation of this system would therefore create a larger reduction in the value of yield as compared to the charge and permit market systems, the so-called efficiency loss.

However, a quota system performs better when income distribution effects are compared. Income distribution effects are defined as total reductions in income, which include changes in the value of yield and payments for actual use of nitrogen. A quota system creates smaller income distribution effects if the increased payments exceed efficiency losses. Since initial permits are distributed free of charge, under a permit market, the income distribution effects are smallest for this system. The ranking of the charge and quota systems with respect to income distribution effects depends on the relation between efficiency losses and increased payments for charges.

All three policy instruments encourage technological change. However, the gains made from switching technologies differ among the policies. The gains are calculated as reductions in income distribution effects from adjusting to a new nitrogen abatement technology. It is found that the incentives for technological adjustment are highest for the charge and permit market systems if the quotas are distributed efficiently. For a permit market it is then assumed that the price of permits is unchanged. It is plausible, however, that the price of permits may fall due to a decrease in the demand for permits brought about by the new technology. In this case, the policy-maker has to reduce the supply of permits at a certain rate if the incentives for technological adjustment are to remain unchanged.

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4. INCENTIVES TO VIOLATE REGULATIONS

Two major difficulties in environmental policymaking on the regional level are enforcing measures and monitoring compliance. When the use of a good such as chemical nitrogen is regulated, noncompliance on the main land can occur simply by smuggling nitrogen from other parts of Sweden since there are no customs which supervise illegal imports. But in the case of Gotland, the water surrounding the island constitutes a natural boundaries which simplifies supervision of compliance. The degree of surveillance required depends on the enforcement agency's expectations of the farmers' violation rate. This rate depends on, among other things, morality, economic incentives, publicity surrounding anti-social behavior, etc. In this chapter we focus on strict economic incentives and analyze how they differ among policy devices. The formulas derived here are then used in Chapter 6 to calculate the profits from violating different policy systems. In the subsequent text, these profits are refeerred to as "violation profits". We also study the effects of changes in different policy parameters on violation profits. The final purpose of this chapter is to compare the effectiveness of enforcement measures and examine possibilities of reaching a given target for the use of nitrogen when violation occurs under different policy systems.

There is a difference in violation behavior depending on whether chemical nitrogen or manure is regulated. In the case of chemical nitrogen, the farmer has to buy nitrogen on the mainland, which implies an extra transport cost. When the application of manure is regulated, the farmer can simply make false reports regarding the amount of manure applied, which is costless. In spite of this difference in violation behavior, the results of the analysis for chemical nitrogen and manure may be regarded as similar. The reason is that the marginal costs of reducing nitrogen are positive and increasing with respect to the amount of reduced nitrogen for both fertilizer and manure. The analysis of this chapter is therefore focused on fertilizer.

When comparing potential profits from violating different policy instruments, two kind of fines are considered: a fixed fine which is of the same size for all policy instruments and a variable fine which varies with the quantity of illegal nitrogen. Violation profits under a variable fine system turn out to be either of the smallest or the largest magnitude under a permit market system. The reason is that the occurence of smuggling reduces the demand for permits and therby the price of permits. For a high enough decrease in the price of permits the violation profits are the smallest under a permit market system.

For variable fines we would expect the violation profits to be higher for a charge system than for a quota scheme since the farmers gain from not paying charges. Under a quota system he receives a certain ration at the old price. But this stronger incentive not to comply under a charge system is reduced by its relatively higher expected marginal violation costs. When the farmer's illicit nitrogen import is detected he must pay a fine plus the charge or the price of permits. He only pays the fine when detected under a quota system. What effect dominates determines the ranking of charges and quotas respectively. When there is fixed fines this difference between the quota and charge systems vanishes since the expected marginal violation costs are the same.

The policy parameters studied are: the transport cost, fine, probability of detection, price of nitrogen, charges and price of permits. Our results show that violation profits are negatively related to changes in the transport cost, fines and the price of nitrogen under all policy systems. The effect of a change in the detection rate is indeterminate under a quota system. Under the charge and permit market schemes, the effects of a change in the detection rate as well as in the charge and price of permits are ambiguous.

The policy parameters regarded as enforcement measures are fines and the probability of detection. Adjustment of the amount of permits issued is also considered as an enforcement measure under a permit market. We find that, in practice, it is almost impossible to reach a given target for the use of nitrogen under a quota system by adjusting fines and the detection rate. These measures are more powerful under the charge and permit market systems. On the other hand, adjustment of issued permits is found to be an effective enforcement measure. The market-clearing price of permits then serves as a mechanism for decreasing violation profits and thereby curbing nitrogen smuggling.

This chapter begins with a description of the basic model. The profits from violating different policies are calculated in Section 4.2.

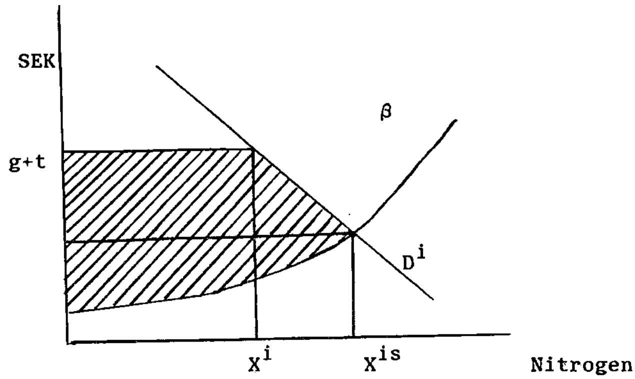
Comparative statics are carried out for different policy parameters in Section 4.3. The effectiveness of enforcement measures and possibilities of reaching a target for the use of nitrogen are examined in Section 4.4. We end this chapter with a summary and discussion of our results.

4.1 The Basic Model.

In this section we present the general model which is used to calculate profits from violating different policy parameters. When contemplating noncompliance the farmer is assumed to consider only expected violation costs and gains. His violation cost is the expected penalty. The expected penalty is the probability of detection times the fine. If the farmer smuggles chemical nitrogen to Gotland there is an additional cost for transporting nitrogen from the mainland. The price of legal nitrogen sold in the island also includes a transport cost. It is assumed that the wholesaler's cost, per unit of nitrogen, for transporting large quantities is lower than the farmer's cost for small quantities. The violation gain consists of the payments of charges or permit prices evaded by the farmer. Under a quota system, the violation gain is the value of the marginal product in excess of the amount of allowed quantity. The incentives to violate regulaions are then calculated as the difference between the expected violation gains and costs.

This setup may be exemplified by profits from violating a charge system as illustrated in Figure 4.1. The charge t is levied on the price of nitrogen g.

Figure 4.1; Profits from violating a charge system



Suppose that the expected marginal violation cost, β, is increasing in the amount of smuggled nitrogen. This assumption is made to facilitate the presentation of the figures throughout this chapter. It does not, however, have any impact on the analytical results. The legal use of nitrogen occurs at X^i according to the analysis in Chapter 3. But, since the expected marginal violation gain exceeds the expected marginal violation cost, a farmer who maximizes expected utility smuggles the quantity X^{is}. The violation profits then amount to the shaded area.

The demand for nitrogen D^i, is derived from the maximization of expected utility under risk aversion, cf. Chapter 2. The violation profit illustrated in Figure 4.1 is therefore not wholly correct. The curve D^i is the demand for legal nitrogen - not for smuggled - nitrogen. It is probably more risky to engage in illicit activities than to comply. When the farmer is risk averse, then the demand for smuggled nitrogen is less for smuggled than for legal nitrogen; see e.g. Pope and

Kramer (1979). Thus the demand for smuggled nitrogen should be lower than X^{is}, which implies a reduction in violation profits.

We do not consider the difference in demand between legal and smuggled nitrogen for two reasons. The main purpose of this chapter is to find formulas which can be used for the empirical calculations in Chapter 6. As a point of departure for these calculations, we use an estimated nitrogen demand function which only includes the use of legal nitrogen. The second reason is that we do not have any measure of the farmers' degree of risk aversion, by means of which the demand for smuggled nitrogen could be derived from the demand for legal nitrogen.

Figure 4.1 exemplified how the violation profit is determined in principle. In the following we show how it is derived from maximization of expected utility. This approach is used to model the economic incentives for violating all of the policy instruments.

If he engages in criminal activities, the farmer knows there is a certain probability, q, of being fined. His profit is then F^i. But he also has a chance of succeeding, 1-q, thereby receiving the profit S^i. The profits in the two states are determined for given values of the fine and the charge. Two kinds of fines are considered; a variable and fixed fine system. The general formulation of profits in the two states are written as

$$(4.1)\qquad \begin{aligned} S^i &= pQ - gX^{i*} - (g+t+z)(X^i-X^{i*}) - (g+a)X^{is} \\ F^i &= pQ - gX^{i*} - (g+t+z)(X^i-X^{i*}) - (g+a+f+t+z)X^{is} - K \end{aligned}$$

where

p: price of output
Q: output
g: price of nitrogen
a: transport cost
f: fine (under a variable fine system)
X^i: legal use of nitrogen
X^{i*}: distributed rations of nitrogen
X^{is}: illegal use of nitrogen
t: charge
z: price of permits
K: fine (under a fixed fine system)

Common to all policy instruments is that the farmers incurs a transport cost, a, when he smuggles nitrogen from the mainland. Under a system with variable fines the farmer who is detected has to pay a fine, f, per unit of smuggled nitrogen, X^{is}. This fine is of the same level to all policy instruments. When we have a system with fixed fines, the detected farmer has to pay the amount K under all policy instruments.

Under a quota system the farmer can buy a given quantity of nitrogen, X^{i*}, at the initial price g. The terms t, z, (X^i-X^{i*}) and K are then zero. Under a charge system the farmer can buy nitrogen as much as he desires at the price (g+t). If he smuggles nitrogen, he has to pay (g+a+t+f) per unit of smuggled nitrogen under a system of variable fines. The terms X^{i*}, z and K are zero. When there is a permit market, the farmer can buy nitrogen in excess of his initial permits at the price (g+z). If he chooses to smuggle nitrogen, he must pay (g+a+z+f) under a system of variable fines. The terms t and K are zero.

The optimal allocation of legal and illicit use of nitrogen, X^i and X^{is}, respectively, is determined by maximization of the expected utility of these two states; see Storey & McGabe (1984). Accordingly, the general decision problem is formulated as

$$(4.2) \qquad \max_{X^i, X^{is}} E[U] = (1-q)U(S^i) + qU(F^i)$$

where q is the rate of detection and U(.) is the expected utility of profits in different states due to weather conditions. The utility maximizing levels of X^i and X^{is} are determined by the first-order conditions, which are

$$(4.3) \qquad \delta E[U]/\delta X^i = (1-q)U'(S)S_X + qU'(F)F_X \leq 0$$

$$(4.4) \qquad \delta E[U]/\delta X^{is} = (1-q)U'(S)S_{XS} + qU'(F)F_{XS} \leq 0$$

Subscripts denote partial derivatives and U'(.) is $\delta U/\delta S$ and $\delta U/\delta F$ respectively. As shown in Section 4.2, nitrogen smuggling occurs as long as the expected marginal profit is positive. The level of X^{is} differs among the policy systems since the profits in the two states S^i and F^i differ. Profits from violating the policy instruments are measured as some integrals of the nitrogen demand function.

The effectiveness of a means of enforcement is measured by its ability to reduce the size of violation profits. This is a relatively strong limitation since complete determination of effectiveness would require comparison of both the costs and benefits of enforcing a policy measure. In this chapter, decreases in violation profits are regarded as benefits, but costs are not considered at all. For a more comprehensive discussion of the costs and benefits associated with enforcement measures, see e.g., Becker (1968) and Lee (1984).

One of the most important enforcement parameters at the disposal open to a regional policy-maker is the rate of detection, defined as the probability of being detected and fined. Enforcement by other measures, such as the fines, do often require decision-making on a national level. On a regional level, decision can be made regarding the amount of resources spent on activities for monitoring compliance and convicting noncompliance. Another enforcement measure available weapon open to the regional policymaker under a permit market system is adjustment of the amount of permits issued. The enforcement measures considered in this study are thus the rate of detection, fines, and, for a permit market, the amount of permits issued.

4.2 Violation Profits of Alternative Policies.

Farmers are thus able to use nitrogen in excess of their ration or evade payments for charges or permits by buying nitrogen from the mainland. This nitrogen smuggling, X^{is}, incurs a cost denoted by a. When the fine varies with X^{s}, the farmer has to pay a fine, f, per unit of X^{is} in the event of detection. This is the only detection cost under a quota system, but for charges and market schemes the farmer also has to pay the charge or permit price he tried to evade. Hence, the marginal expected violation costs, β^{ih}_{xs}, differ for the policy devices. The fixed fine, denoted by K, is the same for all policy instruments.

4.2.1 Quotas

When subjected to a quota system, each farmer receives a ration X^{i*} of nitrogen for which he pays the unit price g. Every time he purchases nitrogen he gives a coupon to the retailer. He cannot buy any nitrogen without coupons. If he wants more than his ration, he has to take the ferry to the mainland and buy nitrogen at the unit cost g+a, where a is the transport cost. His profits from smuggling in states S^i and F^i are then

$$(4.5) \qquad S^i = pQ^i - gX^{i*} - (g+a)X^{is}$$
$$F^i = pQ^i - gX^{i*} - (g+a+f)X^{is}$$

We find the utility-maximizing level of the quantity of smuggled nitrogen, X^{is}, by inserting (4.5) into (4.2) and derive the first-order conditions, which gives

$$(4.6) \quad \delta E[U]/\delta X^{is} = (1-q)U'(S^i)(pQ^i_x-g-a)+qU'(F^i(pQ^i_x-g-a-f)) \leqslant 0$$

Subscripts denote partial derivatives. In terms of expected marginal income and expected marginal violation cost, λ^{iq}_{xs} and β^{iq}_{xs} respectively, equation (4.6) may be written as

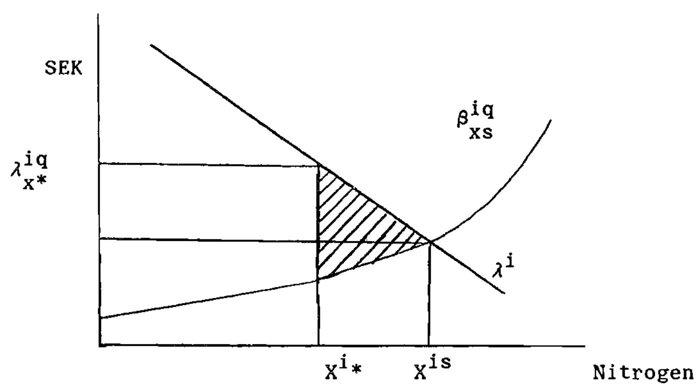
$$(4.7) \quad \delta E[U]/\delta X^{is} = \lambda^{iq}_{xs} - \beta^{iq}_{xs} = 0$$

where
$$\lambda_{xs}^{iq} = (1-q)U'(S^i)pQ_{xs}^{i} + qU'(F^i)pQ_{xs}^{i}$$
$$\beta^{iq}_{xs} = \Omega(g+a) + qfU'(F^i)$$
$$\Omega = (1-q)U'(S^i) + qU'(F^i)$$

According to equation (4.6), expected marginal income is equal to expected marginal violaiton cost in optimum. The expected marginal violation cost includes the price of nitrogen, the transport cost and the expected fine. Smuggling thus occurs when, at the ration X^{i*}, the expected value of the marginal product exceeds the expected marginal smuggling cost, i.e., $\lambda^{iq}_{x*}>\beta^{iq}_{xs}$. The marginal violation cost includes not only the price of fertilizer, but also the smuggling cost and the expected fine.

The farmer's potential violation profit is his income of smuggled nitrogen less the associated cost. This is measured as a certain integral of the demand function whose limit values are expected marginal benefits at X^{i*}, λ^{iq}_{x*}, and expected marginal cost, β^{iq}_{xs}, as illustrated in Figure 4.2.

Figure 4.2: Profits from violating a quota system



At the initial ration X^{i*} expected marginal income exceeds expected marginal violation cost, i.e., $\lambda^{iq}_{x*}>\beta^{iq}_{xs}$. Smuggling thus occurs where $\lambda^{iq}_{xs}=\beta^{iq}_{xs}$, which holds at X^{is}. Violation profit constitutes income less violation cost of smuggled nitrogen, which is illustrated by the shaded area in Figure 4.2.

When a fixed fine is applied, the variable f in (4.5) are replaced by a constant K. This slight change gives the following profits in the two states of outcome.

$$S^i = pQ^i - gX^{i*} - (g+a)X^{is} \tag{4.8}$$

$$F^i = pQ^i - gX^{i*} - (g+a)X^{is} - K$$

The first-order condition for utility maximization is

$$\delta E[U]/\delta X^{is} = \lambda^{iq}_{xs} - \Omega(g+a) = 0 \tag{4.9}$$

The farmer smuggles when condition is positive, given that the violation profit is positive. The expected marginal violation cost of a fixed fine is lower than for a variable fine - differing by the amount $qfU'(F^i)$. This implies that X^{is} is larger when the fine is fixed than when it is variable.

In order to estimate violation profits in Chapter 6, we need a formula for total violation profits. Since, in practise, a system of variable fines is applied, a formula for violation profits with variable fines may be derived, written as

$$\pi^q = \sum_{i=1}^{n} \int_{X^{i*}}^{X^{is}} (D^i - \beta^{iq}_{xs})dX \tag{4.10}$$

As illustrated in Figure 4.2, a farmer's violation profit is measured as the integral of the function $(D^i - \beta^{iq}_{xs})$ between X^{i*} and X^{is}. Note than the first order condition for maximization of expected utility can be derived from (4.10). Total violation profits constitute the sum of these integrals.

If fixed fines were applied instead π^q is changed in two counteracting ways. Total violation profits are reduced by the sum of expected fixed fines qnK, but also increased by a reduction in the expected marginal violation cost. The expected marginal violation cost is lowered to $\Omega(g+a)$ according to (4.9).

4.2.2 Charges

When a charge system is implemented, a farmer can either buy nitrogen in Gotland at the price g+t or smuggle it at the unit cost g+a. If he gets caught, he also has to pay a fine f and the charge t. Accordingly, the unit cost when detected is g+a+t+f. The fixed fine amounts to K. The farmer's profit functions S^i and F^i of a variable fine are

$$(4.11) \qquad S^i = pQ^i - (g+t)X^i - (g+a)X^{is}$$
$$F^i = pQ^i - (g+t)X^i - (g+a+t+f)X^{is}$$

A major difference, as compared to a quota system, is that the farmer now chooses quantities of both legal and smuggled nitrogen. The first-order condition for a maximum are obtained by inserting (4.11) into (4.2) which gives

$$(4.12) \qquad \delta E[U]/\delta X^i = \lambda_x^{ic} - \Omega(g+t) \leq 0$$

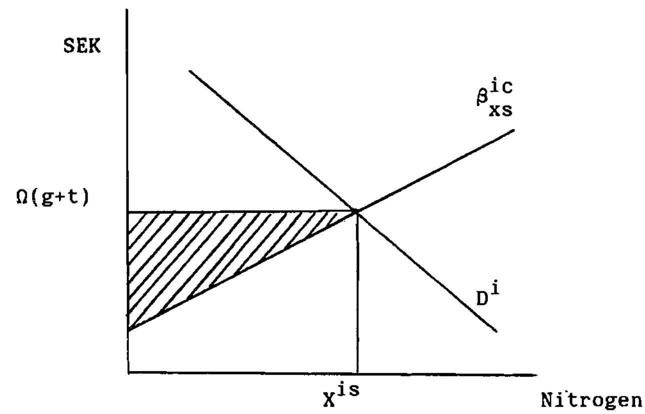
(4.13) $\qquad \delta E[U]/\delta X^{is} = \lambda^{ic}_{xs} - \beta^{ic}_{xs} \leqslant 0$

where $\qquad \beta^{ic}_{xs} = \Omega(g+a) + q(t+f)U'(F^{i})$

At the optimal choice of X^{i}, expected marginal income is equal to the expected marginal cost of legal nitrogen, according to (4.12). Condition (4.13) states that the utility-maximizing choice of X^{is} occurs where expected marginal income equals the expected marginal violation cost of smuggled nitrogen.

It was assumed in Section 4.1 that the marginal value of legal and illegal use of nitrogen is the same. This means that $\lambda^{ic}_{xs}=\lambda^{c}_{x}$, given that Ω is constant. It then follows that $\Omega(g+t)=\beta^{ic}_{xs}$ in optimum. The expected marginal violation gain is $\Omega(g+t)$, which constitutes the cost for legal nitrogen evaded by the farmer. Hence, according to 4.12-13, whether or not he will smuggle depends on the relation between the expected marginal violation gain, $\Omega(g+t)$, and the expected marginal violation cost, β^{ic}_{xs}. He will not smuggle chemical nitrogen as long as it is less costly to comply, i.e. when $\Omega(g+t)\leqslant\beta^{ic}_{xs}$. On the other hand, he chooses to smuggle all the nitrogen demanded when $\Omega(g+t)>\beta^{ic}_{xs}$. His potential violation gain is illustrated in Figure 4.3, where X^{is} denotes his utility-maximizing choice under a charge system. We assume $\Omega(g+t)>\beta^{it}_{xs}$ which gives a positive gain amounting to the shaded area in Figure 4.3.

Figure 4.3: Profits from violation a charge system



At X^{is} the first order condition (4.13) holds, i.e., $\lambda^{ic}_{xs}=\beta^{ic}_{xs}$, which determines the quantity of smuggled nitrogen as long as $\Omega(g+t)>\beta^{ic}_{xs}$. The violation profit then corresponds to the shaded area which includes profits from evaded charges for legal nitrogen and incomes from smuggled nitrogen in excess of the legal amount X^i.

When a system of fixed fines is appplied, the farmer who is detected pays a given amount, K, regardless of X^{is}. The modeling of his income when detected is slightly changed as compared to (4.11) and is written as

$$\text{(4.14)} \quad S^i = pQ^i - (g+t)X^i - (g+a)X^{is}$$
$$F^i = pQ^i - (g+t)X^i - (g+a)X^{is} - K$$

When compared to (4.11) we observe that $(t+f)X^{is}$ is replaced by the fixed fine K. The first-order conditions for choosing X^i and X^{is} are

(4.15) $\delta E[U]/\delta X^{i} = \lambda_{ic}^{x} - \Omega(g+t) = 0$

(4.16) $\delta E[U]/\delta X^{is} = \lambda_{xs}^{ic} - \Omega(g+a) = 0$

Since $\lambda_{x}^{ic}=\lambda_{xs}^{ic}$ equations 4.15-16 are reduced to $\Omega(g+t)=\Omega(g+a)$. However, it is very unlikely that t=a. We would therefore expect the farmer to smuggle nothing or all of the nitrogen he requires. As compared to the conditions under a variable fine system, we note that β_{xs}^{ic} is reduced by $q(t+f)E[U'(F^{i})]$, which implies that the expected marginal cost of smuggling of a fixed fine system is $\Omega(g+a)$. This means that, as in the case of a quota system, X^{is} is larger for fixed fines given that violation profits are positive. We can also observe that the expected marginal cost of violation is the same for the charge and quota systems when fixed fines are applied.

Total violation profits under a variable fine system, which is the measure needed in Chapter 6, are the aggregate of all farmer's violation profits, π^{c}, which is written as

(4.17) $$\pi^{c} = \sum_{i=1}^{n} \int_{0}^{X^{i}} (\Omega(g+t)-\beta_{xs}^{ic})dX + \int_{X^{s}}^{X^{is}} (D^{i}-\beta_{xs}^{ic})dX$$

The first integral corresponds to the profits from evading charges when the smuggled nitrogen amounts to the legal use, i.e. $X^{is}=X^{i}$. The second integral is a measure of the profits from smuggling nitrogen in excess of the legal use, i.e. $X^{is}-X^{i}$.

Under fixed fines, π^c is increased by a reduction in the expected marginal violation cost, which is reduced to $\Omega(g+a)$, and decreased by the subtraction of qnK. Whether or not π^c is larger for fixed fines depends on which of these two offsetting effects dominates.

4.2.3 A Permit Market

Under a permit market system, each farmer is initially given permits to use X^{i*} for which he pays gX^{i*}. Nitrogen in excess of X^{i*} is obatined by using permits. The price of one unit of X is then g+z, where z is the market-clearing price of permits. But a farmer also has the option of smuggling nitrogen at the unit cost g+a. If he smuggles, he takes the risk of being detected in which case he has to pay a fine and the current price of permits under a system of variable fines. In the case of a fixed fine system, he pays the amount K regardless of X^{is}. His two profit functions S^i and F^i under a permit market regime and variable fines are then

$$(4.18) \qquad S^i = pQ^i - gX^{i*} - (g+z)(X^i-X^{i*}) - (g+a)X^{is}$$
$$F^i = pQ^i - gX^{i*} - (g+z)(X^i-X^{i*}) - (g+a+z+f)X^{is}$$

In optimum expected marginal income is equal to the expected marginal cost of legal nitrogen for the choice of X^i and expected marginal income equals expected marginal violation cost of smuggled nitrogen when X^{is} is choosen. However, when smuggling occurs, the demand for legal nitrogen, i.e. the demand for permits, is reduced. This, in turn, implies that the price of permits is reduced. The total model is then determined by the following equations.

(4.19) $\max_{X^i, X^{is}} \quad (1-q)U(S^i) + qU(F^i)$

(4.20) $\delta E[U]/\delta X^i = \lambda_x^{ipm} - \Omega(g+z) = 0$

(4.21) $\delta E[U]/\delta X^{is} = \lambda_{xs}^{ipm} - \beta_{xs}^{ipm} = 0$

(4.22) $\sum_{i=1}^{n} X^i \leqslant \sum_{i=1}^{n} X^{i*}$ and $z(\sum_{i=1}^{n} X^i - \sum_{i=1}^{n} X^{i*}) = 0$

where $\beta_{xs}^{ipm} = \Omega(g+a) + q(z+f)E[U'(F^i)]$

A permit market equilibrium exists if there is a nonnegative price of permits, z, such that when X^i and X^{is} solve the farmer's maximization problem for z, the market-clearing conditions (4.22) hold. From (4.20-21) it is clear that the famer's demand for X^{is} is determined by the condition $\Omega(g+z)=\beta_{xs}^{ipm}$. When this condition holds, total demand for nitrogen includes both legal and smuggled nitrogen and the price of nitrogen is set by (4.22).

If there were no options to smuggle nitrogen, the violation profits of a permit market would be of the same amount as the profits from violating a charge system; see equation (4.17). But since the occurence of smuggling affects the price of permits, violation profits of a permit market system are determined by the price of permits. The profits from violating a permit market system are written as

(4.23) $\pi^{pm} = \sum_{i=1}^{n} \int_{\beta_{xs}^{ipm}}^{\Omega(g+z)} D^i \, dg$

The lower limit of the price of permits is determined by the expected marginal violation cost. Using conditions (4.20-4.21) we solve for the level of z where the farmer is indifferent between X^i and X^{is}. We find the price of permits where the expected marginal violation profit is zero, denoted by z', by solving for z, which gives

$$(4.24) \qquad z^{i\prime} = (1/(1-q)U'S^i))(\Omega a + qfU'(F^i))$$

In fact, $z^{i\prime}$ is the lowest level of the price of permits that could be achieved in optimum for a farmer. The upper limit of z corresponds to the charge t. This is shown by using equations (4.19-22).

Assume that $z<z^{i\prime}$. This implies $\Omega(g+z)<\beta^{ipm}_{xs}$. The demand for X^{is} is then reduced such that $\Omega(g+z)=\beta^{ipm}_{xs}$, which is equivalent to $z=z^{i\prime}$. Let us next assume that z>t. This means, according to (4.12) and (4.20), that $(z+g)>(t+g)=\lambda^{ipm}_{x}$, which violates the condition set by (4.20). Thus, the limits of z are determined by $z^{i\prime}$ and t such that $z^{i\prime}\leq z\leq t$.

Under a system of fixed fines, the outcome of detection is changed slightly, which can be seen from (4.25)

$$(4.25) \qquad S^i = pQ^i - gX^{i*} - (g+z)(X^i-X^{i*}) - (g+a)X^{is}$$

$$F^i = pQ^i - gX^{j*} - (g+z)(X^i-X^{i*}) - (g+a)X^{is} - K$$

The variable fine $(z+f)X^{is}$ is now replaced by K. The first-order conditions for a maximum when solving for X^i and X^{is} are given by (4.26-27).

(4.26) $\delta E[U]/\delta X^{i} = \lambda_{x}^{ipm} - \Omega(g+z) = 0$

(4.27) $\delta E[U]/\delta X^{is} = \lambda_{xs}^{ipm} - \Omega(g+a) = 0$

Since $\lambda_{xs}^{ipm}=\lambda_{x}^{ipm}$ it follows that conditions (4.26-27) can be written as $\Omega(g+z)=\Omega(g+a)$. This condition is very similar to that of a charge system with fixed fines; see (4.12-13). The difference is that the charge t is replaced by the price of permits z. We also note that the marginal violation cost, $\Omega(g+a)$, is the same for all policy instruments.

Violation profits of a permit market are changed in two ways similar to the other policy instruments. They are increased since β_{xs}^{ipm} is decreased and π^{pm} are reduced by the amount qnK. The decrease in β_{xs}^{ipm} lowers $z^{i}{}'$, which increases the demand for smuggled nitrogen. When solving for $z^{i}{}'$ in (4.26-27) we get $z^{i}{}'=a$. That is, under a system of fixed fines, the price of permits is determined solely by the transport cost as long as $a<t$.

4.2.4 A comparison.

We now compare potential profits from violating different regulation schemes, i.e., π^{q}, π^{c} and π^{pm}. Since, in practice, a system of variable fines is applied, the comparision is focused on the profits from violating policy instruments under this system, which are written as

$$(4.10) \qquad \pi^{q} = \sum_{i=1}^{n} \int_{X^{j*}}^{X^{i*}} (D^{i} - \beta_{xs}^{iq})dX$$

$$(4.17) \qquad \pi^{c} = \sum_{i=1}^{n} \int_{0}^{X^{i}} (\Omega(g+t)-\beta_{xs}^{ic})dX + \int_{X^{j}}^{X^{is}} (D^{i}-\beta_{xs}^{ic})dX$$

$$(4.23) \qquad \pi^{pm1} = \sum_{i=1}^{n} \int_{\beta_{xs}^{ipm}}^{\Omega(g+z)} D^{i}dg$$

The violation profits for a permit market are the same as for a charge system when z=t. Whether or not $\pi^{pm}=\pi^{c}>\pi^{q}$ in this case depends on the relation between the efficiency losses of a quota system and charge payments. Furthermore, we know that $\beta_{xs}^{ic}=\beta_{xs}^{ipm}\geqslant\beta_{xs}^{iq}$. That is, the violation profits from a quota system are larger than profits from violating a charge and permit market system when the efficiency losses of a quota system are high enough and/or the expected marginal violation cost of a quota system is sufficiently low as compared to the other two policy instruments. The latter is brought about by either a high enough charge (price of permits) or probability of detection.

Under a system of fixed fines, the expected marginal violation costs are the same for all policy instruments. The violation profits of a quota system are then largest when the efficiency losses are high enough.

However, when smuggling of nitrogen occurs, the demand for legal use of nitrogen, i.e. for permits, is reduced. This implies that the price of permits is decreased. When the price of permits decreases, the profits from violating permit market may decrease. In order to see this, we differentiate π^{pm} with respect to z, which gives

$$(4.27) \quad \pi_z^{pm} = \Omega(D^i(\Omega(g+t))) - D^i(\beta_{xs}^{ipm})(\delta\beta_{xs}^{ipm}/\delta z) + \int_{\beta_{xs}^{ipm}}^{\Omega(g+t)} D_z^i \, dg$$

According to equation (4.27), the expected violation gains made from evading payments of permits are reduced when the price of permits decreases. On the other hand, the expected marginal violation cost is decreased, which has a positive impact on the violation profits. Equation (4.27) is then positive if the probability of detection, q, is small enough. Thus, when we assume the q is sufficiently small, the occurence of smuggling reduces the profits from violating a permit market system. This means that the violation profits of a permits market system may be the smallest of all the policy instruments.

4.3. Changes in Policy Parameters.

Next we differentiate the profits from violating each policy with respect to the exogenous policy parameters. Parameters common to all of the policy instruments are transport cost, fine, rate of detection and price of nitrogen. Under the charge and permit market systems, the charge and price of permits are also regarded as policy parameters. All calculations refer to a single farmer. The superindex indicating a farmer is therefore omitted.

In the following we study how π^q is affected by changes in the policy parameters. The transport cost a, the fine f, and the price of nitrogen g, are all positively related to the expected marginal violation cost and are therefore negatively related to π^q according to equations (4.28)-(4.30).

$$(4.28) \qquad \pi^q_a = (D(X^s)-\beta^q_{xs}(X^s))\delta X^s/\delta a + \int_{X^*}^{X^s} (D_a-\Omega)dX < 0$$

$$(4.29) \qquad \pi^q_f = (D(X^s)-\beta^q_{xs}(X^s))\delta X^s/\delta f + \int_{X^*}^{X^s} (D_f-qU'(F^i)dX < 0$$

$$(4.30) \qquad \pi^q_g = (D(X^s)-\beta^q_{xs}(X^s))\delta X^s/\delta g + \int_{X^*}^{Xs} (D_g-\Omega)dX < 0$$

These equations are all negative when the first term in parentheses is zero and when $D_a,D_f,D_g<0$. The first term is zero due to the first order condition for maximization of expected utility; see equation (4.7). The effect of a change in the transport cost can be compared with a change in the price of nitrogen, which was shown to be negatively related to the demand for nitrogen; cf. Chapter 2. Storey and McGabe (1980) found that an increase in the fine has a negative impact on the magnitude of violation, i.e., the demand for smuggled nitrogen is decreasing in f.

A change in the probability of detection, q, has an ambiguous impact on π^q, which is shown by equation (4.30).

$$(4.31) \qquad \pi^q_q = \int_{X^*}^{X^s} (D_q - \beta^q_{xs})dX$$

In order to determine whether $\pi^q_q<0$, we differentiate D and β^q_{xs} with respect to q, which yields

$$(4.32) \qquad D_q = (-U'(S)+U'(F))pQ_x > 0$$

$$(4.33) \qquad \delta\beta^q_{xs}/\delta q = (-U'(S)+U'(F))(g+a) + fU'(F^i) > 0$$

Both equations are positive when $U''<0$, since then $U'(S^i)<U'(F^i)$. This means that the sign of (4.31) is ambiguous.

The effects of changes in a, f, and g on the profits from violating a charge system are shown by equations (4.34)-(4.36)

$$(4.34) \qquad \pi^c_a = (\Omega(g+t)-D(X))\delta X/\delta a + \int_0^X (-\Omega)dX + \int_X^{X^s} (D_a-\Omega)dX < 0$$

$$(4.35) \qquad \pi^c_f = (\Omega(g+t)-D(X))\delta X/\delta f + \int_0^X (-q)dX + \int_X^{X^s} (D_f-qU'(F))dX < 0$$

$$(4.36) \qquad \pi^c_g = (\Omega(g+t)-D(X))\delta X/\delta g + \int_X^{X^s} (D_g-\Omega)dX < 0$$

Equations (4.34-36) are negative when the first term in parentheses is zero and $D_a, D_f, D_g<0$. The first term is assumed to be negative according to the first order condition (4.12).

The impacts of the charge and probability of detection, i.e., t and q, are less straightforward, which can be seen from equations (4.37-38)

$$(4.37)\qquad \pi_t^c = \int_0^X (1-q)U'(S)dX + \int_X^{X^s} (D_t-qU'(F))dX$$

$$(4.38)\qquad \pi_q^c = \int_0^X (\Omega_q(g+t)-\delta\beta_{xs}^c/\delta q)dX + \int_X^{X^s} (D_q-\delta\beta_{xs}^c/\delta q)dX$$

The first integral in (4.37) is positive. The second is negative, given that $D_t<0$. Thus, the impact of a change in the charge on violation profits is ambiguous.

According to equations (4.32-33), $\delta\beta_{xs}^c/\delta q$ and D_q are positive when $U''<0$. This implies that the second integral in equation (4.38) is negative. In order to determine the sign of 4.38, we calculate Ω_q, which gives

$$(4.39)\qquad \Omega_q = -U'(S)+U'(F) > 0 \quad \text{when } U''<0$$

Thus, the sign of 4.38 is ambiguous.

The results of the comparative statics regarding the violation profits are similar to the results of the other two policies. This is shown by the following equations (4.40)-(4.44).

$$(4.40) \quad \pi_a^{pm} = -(\delta\beta_{xs}^{pm}/\delta a)D(\beta_{xs}^{pm}) + \int_{\beta_{xs}^{pm}}^{\Omega(g+z)} D_a \, dg < 0$$

$$(4.41) \quad \pi_f^{pm} = -\delta(\beta_{xs}^{pm})/\delta f)D(\beta_{xs}^{pm}) + \int_{\beta_{xs}^{pm}}^{\Omega(g+z)} D_f \, dg < 0$$

$$(4.42) \quad \pi_g^{pm} = \Omega D(g+z) - (\delta\beta_{xs}^{pm}/\delta g)D(\beta_{xs}^{pm}) + \int_{\beta_{xs}^{pm}}^{\Omega(g+z)} D_g dg < 0$$

$$(4.43) \quad \pi_z^{pm} = \Omega(D(g+z) - (\delta\beta_{xs}^{pm}/\delta z)D(\beta_{xs}^{pm}) + \int_{\beta_{xs}^{pm}}^{\Omega(g+z)} D_z \, dg$$

$$(4.44) \quad \pi_q^{pm} = \Omega_q(g+z)D(g+z) - (\delta\beta_{xs}^{pm}/\delta z)D(\beta_{xs}^{pm}) + \int_{\beta_{xs}^{pm}}^{\Omega(g+z)} D_q Dg$$

Given that smuggling occurs, equations (4.40)-(4.44) are negative when $D_a, D_f, D_g < 0$. The last two equations are negative only if, for each equation, the effects of the increase in the violation cost are higher than the value of the increase in the violation gain. That is, the value of the last two terms must exceed the value of the first term.

4.4 Effectiveness of Enforcement Measures

The policy parameters regarded as enforcement measures are the detection rate, fines, and, for a permit market, the amount of permits isued. In practice, fines might not be a powerful instrument because they are determined by decision-making on a national level. But the detection rate and the amount of permits issued are decided on by regional policymakers. We therefore focus on analyzing the effectiveness of these two regional measures. Effectiveness is defined as the decrease in violation profits due to a change in any of the enforcement measure.

We begin by comparing the effects of a change in the detection rate on the profits from violating different policies. The formulas are repeated as follows.

$$(4.31)\quad \pi_q^q = \int_{X^*}^{X^s} (D_q - \delta\beta_{xs}^q/\delta q)\,dX$$

$$(4.38)\quad \pi_q^c = \int_0^{X} (\Omega(g+t) - \delta\beta_{xs}^c/\delta q)\,dX + \int_X^{X^s} (D_q - \delta\beta_{xs}^c/\delta f)\,dX$$

$$(4.44)\quad \pi_q^{pm} = D(g+z)\Omega_q(g+z) - D(\beta_{xs}^{pm})(\delta\beta_{xs}^{pm}/\delta q) + \int_{\beta^{pm}}^{\Omega(g+z)} D_q\,dg$$

The results are ambiguous, so that very little can be said about under what system the detection rate is the most effective measure. When z=t, we can say that $\pi_q^c = \pi_q^{pm}$. Even if we make the simplifying assumption that the quotas are distributed efficiently the outcome remains indeterminate. Equation (4.31) is then equal to the second integral in equation (4.38). But the first integral in (4.38) can be either positive or negative, which makes violation profits of a quota system more or less sensitive to changes in the detection rate than a charge system.

The effects of a change in the fine may be compared in the same way; the corresponding equations are

$$(4.29) \qquad \pi_f^q = \int_{X^*}^{X^s} (D_f - qU'(F))dX < 0$$

$$(4.35) \qquad \pi_f^c = \int_{0}^{X} (-qU'(F))dX + \int_{X}^{X^s} (D_f - qU'(F))dX < 0$$

$$(4.41) \qquad \pi_f^{pm} = -D(\beta^{pm})(\delta\beta^{pm}/\delta f) + \int_{\beta_{xs}^{pm}}^{\Omega(g+z)} D_f \, dg < 0$$

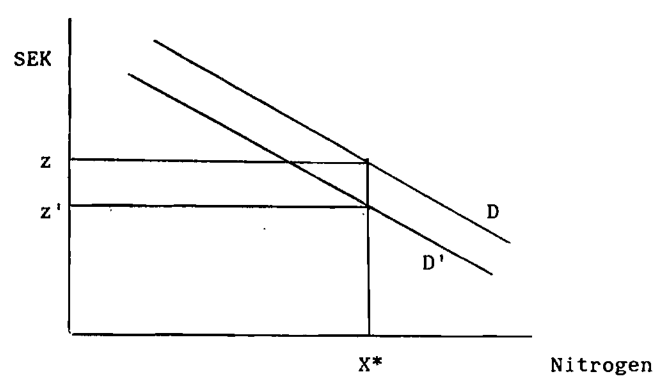
If the quotas were efficiently distributed, then a charge system would be more sensitive to changes in the fine than a quota system. All other comparisons give ambiguous results.

In principle, the enforcement measures q and f can be adjusted such that the violation profits are zero. This means that we could reach a target for the use of nitrogen by adjusting these parameters. Under the quota system, the policymaker has to find q and f such that $\lambda_{xs}^{iq}=\beta_{xs}^{iq}$, which implies adjusting q and f for each single farmer. In practice, such an approach is more or less impossible. This makes smuggling unavoidable under a quota system, which implies that the target use of nitrogen, X*, cannot be obtained. Under a charge system the condition $\Omega(g+t)=\beta^{c}_{xs}$ must hold, which could be found in practice. For a permit market, the same condition must hold, except for t is replaced by z. As in the case of a charge system, this could be obtained by adjusting q and f. Another possibility would be to adjust the amount of permits issued.

From Section 4.2 we know that when smuggling occurs under a permit market system, the price of permits is reduced to the level where it is equal to the smuggling cost plus the expected fine, denoted by $z^{i\prime}$. At this price $\pi^{pm}=0$, and no smuggling occurs. If we could find the amount of permits issued such that z=z' at X*, smuggling would not be avoided but the desired use of nitrogen, X*, would be obtained.

According to the market-clearing condition (4.22), the price of permits is determined by the supply and demand for legal nitrogen, i.e., for permits, which can be illustrated as in Figure 4.4.

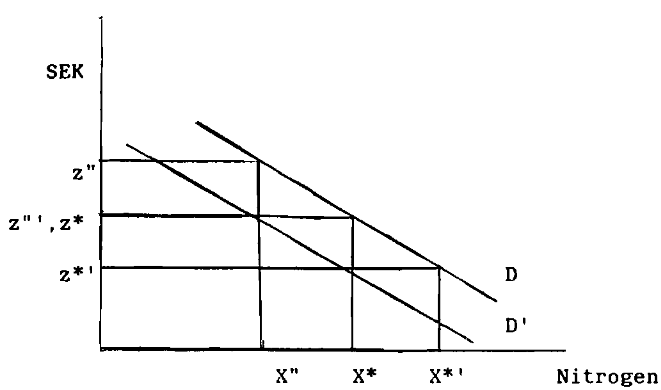
Figure 4.4: The market for permits to use nitrogen



If there were no smuggling, the price of permits would clear the market at X*. The occurrence of smuggling reduces the demand for permits such that the price decreases to z'.

If the shape of the nitrogen demand function is known, then for each level of permits issued, we can calculate the two prices z and z'. The smuggling cost, the fine, the detection rate and the price of nitrogen are given. Hence we can also calculate total demand for nitrogen, including legal and smuggled use, for each level of permits issued. This means that we can find the amount of permits which gives the targeted use of nitrogen. As an illustration let us suppose that the relation between z and z' for different levels of the demand for nitrogen is expressed by the functions D and D' in Figure 4.5.

Figure 4.5: Legal and illegal use of nitrogen for different levels of the supply of permits



The targeted use of nitrogen is X*. If the policy-maker issues permits corresponding to X*, the total use of nitrogen will amount to X*' and the price of permits is z*'. The smuggled quantity is then X*'-X*. Considering the effect of smuggling, the amount of permits corresponding to X" would give the desired use X*. The price of permits would be z"'. Thus, for given values of q,g,a and f, we can derive the total use of nitrogen when we know the shape of the nitrogen demand function.

4.5 Discussion and Summary of the Results

One of the main purposes of this chapter was to model the incentives to violate different policies. These incentives were measured by violation profits, defined as the violation gain less the violation cost. Under a quota system, violation gain is regarded as the increase in the net value of yield due to use of nitrogen in excess of the quotas. Under the charge and permit market systems, the violation gains consist of the payments for charges and permits, respectively, evaded by the farmers. The violation cost consists of a cost for transporting nitrogen from the mainland and the expected fine. Two types of fines are considered: a fixed fine which is the same for all policy instruments and a variable fine which varies with the quantity of smuggled nitrogen. Under a system of variable fines, a fine is paid per unit of smuggled nitrogen. Under a charge and a permit market system, the farmers also have to pay the charge and current price of permits which they tried to evade.

It turns out that, there are no determinate results regarding a comparison of profits from violating the policy instruments. The profits from violating a permit market system can be either the largest or smallest. The reason is that when smuggling occurs, the demand for legal use of nitrogen, i.e., demand for permits is reduced. This means that the price of permits is reduced, which, in turn, affects the violation profits. The upper limit of the price of permits was shown to correspond to a charge under a charge system. When the price of permits equals the charge, profits from violating a permit market are the same as for a charge system.

Whether or not violation profits under a charge are higher than under a quota systems depends on the relation between charge payments and efficiency losses. Under a system of variable fines, the violation profits under the charge and quota systems are also determined by the following offsetting effects. The rations under a quota system are distributed at no extra cost to the farmer, which reduces potential violation gains. On the other hand, the expected marginal violation cost is lower under a quota system, which strengthens the incentives to smuggle. Under a quota system, the farmer only has to pay a fine when he is detected. Under a charge system, he also has to pay the charge or the current price of permits. When fixed fines are used, the expected marginal violation cost is the same for all policy instruments, which implies that the profits from violating of a charge system is higher than for a quota system.

Another purpose of this chapter was to study the effects of changes in different policy parameters on violation profits. The parameters studied are: transport cost, fines, probability of detection, price of nitrogen, charge and price of permits. Violation profits are found to be decreasing in the transport cost, the fine and the price of nitrogen under all policy systems, given that the demand for smuggled nitrogen is decreasing in these parameters. All results regarding effects on violation profits of changes in the detection rate, the charge and the price of permits turned out to be ambiguous.

The third and final purpose of this chapter was to compare the effectiveness of different enforcement measures among the policies and determine whether and, if so, how a target for the use of nitrogen could be reached by adjusting the enforcement measures. The enforcement measures studied are the detection rate and fines. Under a permit market system there is a further possibility of adjusting the amount of permits issued. Effectiveness is defined as the decrease in violation profits due to a change in any of the enforcement measures. It was found that no definite conclusions could be drawn from these comparisons of effectiveness. This is because both violation costs and violation gains react differently to changes in enforcement measures. It was also found that, in practice, by adjusting the fine and the detection rate, a target for the use of nitrogen could be obtained under the charge and permit market systems but not under a quota scheme. Under a permit market system, it also possible to issue the amount of permits corresponding to a targeted use of nitrogen which includes the smuggled quantity. The policymaker then make use of the market-clearing mechanism of the price of permits, which determines the level where smuggling becomes unprofitable.

For given values of the enforcement parameters, potential use of illegal nitrogen is the largest under a charge system. In fact, when calculating the violation profits for a charge scheme we assume that all nitrogen use is illegal. This is also valid for one smuggling option under a permit market system. For quotas, the farmers smuggle only in excess of the quantity.

It is not very realistic to conceive of all nitrogen use as illicit. If this was the case, the enforcement agency would be suspicious and intensify its monitoring activities, thereby increasing the probability of detection. The farmers would in all likelihood foresee such a reaction and, in order to inhibit it, they would engage in strategic behavior where some nitrogen is bought in Gotland or declared. But changes in the detection might not occur in the short run, so that considerable smuggling or false declarations could be expected as long as they are economically beneficial.

There are however other factors not considered in this chapter which probably curb noncompliance. There is general respect for the law and regulation which prohibits violation. Water pollution in Gotland is regarded as an environmental problem of vital concern. A majority of the population is therefore expected to approve of policy devices designed to improve the water quality. The farmers are thus subjected to extra pressure to obey regulations. These factors influence the policy devices in a similar way and certainly contribute to decreasing the enforcement costs for all instruments.

Another factor could further reduce the profits from violating a permit market system. The sellers of permits will lose from a reduction in the permit price and "self policing" might therefore occur. That is, the farmers could start to supervise each other in order to inhibit a decrease in the permit price. Thus, the detection rate would rise, which implies an increase in the violation cost.

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5. ESTIMATION OF NITROGEN DEMAND FUNCTIONS

We have referred to this chapter several times in the preceding text. This was mainly in connection with our finding that the size of the costs of different policy devices depends on the slope of the nitrogen demand function. In order to measure the farmers' total yield losses and violation profits under the charge and permit market systems, we only need to estimate an aggregated nitrogen demand function. But the efficiency losses of a quota system cannot be measured unless we estimate nitrogen demand functions for different groups of farmers. The purpose of this chapter is to carry out these estimations.

The farmers are assumed to make a simultaneous decision regarding the quantity to be produced and the use of production factors. The most simple approach would then be to estimate a profit function from which the nitrogen demand function could be derived by applying duality analysis. However, this approach is not applicable in our case for two reasons. The first is that figures on profits from vegetable production are not available. The second is that, even if data existed, a profit function necessitates an assumption about profit-maximizing behavior. In Chapter 2 we showed there are strong reasons to believe the farmers do not maximize expected profits; they maximize expected utility instead due to risk aversion. We therefore estimate a nitrogen demand function which is assumed to be derived from maximization of expected utility. Some recent studies consider simultaneous decisions on output and factor use. They differ from our study by assuming profit-maximizing behavior.

Five different models which are all linear in parameters are estimated; i) linear, ii) logarithmic, iii) semilog, iv) hyperbolic and v) exponential function. Both variable and fixed production factors are incorporated in the models. Chemical fertilizer and labor are regarded as variable factors. Application of manure nitrogen should also be treated as a variable factor, but owing to the lack of data, we have to regard the supply of manure as a fixed factor of production. Other fixed factors are acreage of land, precipitation and a trend variable. Precipitation is also assumed to capture the effect of stochastic yield conditions on the demand for nitrogen.

The results obtained from the aggregate demand functions are rather similar. The price elasticities of nitrogen vary between .09 and .62 in absolute values for different models. These results are close to those found in the fertilizer demand studies reviewed below (Section 5.1).

When carrying out the estimates, the farmers are divided into six different groups according to their holdings of land. Since individual data are available for only a short period of time, we pool time-series and cross-section data in order to get a sufficient number of observations. There are no data on nitrogen use for different farmers but only on fertilizer use. We therefore have to estimate price elasticities for fertilizer use which includes not only nitrogen but also potassium and phosphorous. The results differ between the models.

The mean value of the price elasticities range between 1.30 and 9.43 in absolute values for different groups of farmers. However, the data are rather poor and so are the estimates. The results must therefore be treated with care.

We begin this chapter, with a brief review of some fertilizer demand studies. Next, we describe the derivations of the functions which are estimated and the statistical methods used. The data are presented in Section 5.3 and the results in Section 5.4.

5.1 A Brief Survey of some Fertilizer Demand Studies

Our approach differs from that of most of the other studies under review. As a consequence, our analysis is not influenced to any large extent by their choice of functional forms and estimation methods. Instead this survey provides a means of choosing explanatory variables and may serve as a reference for comparing our results. Our intention is not to cover the entire field of fertilizer studies, but to focus on some representative studies.

Other studies vary with respect to functional forms, estimation periods and regions. The short run elasticities vary between 0.1 and 1.8 in absolute values. Two studies also estimate long-run elasticities which are higher than the short-run elasticities. Price elasticities of some studies are listed in Table 5.1.

Table 5.1: Fertilizer price elasticities in different studies

	Estimation period and location	Result
Boyle (1982)	1957-78, Ireland	1.0 (nitrogen)
Carman (1979)	1955-76, U.S.	0.3-1.8 (nitrogen)
Griliches (1958)	1911-56, U.S.	Short-run 0.5 Long-run 2.2
Griliches (1959)	1931-56, U.S.	Short-run 0.1-0.8 Long-run 1.3-9.1
Hayami (1964)	1883-1937, Japan	0.6 (nitrogen)
Heady & Yeh (1959)	1910-56, U.S.	0.4 (nitrogen)
Rausser & Moriak (1970)	1949,54,59,64, U.S.	0.7-1.0
Roberts & Heady (1982)	1952-76, U.S.	0.2-1.2 (nitrogen)
Sidhu & Baanante (1979)	1971, India	1.2 (nitrogen)

Most of the models during the late 1950s were rather simple. The demand for fertilizer was expressed as a logarithmic function of the prices of fertilizer and output; see Griliches (1958 and 1959). Such equations were also estimated in the mid-1960s; see Hayami (1964). Long run elasticities were estimated by introducing a lagged dependent variable. Griliches undertook national (1958) as well as regional studies (1959). Price elasticities the different nutrients; i.e., nitrogen, potassium and phosphorous, were estimated in Griliches (1959). Heady & Yeh (1959) also made regional estimates for different nutrients the prices of output, land, yield income and time were added as independent variables. Except for land, all of the added variables turned out to have a positive impact on the use of fertilizer. The trend variable was used in the remaining studies reviewed below.

All of the studies mentioned thus far used time-series data. In the 1970s cross-sectional data were used to estimate e.g. regional demand functions; cf. Rausser & Moriak (1970). Prices of labor and land were added to the fertilizer price. All three variables turned out to be negatively correlated with the use of fertilizer. Cross-sectional data were are also used in another study by Sidhu & Baanante (1979) which differs from the preceding studies in one - for our purpose - important way. Instead of estimating a demand function, they estimated a profit function from which input demand functions were derived. Prices of labor and irrigation together with acreage of arable land, capital and education were used as explanatory variables. Prices of labour and irrigation were shown to be negatively correlated with the use of fertilizer, while the other three exhibited a positive relation.

Carman (1979) estimated regional price elasticities for different nutrients: nitrogen, potassium and phosphorous. In addition to the price of fertilizer, price of land and income from yield were used as explanatory variables. He found that the price of land is negatively related, and income is positively related to use of fertilizer.

Most of the above-mentioned studies assumed that the production function can be represented by a Cobb-Douglas production function. This assumption were abandoned in a study where fertilizer demand was derived from an estimated translog cost function; see Boyle (1982). Price elasticities for different nutrients were derived. Boyle used prices of different nutrients as independent variables. Roberts & Heady (1982) estimated linear fertilizer demand functions for different crops, where the explanatory variables were prices of output and nutrients. The own-price elasticities were negative and the output price and time coefficients were positive.

One results, common to the studies surveyed here, is that the price of output, time and income from yield all have a positive impact on the use of fertilizer. Furthermore, the price of labor is negatively correlated and acreage of land shows both a positive and a negative relation to the use of fertilizer. We present similar results in Section 5.4.

5.2 Derivation of the Estimated Functions and Statistical Methods

As indicated in the above survey, not only the price of fertilizer, but also land, labour and time have significant influence on the use of fertilizer. These variables are therefore included in our regression equations. But we also want to examine the relationship between the use of chemical fertilizer and manure. Thus manure is added as an explanatory variable. Furthermore, as discussed in Chapter 2, the stochastic aspects of yield might affect the use of fertilizer. Since precipitation is such an important factor, it is added as an exogenous variable. Irrigation, which makes the farmers less sensitive to random weather conditions, has been used only to a minor extent during the time period under study.

Owing to insufficient data, the choice of variables is limited for the functions which are estimated for each group. We also have to pool cross-section and time-series data in order to increase the number of observations. But the derivation of the demand functions is the same for both the aggregated and group-specific estimations. After describing this derivation, we show how the group-specific functions differ from the aggregate functions.

5.2.1 Aggregate Nitrogen Demand Functions

A common approach in studies where factor demand is estimated involves applying duality analysis on an estimated profit function; see e.g., Lau & Yotopoulos (1972). This approach could also be applied to a cost function; see e.g., Boyle (1982). Even though the cost function approach would not be any more complicated, we have not chosen it here because output would then be regarded as an exogenous variable. In most countries, prices of agricultural output are determined by negotiations. Farmers can then sell their entire yield at these prices. We therefore assume that the farmers make simultaneous decisions regarding factor use and output. Output is then an endogenous variable which is taken into consideration by the profit function approach.

As discussed in Chapter 2, farmers are assumed to maximize expected utility of profits. The production function contains variable and fixed factors of production, V_i and F_i respectively. A variable factor is defined as a factor where the use of which can be adjusted during the period in question. A fixed factor is given and cannot be adjusted. A weather variable, precipitation, is introduced to measure the effects of weather changes, R. Given a production function, $Q=f(V_i,F_i,R)$, and prices of output and different inputs, p, v_i and f_i, the farmer maximizes expected utility according to 5.1

$$(5.1) \quad \max_{V_i} \quad E[U(pQ(V_i,F_i,R) - v_iV_i - f_iF_i]$$

where p: output price
v_i: price of variable factors
f_i: price of fixed factors
R; precipitation

Solving (5.1) we get the factor uses, V_i*, which maximize expected utility, E[U(π*)]. These factor demands are directly derived from E[U(π*)] by means of Hotellings lemma; see Pope (1982). This gives

$$(5.2) \quad \delta E[U(\pi^*)]/\delta v_i = -V_i$$

Nitrogen and labor are taken to be variable production factors. The supply of arable land and manure are regarded as fixed factors. Using (5.2) the optimal nitrogen demand, X, can then be expressed as a function of the price of nitrogen g, wage w, acreage of arable land L, manure M, and precipitation; see Lau (1979):

$$(5.3) \quad X = X(g, w, L, M, R,)$$

Equation 5.3 is not quite consistent with the utility maximizing model in Chapter 2, where it was shown that the costs of applying or storing manure affect the demand for chemical nitrogen. Unfortunately, we could not find any measures of these costs. Instead, the supply of manure is used as an explanatory variable. The size of livestock holdings is used to measure this variable. We could therefore also expect the variable for manure to capture some effects of changes in the capital stock. A measure of a variable for capital could not possible be found.

Five common factor demand models, all linear in parameters, are estimated; see e.g., Lau (1978). The models are i) linear, ii) logarithmic, iii) exponential, iv) semilog and v) hyperbolic. They are specified according to equations 5.4-5.8, where a trend variable T, is introduced

(5.4) $$X_t = \alpha_1 + \alpha_2 g_t + \alpha_3 w_t + \alpha_4 L_t + \alpha_5 M_t + \alpha_6 R_t + T + \varepsilon_t$$

(5.5) $$\ln X_t = \beta_1 + \beta_2 \ln g_t + \beta_3 \ln w_t + \beta_4 \ln L_t + \beta_5 \ln M_t + \beta_6 \ln R_t + T + \varepsilon_t$$

(5.6) $$\ln X_t = \gamma_1 + \gamma_2 g_t + \gamma_3 w_t + \gamma_4 L_t + \gamma_5 M_t + \gamma_6 R_t + T + \varepsilon_t$$

(5.7) $$X_t = \lambda_1 + \lambda_{2\ln} g_t + \lambda_3 \ln w_t + \lambda_4 \ln L_t + \lambda_5 \ln M_t + \lambda_6 \ln R_t + T + \varepsilon_t$$

(5.8) $$X_t = \nu_1 + \nu_2/g_t + \nu_3/w_t + \nu_4/L_t + \nu_5/M_t + \nu_6/R_t + T + \varepsilon_t$$

Note that the first two equations are derived from a quadratic and a Cobb-Douglas production function, given that the farmer maximizes expected profits; see Pope (1982). The nitrogen price elasticities are calculated as $(\delta X/\delta g)(g/X) \equiv \eta_g$ which, when applied to 5.4-5.8, yields

(5.9) $$\eta_{g1} = \alpha_2(g/X)$$

(5.10) $$\eta_{g2} = \beta_2$$

(5.11) $\eta_{g3} = \gamma_2 g$

(5.12) $\eta_{g4} = \lambda_2/X$

(5.13) $\eta_{g5} = -\nu_2/gX$

It is assumed that ε_t is normally distributed with $E(\varepsilon_t)=0$, $e(\varepsilon_t^2)=\sigma^2$ and $E(\varepsilon_t\varepsilon_j)=0$ $(t\neq j)$. However, as mentioned above, an accurate measure of the variable for manure is not available. This variable is probably concurrently correlated with the disturbance term, that is, $Cov(M_t,\varepsilon_t)\neq 0$. This means that neither the least squares estimator nor the maximum likelihood estimator gives consistent estimates of the parameters; cf. Johnston (1963). Moreover the maximum likelihood method would not be a good estimator because of its ambiguous small-sample properties. One procedure known to give consistent estimates of models with errors in variables for small samples is the method of instrumental variables. This method is applicable when a new variable can be found which is highly correlated with the explanatory variable and uncorrelated with the disturbance term. Such a variable in our case is the variable for manure lagged one period. Thus, equations 5.4-5.8 may be estimated by the method of instrumental variables using the lagged variable for manure as an instrumental variable.

Given that equations 5.4-5.8 are derived from maximization of expected utility, what sign would the coefficients be expected to have? The impact of the price of nitrogen is supposed to be negative. Labor can be either a complement or a substitute to chemical fertilizer and the wage coefficient will then be negative or positive.

We cannot expect any significant correlation between chemical fertilizer and application of manure if manure is regarded as a disposal problem. But if there is substitutability between the two factors, the sign is negative. The impact of manure on use of nitrogen can also be positive if, as noted in the preceding section, the variable for manure contains some influence of a variable for capital. Due to investment in vegetable production, higher yields can be stored, dried etc., which in turn increases the demand for nitrogen. The acreage of arable land is expected to be positively related to use of nitrogen since more land needs more fertilizer.

It is more difficult to guess what effect the rain variable could have on the use of nitrogen. If its effect is random the coefficient should not be significantly different from zero. But according to Chapter 2, we know that some fertilizer is applied in the autumn. After a dry spring/summer the farmer could compensate for low yields by increasing fertilization in the autumn. The rain coefficient should then be negative.

5.2.2 Fertilizer Demand Functions for Different Groups of Farmers

The same approach as in Section 5.2.1 is used to estimate the group-specific demand functions. That is, the demand functions are assumed to be derived from maximization of expected utility. But the group-specific estimates differ from the aggregated estimates in three respects due to insufficient data. First, we estimate the demand for fertilizer which includes not only nitrogen but also potassium and phosphorous. Second, the data is measured in values per farmer and not in total values as for the aggregate demand functions. Third, cross-section and time-series data are pooled in order to increase the number of observations.

Data on individual farmers are available for eight years. The sample was however changed every fourth year which implies that observations regarding the same farmer extend to, at most, four years. A covariance model is therefore used which characterizes each cross-sectional unit and time period by a binary variable. A random effect model is also estimated which assumes that all differences between farmers and time periods are captured by the disturbance term.

Different models which are linear in parameters are estimated for both the covariance and random effect models. The farmers are divided into six groups according to their holdings of land. This means that six equations are estimated for each model. The explanatory variables are the price of nitrogen g, wage rate w, holdings of arable land L_i, manure M_i, and precipitation R. The regression equation (5.14) is thus estimated for each group of farmers and for each model

$$(5.14) \qquad X_{it} = f(g_t, w_t, L_{it}, M_{it}, R_t, Z_{it}, Y_{it}, \varepsilon_{it})$$

where Z_{it} = 1 for the i'th farmer (i=2,...,N)
= 0 otherwise
Y_{it} = 1 for the t'th time period (t=2,...,K)
= 0 otherwise

Equation 5.14 contains 6+(N-1)+(k-1) regression coefficients to be estimated from NK observations. In the random effect model, the Z_{it} and

Y_{it} terms are excluded. Then only six regression coefficients are estimated from NK observations.

The disturbance ε_{it} is taken to satisfy the assumptions of the classical normal linear regression model. However, the problem of simultaneous error remains the same as in the aggregate models. As mentioned in the preceding section, the method of instrumental variables gives consistent estimates of the parameters in this case. But we will probably not obtain efficient estimates using this method because of correlated disturbances between the six equations. Such correlation could be caused by weather effects which are not captured by the rain variable. An approach to the problem of seemingly unrelated regression equations is to use the maximum likelihood method which is asymptotic efficient; see Kmenta (1971). But this estimator does not give consistent estimates of the parameters of models with errors in variables and is not appropriate for small samples. We nevertheless use both estimators: the maximum likelihood method where the six equations are estimated jointly and the method of instrumental variables applied to each equation separately.

5.3 Description of the Data

Before presenting the regression results, it is interesting to see what the "pure" data tell us. Do the scattered observations show a negative relationship between the price and use of nitrogen? In this section we find that they actually do show such a relationship. But since our interpretations of both visual and econometric estimations depend on how the variables are measured, we also describe how they are calculated. As mentioned earlier in this chapter, aggregated and group-specific estimations are based on different sample populations and are therefore described in separate sections. Several statistical sources are used many times. References to these sources are indicated by a number in parentheses and listed at the end of this chapter.

5.3.1 Aggregated Data.

The variable factors included in the aggregated production function are chemical fertilizer and labor; the fixed factors are manure, precipitation, land and technology. The last variable is measured as a time variable. Time-series data are used and the estimation period is 1948-84. In the following we describe how the measurements are calculated.

Chemical fertilizer: Regional figures on use of nitrogen are available from 1963 (2,4,8 and 11). The only figures we have for the preceding period refer to total chemical fertilizers (1). The proportion of nitrogen during this period is assumed to be constant and correspond to the average of 1963-84.

Manure: The nitrogen content of manure from pigs, cattle and poultry has been summarized. The content per ton manure is assumed constant for the whole period under study. The following values of nitrogen per ton fluid of manure and year were used; cows 28 kg, pigs 5.5 kg and poultry 0.042 kg (5).

Yield: A measure of yield is constructed by weighting yields of wheat, sugar beets, hay, potatoes, rye, oats and grain. As weights we use constant output prices which are calculated as the average prices of each crop for the estimation period. The total yield of the crops included amounts to 80 % of total vegetable production (4).

Labour: We have regional figures on the employment in the agricultural sector from 1967 (4). The agricultural labor force in Gotland for the preceding period is assumed to follow the changes in national agricultural employment. The proportion employed in vegetable production is assumed to be one third (6).

Land: Figures on the acreage of arable land in Gotland are available for the entire estimation period (4).

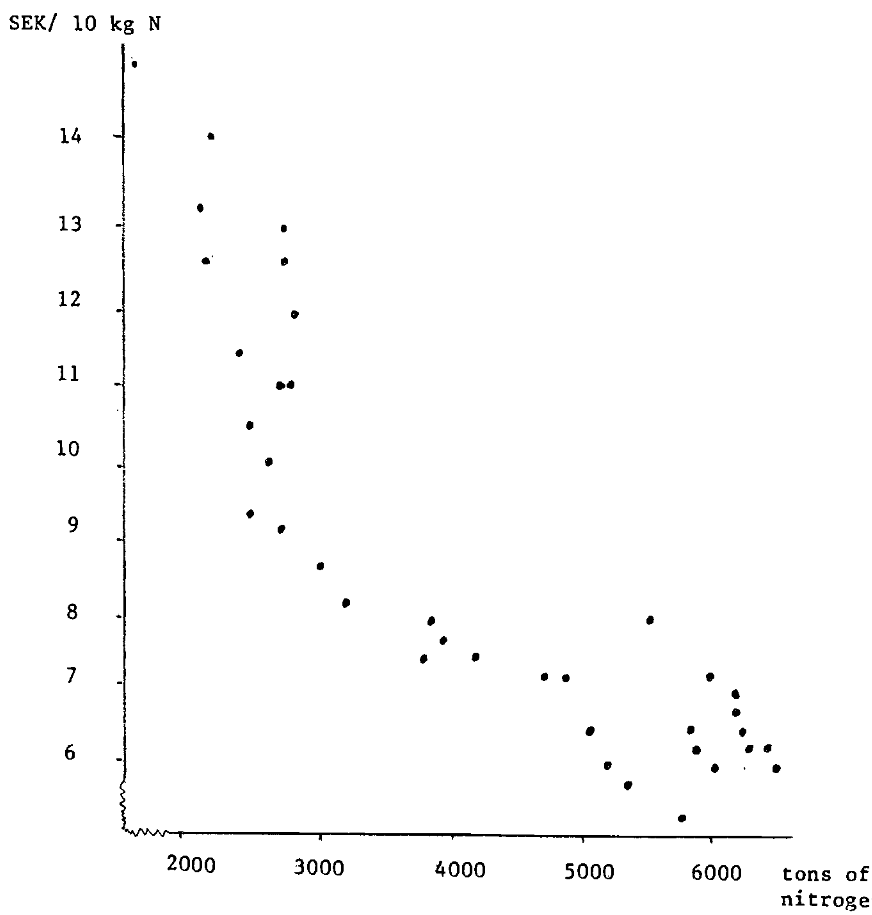
Rain: Yearly precipitation gauged at four stations in different parts of Gotland (9).

Nitrogen price, wage, output price, producer price index and consumer price index: National measures are used for all these variables (7). In order to obtain real values, the price of nitrogen and the wage are deflated by an agricultural producer price index and output price is divided by the consumer price index.

One important production factor is missing, i.e., capital. But it was not even possible to find national data on agricultural investment less depreciation. However, the measurement of the variable for manure is based on the size of livestock holdings which may be regarded as part of the capital stock. It is therefore probable that the variable for manure also captures the influence of a capital variable to some extent.

As a first guess about the relationship between real price of nitrogen and use of nitrogen, we plot these variables in Figure 5.1.

Figure 5.1: Use and real price of chemical nitrogen, 1948-84.



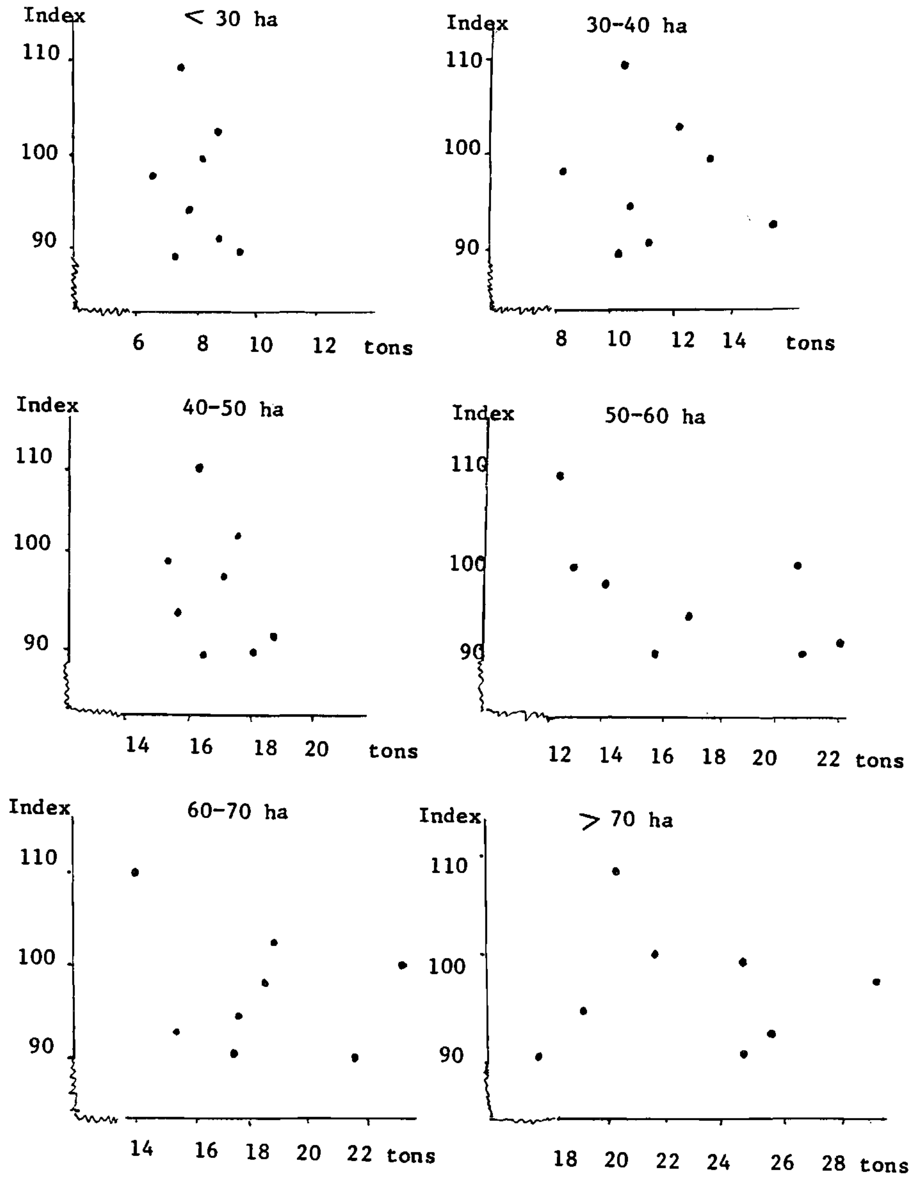
The observations in figure 5.1 show a strong negative relationship between use of nitrogen and price. We thus expect the nitrogen price coefficient to have a negative sign.

5.3.2 Group-Specific Data

An annual inquiry into the economic conditions of farmers on the island of Gotland was undertaken for the period 1976-1983 (10). A sample of farmers are given a questionnaire to answer. (It should be noted that this is a random not a stratified sample.) These questionnaires were used to obtain data on the use of fertilizer, working hours in vegetable production, acreage of arable land and livestock holdings. Use of fertilizer, which includes all nutrients, is measured as expenses for chemical fertilizer. In order to determine quantities, we divided expenses by the nominal price of fertilizer. The price of fertilizer is a weighted index of the prices of nitrogen, potassium and phosphorous (7). The measurements of the other price variables are the same as in the preceding section.

The yearly samples of about 50 farmers are divided into six groups according to their acreage of land. The average use of fertilizer per farmer and the real price of nitrogen for all six groups are plotted in Figures 5.2-5.7. The vertical axis denotes an index of the price of nitrogen and the horizontal axis expenses for fertilizer in thousands of SEK.

Figures 5.2-7; Price of nitrogen and use of fertilizer for different groups of farmers.



There is a weak negative relation between the use and price of fertilizer for all groups. One difference between the groups is that the observations are more concentrated for the first three groups. It also seems as if the use of fertilizer for these groups is less sensitive to price changes. This could be explained by the fact that small farms rely on livestock production to a greater extent. On the other hand, large farms have relatively more vegetable production and might therefore be more sensitive to changes in the price of nitrogen; see Mattsson (1986). However, the mean values in the figures are based on a different number of observations. This in turn affects the variances. We therefore show the means and variances for all groups in Appendix A:2.

The number of observations also differs between years for each group. The smallest number of observations in one year was four for all groups. When estimating the regression equations, we therefore have four cross-sectional units for each group. When cross-section and time-series data are pooled, there is a total of 32 observations in each group.

5.4 Results

The results from all five aggregate nitrogen demand equations are similar. The signs of the coefficients are robust with respect to the choice of model. The nitrogen-price elasticities are all negative and vary between 0.09 and 0.62 in absolute values. The wage coefficients are positive, implying that labor is a substitute for nitrogen. Both the rain and manure coefficients are negative. However, the rain coefficient is never significant. On the other hand, the manure coefficient is significant in most equations, which can be interpreted to imply that manure is a substitute for chemical nitrogen. The land coefficient shows a positive sign, as expected.

Unfortunately, the results from the equations for different groups of farmers are not as robust. The covariance model fails to give us the expected negative sign for the nitrogen-price coefficient for all groups. The random effect model is more successful in this respect and gives expected signs for different model specifications. The final nitrogen-price elasticity is calculated for each group as the mean of the price elasticities of the different model specifications. The mean price elasticities vary between -1.30 and -9.43 for different groups of farmers.

5.4.1 Aggregated Nitrogen Demand Functions

As mentioned in Section 5.2, the method of instrumental variables is used to estimate the aggregate nitrogen demand functions. The lagged manure variable is used as an instrumental variable. In Table 5.2 the results are presented as elasticities, which are evaluated at the mean value of each variable, respectively. The underlying estimated regression equations are given in the Appendix. The figures in parentheses in Table 5.2 are t-statistics; they are denoted by an asterisk when the coefficients are significant at the 90 percent level.

Table 5.2: Estimated elasticities of the aggregated nitrogen demand functions

	g	w	R	L	M	T	R^2
Linear	-.43 (2.17)*	.06 (.20)	-.13 (1.24)	1.16 (.87)	-1.20 (1.54)	.86 (1.65)*	.97
Logarithmic	-.60 (3.45)*	.21 (2.14)*	-.09 (.95)	1.32 (1.02)	-.88 (4.34)*	.33 (4.24)*	.97
Exponential	-.62 (4.01)*	.16 (1.76)*	-.12 (1.25)	.55 (.46)	-.81 (3.23)*	1.30 (4.83)*	.97
Semilog	-.09 (.52)	.47 (3.56)*	-.06 (.79)	1.77 (1.61)	-.81 (4.66)*	.02 (4.30)*	.97
Hyperbolic	-.32 (1.88)*	.11 (2.04)*	-.08 (.91)	1.06 (2.83)*	-1.08 (5.90)*	.71 (7.80)*	.96

Not only the price coefficients, but also all the other coefficients, show the same signs for all equations. Thus, the impact of manure on the use of chemical nitrogen is found to be negative. This can be interpreted to imply that manure is a substitute for chemical nitrogen, in which case its marginal product should be positive. But it could also be the case that vegetable production decreases when the size of the livestock holdings increases. Then the marginal product of manure can be zero. The effects of the rain and wage variables are negative and positive, respectively. The negative rain coefficient is expected. The positive wage coefficient can imply that labor is a substitute for chemical nitrogen. When the wage is raised labour demand decreases and use of nitrogen increases. The coefficients of land and time are, as expected, positive in all equations.

While the sign of the nitrogen-price coefficients are robust with respect to different specifications of the model, the levels of the coefficients are not robust. The price elasticities vary between 0.09

and 0.62 in absolute values. If we consider only the significant results, the variation is smaller. The price elasticities then range between 0.32 and 0.62. Later on, the mean value of these significant elasticities is used, which gives a value of 0.50; cf. Chapter 6.

5.4.2 Fertilizer Demand Functions for Different Groups of Farmers.

Recall from Section 5.2 that we intend to apply two estimators, the methods of maximum likelihood and instrumental variables, to two models which treat cross-section units and time periods in different ways. Five different equations are estimated for each model, using the same specification as in the aggregated demand function. This means that 20 regression equations are estimated for each group of farmers.

One important criterion for an acceptable result is that the nitrogen-price coefficients are negative for all groups. A general result, however, is that the covariance model, i.e., where each cross-sectional unit and time period is characterized by a binary variable, does not give negative price coefficients regardless of which estimator is used. The random effect model is more successful in this respect. But not for all of the models. The maximum likelihood method gives expected signs for two equations: the logarithmic and the semilog function. The semilog function also shows negative price coefficients when the method of instrumental variable is used. In addition, this method gives acceptable results for the hyperbolic and exponential functions.

Thus, we obtain negative signs from five different equations, which are all presented in the Appendix. The final price elasticities for each group of farmers is calculated as the mean of the price elasticities from these five equations. the mean price elasticities for all six groups of farmers are shown in Table 5.3.

Table 5.3: Mean nitrogen-price elasticities for different groups of farmers

Hectares of arable land	>30	30-40	40-50	50-60	60-70	>70
Nitrogen-price elasticity	-1.75	-6.96	-3.05	-3.60	-1.30	-9.43

There is no perceptible pattern in Table 5.3, such as a positive relationship between farm size and price elasticity in absolute values as was expected according to Section 5.3. However, as shown in the Appendix, the coefficients are very seldom significant. The results in Table 5.3 must therefore be treated with caution.

5.5 Summary and Conclusions

The main purpose of this chapter has been to estimate an aggregated nitrogen demand function. Our estimation approach differs from that of most other fertilizer demand studies in that we estimate a nitrogen demand function which is assumed to be derived from maximization of expected utility. The reason why we did not chose a more simple approach, such as estimating a profit function and applying dual analysis, is that we believe that the farmers maximize expected utility and not expected profits. The same approach is applied when fulfilling a second aim of this chapter, i.e., estimation of fertilizer price elasticities for six different groups of farmers according to their holdings of land.

Five different aggregated nitrogen demand functions were estimated: i) linear, ii) logarithmic, iii) semilog, iv) hyperbolic and v) exponential function. We considered both variable and fixed factors of production. Chemical nitrogen and labor were regarded as variable. The fixed factors were manure nitrogen, precipitation and land. Due to measurement errors in the manure variable, we used the instruments variable method to estimate all equations.

When carrying out the group-specific estimations, we pooled cross-section and time-series data in order to get a sufficient number of observations. Two estimators were used; the method of maximum likelihood estimates was applied jointly to the equations for all groups of farmers and the instrumental variable method was applied separately to each equation. We then tested a covariance model and a random effect model which treat the cross-sectional units and the time periods in different ways. Due to lack of data, we could not estimate the demands for nitrogen but only for fertilizer, which also includes potassium and phosphorous.

The results of the estimations of the aggregated nitrogen price elasticities vary between 0.09 and 0.62 in absolute values. The values come close to those found in other fertilizer demand studies, which is a reason for regarding them as credible. Other - perhaps more convincing - reasons are that they are statistically significant and they correspond to the conclusions drawn from "eye statistics".

The covariance model did not give the expected signs for the nitrogen-price elasticities for all groups of farmers. Five regression equations gave negative signs from the random effect model. The final price elasticity for each group of farmers was calculated as the mean of the elasticities from these five equations. The mean price elasticities range between -1.30 and -9.43.

APPENDIX

A:1 Regression Equations

Table 1: Aggregated demand functions

	Constant	Nitrogen price	Wage	Manure	Land	Rain	Time
Linear	2704	-1563	676	-.64	.06	-.98	187
Hyperbolic	263	1452	-161	$351x10^5$	$363x10^6$	179006	155
Exponential	8.38	-.55	.43	.0010	.000007	-.00022	-.036
Semilog	-50840	-396	1962	-3335	7336	-263	97

Tables 2-6: Demand functions for different groups of farmers.

(Figures in parentheses are t-values.)

Table 2: Hyperbolic function, instrumental variable

	Constant	Nitrogen price	Wage	Manure	Land	Rain	R^2
< 30 ha	1446	15989	5334	-3889	-239229	-3232430	.14
	(.50)	(.56)	(.32)	(.07)	(1.66)	(.60)	
30-40 ha	-242127	891754	94696	-280507	-588396	2087414	.33
	(.62)	(.57)	(.89)	(.08)	(1.06)	(.27)	
40-50 ha	-199415	566292	89941	-4179943	289099	-1925551	.40
	(.48)	(.34)	(.77)	(1.87)	(.28)	(.19)	
50-60 ha	-345285	1643171	175111	-86856	-5499300	17470000	.20
	(.57)	(.64)	(.93)	(1.21)	(1.60)	(1.40)	
60-70 ha	-91667	9760	30949	190910	3471472	6330816	.30
	(.79)	(.14)	(.83)	(.77)	(1.42)	(.54)	
> 70 ha	-1051134	3810759	388865	62	-3729038	-6715205	.10
	(.73)	(.65)	(.76)	(.01)	(1.38)	(.27)	

Table 3: Exponential functions, instrumental variable

	Constant	Nitrogen price	Wage	Rain	Land	Manure	R^2
< 30 ha	9.1	-1.00	-.52	-.0001	.048	.000034	.12
	(1.42)	(.08)	(.08)	(.04)	(.89)	(.10)	
30-40 ha	20.1	-.72	-8.06	-.14	-.025	-.00023	.19
	(.49)	(.20)	(.31)	(.59)	(.54)	(.76)	
40-50 ha	13.7	-.032	-3.63	-.00051	-.0094	-.00015	.32
	(4.36)	(.23)	(.14)	(.42)	(.46)	(1.86)	
50-60 ha	44.0	-3.22	-29.9	.0034	.10	.00023	.10
	(.55)	(.44)	(.52)	(.72)	(.77)	(.56)	
60-70 ha	26.0	-1.12	-10.9	-.00028	-.01	-.00007	.19
	(.50)	(.24)	(.34)	(.12)	(.25)	(.77)	
> 70 ha	16.3	2.0	-8.5	.00021	.011	.000048	.31
	(.29)	(.10)	(.24)	(.77)	(1.26)	(.21)	

Table 4: Semilog functions, instrumental variable

	Constant	Nitrogen price	Wage	Rain	Land	Manure	R^2
< 30 ha	-60772	-12696	-7382	5705	9605	72	.44
	(.86)	(.51)	(.29)	(.54)	(1.53)	(.10)	
30-40 ha	208998	-153901	-157953	-3198	14958	1023	.33
	(.52)	(.59)	(.89)	(.22)	(.88)	(.19)	
40-50 ha	230659	-106832	-147960	1118	-8746	4613	.36
	(.48)	(.84)	(.67)	(.07)	(.37)	(1.81)	
50-60 ha	-166030	-35165	-349751	38248	118139	1514	.10
	(.30)	(.62)	(.81)	(1.19)	(1.32)	(.88)	
60-70 ha	280751	-30080	-20131	-14729	-51884	-1225	.30
	(.40)	(.10)	(.10)	(.58)	(.96)	(.78)	
> 70 ha	510145	-214496	-206445	426	-36508	798	.40
	(.89)	(.55)	(.74)	(.02)	(3.26)	(.73)	

Table 5: Logarithmic functions, maximum likelihood

	Constant	Nitrogen price	Wage	Rain	Land	Manure
< 30 ha	3.16	-2.13	-1.68	.32	3.13	-.07
	(.34)	(.66)	(.51)	(.24)	(5.05)	(.89)
30-40 ha	5.06	-8.39	-1.51	-1.01	3.46	-.30
	(.49)	(1.30)	(.41)	(.70)	(2.38)	(.90)
40-50 ha	20.4	-3.30	-4.83	-.07	-1.23	-.10
	(3.37)	(1.18)	(2.28)	(.14)	(1.84)	(1.50)
50-60 ha	.19	-.02	-2.88	.61	1.21	.02
	(.02)	(.10)	(1.57)	(.86)	(1.05)	(.67)
60-70 ha	10.3	-1.44	-2.6	-.22	.93	-.13
	(1.48)	(.46)	(1.09)	(.39)	(1.16)	(4.36)
> 70 ha	17.9	-5.86	9.00	.27	-.44	-.04
	(1.43)	(.92)	(1.88)	(.24)	(.83)	(1.03)

Table 6: Semilog functions, maximum likelihood

	Constant	Nitrogen	Wage	Rain	Land	Manure
< 30 ha	-92714	-15942	-12155	7274	16565	-218
	(1.43)	(.71)	(.54)	(.81)	(3.25)	(.32)
30-40 ha	24288	-107116	-131837	-3514	50832	1793
	(.16)	(1.39)	(2.30)	(.26)	(3.95)	(.52)
40-50 ha	233961	-69550	-119981	703	-26996	-3319
	(1.51)	(.98)	(2.23)	(.55)	(1.50)	(1.87)
50-60 ha	449922	-14515	-98291	25051	74599	1440
	(2.00)	(.17)	(1.39)	(1.53)	(2.07)	(1.38)
60-70 ha	109671	-49549	-72431	-6153	8021	-4059
	(.51)	(.42)	(1.00)	(.35)	(.30)	(4.04)
> 70 ha	319473	-296572	390516	6782	16254	2510
	(.74)	(1.35)	(2.35)	(.17)	(.75)	(1.36)

A2: Use of Fertilizer for Different Groups of Farmers;
Means and Variances SEK, 1976-1983

	Group 1 < 30 ha	Group 2 30-40 ha	Group 3 40-50 ha	Group 4 50-60 ha	Group 5 60-70 ha	Group 6 > 70 ha
1976	8661	13656	15087	20521	23116	24943
	(5295)	(5785)	(8258)	(10012)	(11642)	(14745)
1977	8767	15342	18823	22060	15754	25789
	(5001)	(10075)	(13272)	(10512)	(8937)	(15915)
1978	9447	11346	18314	20722	17618	24992
	(5773)	(6846)	(10207)	(12842)	(11283)	(13642)
1979	7020	10404	16582	15885	21574	17481
	(4228)	(5964)	(7819)	(7759)	(12581)	(11050)
1980	7751	10901	15846	16889	17783	19214
	(5628)	(6294)	(10743)	(11648)	(10529)	(12802)
1981	6575	8533	17014	14185	18640	29066
	(4380)	(5887)	(9746)	(7420)	(11952)	(18652)
1982	8757	12498	17331	12978	18796	26926
	(4482)	(8874)	(8314)	(8587)	(10004)	(18849)
1983	7412	10415	16204	12373	14074	20763
	(5970)	(5568)	(6485)	(7919)	(8518)	(15433)

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6. EMPIRICAL ESTIMATES OF SOCIAL VALUE OF YIELD LOSSES, INCOME DISTRIBUTION EFFECTS AND VIOLATION PROFITS

The results obtained from estimating price elasticities in the preceding chapter constitute the point of departure for this chapter. We use the mean value of the significant results, which is 0.5 in absolute value. It should be recalled from Chapter 1 that the leakage of nitrogen can be as much as twice as high from manure as from fertilizer. This is accounted for here through two estimates of the social value of yield losses, income distribution effects and violation profits for each policy instrument.

We cannot carry out any calculations until cost efficient reductions in the use of fertilizer and manure have been determined. The cost efficient allocation occurs when the marginal reduction costs are equal. It turns out that when the leakage of nitrogen from fertilizer and manure are assumed to be the same, a reduction is not cost efficient. The use of fertilizer must then be decreased by 87 percent in order to obtain the desired total reduction in nitrogen which, as shown in Chapter 1, amounts to 60 percent. However, when the nitrogen leakage from manure applied in the autumn time is assumed to be twice as high as from fertilizer, regulation on the application of manure become cost efficient. Applications of fertilizer and manure are then reduced by 55 and 35 percent respectively.

The empirical results show that the social value of yield losses from a charge and permit market are always lower than from a quota system. This outcome is in accordance with the analytical results in Chapter 3. The social value of yield losses from a quota system can be up to 50 percent higher. The income distribution effects, defined as the farmers' costs of reducing the use of nitrogen, are lowest for a permit market in all cases. This result was expected from the analysis in Chapter 3 where it was also shown that whether or not the income effects of a charge system exceed those of a quota system depends on the relation between the increase in the cost of due to a charge system and the efficiency losses from a quota system. It turns out that the income effects of a charge system are higher when the reduction in the use of fertilizer is 55 percent. When the use of fertilizer is decreased by 87 percent, the income distribution effects of a quota system exceed those of a charge system by, at the most, 30 percent.

As shown in Chapter 4, the values of what we call violation profits are related to the income distribution effects. The results of the empirical calculations of violation profits in this chapter are therefore similar to the results for income distribution effects. That is, the violation profits from a permit market are always the lowest when the farmers smuggle nitrogen in excess of their initial permits. They are higher for charges than for quotas when we have the lower reduction of fertilizer and we get the opposite result for the higher reduction of fertilizer.

We begin this chapter by determining the cost efficient allocation of reductions in the use of manure and fertilizer. The results of calculations of the social value of yield losses and income distribution effects are given in Section 6.2. Next, violation profits are estimated in Section 6.3. The main results of this chapter are summarized in a concluding section.

6.1 Cost Efficient Reductions in Fertilizer and Manure

Reductions in the application of fertilizer and manure are determined on the basis of the marginal costs. The marginal cost of reducing the use of fertilizer is defined as the marginal value of fertilizer minus the price; cf. Chapter 2. The marginal cost of a reduction in the application of manure is assumed to be the disposal cost less the application cost. However, it has not been possible to find any measure of the application cost. On the other hand, one of the main purposes of many studies has been to calculate the costs of reducing the application and leakage of manure. Such results are used to find measures of disposal costs in this chapter.

The marginal value of fertilizer is determined by the slope of the demand function, as shown in Chapter 3. According to the demand functions estimated in Chapter 5, the mean value of the nitrogen price elasticity turned out to be 0.5 in absolute value. If all of the necessary decrease in the use of nitrogen, 5100 tons, had to consist of fertilizer it would have to be reduced by 87 percent. Thus, the price of fertilizer would have to increase by 174 percent in order to obtain this decrease. In 1985, the price of nitrogen was SEK 6. The marginal value of fertilizer when use of nitrogen is curtailed by 87 percent would thus amount to SEK 16.44. The marginal reduction cost would then be SEK 10.44/kg N.

In order to determine the optimal allocation of reductions in the use of fertilizer and manure, the marginal reduction cost of fertilizer, SEK 10.44, may be compared with the marginal reduction cost of manure. The marginal costs of different measures for reducing the application and leakage of manure are given in Table 6.1. The leakage of manure and fertilizer are assumed to be the same, i.e., 25 percent of applied nitrogen; cf. Chapter 1. The calculations are described in the Appendix.

Table 6.1: Marginal costs of and maximum reductions in nitrogen under different measures; leakage is 25 % of applied nitrogen

	Marginal cost SEK/kg N	Maximum reduction tons of N
Reduced holdings of livestock:		
Pigs	15	253
Chickens	28	283
Drying of manure:		
Chickens	40	283
Cattle	75	1902
Change in spreading time:		
Pigs	12	127
Chickens	14	142
Cattle	53	951
Cover crops	11	950
Grassland	26	650
Energy forestry	20	960

According to Table 6.1, the marginal cost of reducing the application of manure varies between SEK 11 and SEK 75/kg N. Note that all of the marginal costs in the table are constant. This is a strong simplification since, in practice, increasing marginal costs are most probable. It has not been possible to find any measures of such cost functions, however.

When we compare the lowest marginal cost of reducing the application of manure, SEK 11, with the marginal cost of reducing fertilizer, SEK 10.44, it is obviously not cost efficient to include any regulations on manure. But when the fact that the nitrogen leakage from manure applied in autumn could be twice as high as the leakage from fertilizer is taken into account, some measures become cost efficient. The marginal costs and maximum reductions in the leakage of manure when the leakage is 50 percent of applied nitrogen are given in Table 6.2.

Table 6.2: Marginal costs of and maximum reductions in applied manure; nitrogen leakage is 50 %.

	Marginal cost SEK/kg N	Maximum reduction tons of N
Reduced holdings of livestock:		
Pigs	15	127
	7.5	254
Chicken	28	142
	14	284
Drying of manure:		
Chicken	40	127
	20	254
Cattle	75	951
	38	1902
Change of spreading time:		
Pigs	12	63
	6	126
Chicken	14	71
	7	142
Cattle	53	476
	26	952
Cower crops	5.5	1900
Grass land	13	1300
Energy forestry	10	1920

According to the table all marginal costs of measures for reducing application in the autumn application are reduced by the half. The following measures then become cost efficient: reduced holdings of pigs, change in spreading time for pig and chicken manure, cover crops and energy forestry. It should be recalled from Chapter 1 that we regard these measures as mutually exclusive. Thus, only one measure can be applied. Cultivation of cover crops may then be chosen since its marginal cost is the lowest. The leakage of nitrogen is then reduced by 1900 tons, which implies that the use of fertilizer has to decrease by

3200 tons. The social value of yield losses, income effects and violation profits with respect to each policy instrument may then be calculated for two reductions in the use of fertilizer, 87 and 55 percent, depending on what is assumed about the leakage of manure.

6.2 Social Value of Yield Losses and Income Distribution Effects

Income distribution effects are defined as the total loss in farmers' income due to a reduction in the use of nitrogen. Total loss is divided into two parts: increase in the cost of nitrogen and net value of the reduction in yield. The latter would also constitute the social value of the yield loss if the price of crops were not subsidized. The increase in the cost of nitrogen is regarded as a transfer of income and is therefore not a social cost. In this section, results of empirical calculations of these two kinds of costs show that a permit market is the least costly to both society and the farmers.

According to equations 3.15-17 in Chapter 3, income distribution effects and yield losses due to all policies are calculated as integrals of the nitrogen demand function between the unregulated and regulated use of nitrogen plus the increase in the cost of nitrogen. Different equations of the demand for fertilizer were estimated in Chapter 5. The results did not reveal any significant difference between the regression equations. Here we use the linear demand function, since the value of yield losses can be calculated then simply as the area of a triangle. Since the marginal cost of reducing the application of manure is constant, total costs are calculated as the area of a rectangle.

When calculating costs of reduction in the use of fertilizer, the base of a triangle corresponds to the reduction in the use of fertilizer. The reduction is 87 percent of the unregulated level when the leakage of fertilizer and manure is assumed to be the same and 55 percent otherwise. Thus, the base corresponds to 5100 or 3600 tons of nitrogen. The height of the triangle is determined by the marginal value less the price of nitrogen. Given that the price elasticity is 0.5 and the initial price of nitrogen is SEK 6/kg N, the height of the triangle is SEK 10.44 and SEK 5.40/kg N respectively. This method is also used to estimate the value of yield losses for different groups of farmers. The mean price elasticities of the groups of farmers in Table 5.3 in Chapter 5 may then be used for this purpose. The unregulated quantities of the use of fertilizer for different groups of farmers are given in Table 3 in the Appendix at the end of this chapter.

Total costs of reducing the leakage from nitrogen of manure by cultivating cover crops are calculated as the constant marginal cost, SEK 11/kg N, times the quantity of reduced leakage, 950 tons. Since we do not have any data regarding the possibilities of planting cover crops for different groups of farmers, it is assumed that the marginal cost is the same for all farmers.

When estimating the social costs and income distribution effects of a quota system, we have to calculate the value of yield losses for each of the six groups of farmers. As described in Chapter 3, it is assumed that each farmer is given a ration of nitrogen in proportion to his unregulated use. The farmers are then given 55 and 87 percent, respectively, of their initial use of fertilizer and 35 percent of their use of manure. The social value of yield losses is then calculated as described above. The results for each policy instrument are given in Table 6.3.

Table 6.3: Social value of yield losses, millions of SEK

Reduction in fertilizer is:	Quotas	Charges	Permit market
55 %	24.1	18.7	18.7
87 %	34.2	21.2	21.2

The cost of planting cover crops is SEK 10.5 millions in all cases when the reduction in fertilizer is 55 percent. The social costs of reducing the use of nitrogen are highest for a quota system. It may also be noted that the difference is larger for a high reduction in the use of fertilizer.

When estimating income distribution effects, the prices of crops include subsidies. This means that the social costs in Table 6.3 are increased by about 25 percent (see Appendix). The income distribution effects of a charge system also include increases in the cost of nitrogen. The results of the estimates income distribution effects are presented in Table 6.4.

Table 6.4: Income distribution effects of reducing the use of nitrogen, millions of SEK

The reduction in fertilizer is:	Quotas	Charges	Permit market
55 %	27.7	38.4	21.1
87 %	42.7	34.4	26.5

The income distribution effects are always lowest for a permit market, regardless of the fact that the reduction in the use of fertilizer is almost 40 percent lower than for a quota system when the reduction in fertilizer is 87 percent. It was indicated earlier that nothing definite could be said about the relation of income distribution effects between a charge and a quota system; cf. Chapter 3. In Table 6.3, we see that the income distribution effects of a quota system exceed a charge system when the reduction in fertilizer is 55 percent and the opposite is valid when the reduction of fertilizer is 87 percent. It is noteworthy that the income distribution effects of a charge system are higher when the reduction in fertilizer is 55 percent then when it is 87 percent. An important reason is that charge payments dominate for the smaller reduction.

The charge payments in a charge system amount to SEK 17.3 millions when the reduction in the use of fertilizer is 55 percent, which constitutes 45 percent of the total income effect. The cost of planting cover crops is SEK 10.5 millions and the net value of the yield loss is SEK 10.6 millions. The main part of the income distribution effects is thus comprised of payment of the charges when the use of fertilizer is reduced by 55 percent. When the reduction in fertilizer is 87 percent the major part of the income distribution effect instead consists of the net value of the yield losses which amount to SEK 26.5 millions, that is, 77 percent of the income distribution effect.

The farmers' total net income, which includes incomes minus costs from both livestock and vegetable production, is at the most reduced by approximately 15 percent. This occurs under a quota system when the fertilizer reduction is 87 percent. In 1985, farmers' total income was 277 millions of SEK, which gives the following income effects as percentages of total income shown in Table 6.5.

Table 6.5: Income distribution effects as percentages of total net income from livestock and vegetable production

Reduction in fertilizer:	Quotas	Charges	Permit market
55 %	10.0	13.9	7.6
87 %	15.4	12.4	9.6

The income distribution effect is never lower than 7.6 percent of total net income, which occurs under a permit market when the reduction in the use of fertilizer is 55 percent. A charge system is most costly to the farmers when the reduction is 55 percent; incomes are then reduced by 13.9 percent. The worst case for the farmers occurs when the reduction is 87 percent as incomes are reduced by 15.4 percent under a quota system.

6.3 Violation Profits

Violation profits are calculated in the same way as income distribution effects, i.e., as a the integral of some demand function. When violation profits are estimated, the lower limit of the integral is the marginal violation cost, as shown in Chapter 4. The marginal violation cost of all the policy instruments is a function of the given price of nitrogen, the transport cost, the rate of detection and the fine. In Chapter 4 it was also assumed that all these variables are of the same magnitude for all the policy instruments. Under the charge and permit market systems a farmer who is detected also has to pay a charge or the current price of permits. In this section it is further assumed that the violation marginal cost is constant.

We begin by describing the measurement of the variables and the determination of the marginal violation costs. This is followed by the results of the calculations of the profits from violating each policy instrument when the use of fertilizer is reduced by 55 and 87 percent.

Actual implementation of the Swedish environmental protection legislation is used as the basis for measuring the rate of detection and the fines. Measures of the rate of detection and the fine for violating regulation on manure may be are found from the enforcement of a Swedish law which states that farmers must have equipment necessary to store manure for a period of six months. A measure of the fine for violating controls on the use of fertilizer may be found in a law which stipulates an "environmental protection charge" (which should not be confused with the charge of a charge system).

Every year a supervisor in Gotland visits one fourth of all the farmers on the island in order to control their equipment for storing manure (Söderström). If he finds that a farmer does not have the proper equipment the farmer is first told what rules have to be followed. It could be that a farmer is not informed about current rules or has interpreted them incorrectly. In such instances he will usually obey the supervisor's instructions. But if he does not comply, the supervisor will make further efforts to convince the farmer. The supervisor spends an average of three days on persuading the farmer and writing necessary reports. If the farmer insists on refusing to comply, he is finally fined. The fine amounts to one-half of the investment costs of storing manure.

According to this brief description of the implementation in practice in Gotland, the rate of detection is assigned a value of 0.25 since one-fourth of all farmers are supervised every year. The actual fine for violating the rules for storing manure amounts to one-half of the investment cost. The investment cost of cover crops is assumed to constitute the total cost of cultivation, which is SEK 10.5 million or SEK 11/kg N. The farmer is then fined by SEK 5.5/kg N if he does not plant the cover crops he is supposed to cultivate.

The fine for violating regulation on fertilizer consists of two parts: an "environmental protection charge" and an "extra fine". According to Swedish environmental protection legislation a polluting firm has to pay an "environmental protection charge" which is supposed to amount to the profits gained from violating the law (Holmgren). In addition, the polluting firm has to pay an "extra fine" which is proportional to income and to the "severity" of the crime. The fine per day is usually 1/1000 of income and "severity" is measured in terms of the number of days the fine must be paid. Environmental crimes commonly carry a 30-day fine.

We make a rough and simple estimate of the "extra fine" because it is very difficult to find a measure per unit of nitrogen. We assume that the "extra fine" is the same for all policy instruments. According to agricultural statistics the average income of farmers in Gotland is about SEK 107 000 (Yearbook of Agricultural Statistics, 1986). The "extra fine" to be paid by a farmer who is detected then amounts to SEK 3210. We now make the very simplifying assumption that the fine per unit of smuggled nitrogen is 3210 divided by the potential amount of illegal use of nitrogen, which is 2.04 tons per farmer. In order to obtain the potential amount of illegal use, we have simply taken the amount of regulated nitrogen, which is 5100 tons; cf. Chapter 1. These strongly simplified calculations give the value of SEK 1.57/kg nitrogen as the "extra fine".

The size of the "environmental protection charge" is measured as the charge under a charge system and as the price of permits under a permit market. A measure of the marginal value of smuggled fertilizer is required to determine the "charge" under a quota system, which implies that the fine is a function of the quantity of smuggled fertilizer. In practice, however, it is impossible to measure the marginal value for fertilizer of each farmer. This "charge" is therefore excluded. Thus the fine under a quota system constitutes the "extra fine" as described above.

A farmer may violate rules regarding cultivation of cover crops simply by refusing to plant. This type of violation is assumed to be costless for the farmer. On the other hand, in order to when smuggle fertilizer a farmer has to travel to the mainland and buy it. He thereby incurs a cost of transport, which is SEK 0.06/kg N (Erlandsson).

Given these assumptions, we can now estimate the marginal cost of violating cost of each policy device. In the case of cover crops this cost is the same for all instruments and amounts to the detection rate, 0.25, times the fine, SEK 5.5/kg N, which gives SEK 1.38/kg N. The marginal violation cost of fertilizer differs among policy instruments. Under the charge and permit market systems, the marginal violation cost is also a function of the reduction in the use of fertilizer. The calculations of the marginal violation costs of all policy instruments are based on equations (4.6, 4.12 and 4.19) in Chapter 4. The results are as follows.

Quota system:

$$\beta^{q} = 6 + 0.06 + 0.25(1.57)$$

Charge system and permit market:

$$\beta^{c}_{.55} = \beta^{pm}_{.5} = 6 + 0.06 + 0.25(1.57+6.6) = 8.10$$

$$\beta^{c}_{.55} = \beta^{pm}_{.5} = 6 + 0.06 + 0.25(1.57+10.44) = 9.36$$

When the reduction amounts to 0.55 and 0.87 percent, the marginal values of fertilizer are SEK 12.6 and SEK 16.44/k,g given that the price elasticity is 0.5 and the price of fertilizer is SEK 6/kg N. This means that smuggling of fertilizer occurs under both the charge and permit market systems since the marginal values of fertilizer exceed the marginal violation costs. The marginal violation cost of a quota system has to be compared with the marginal value of fertilizer for each group of farmers. It is found that smuggling will occur within all groups, regardless of the size of the reduction in fertilizer (see Appendix).

As shown above, the marginal violation cost of manure is SEK 1.38/kg N. The cost of complying, i.e., planting cover crops is SEK 11/kg N. Thus, violation occurs and the profits in this case amount to SEK 9.1 millions (9.6x950). When the reduction in fertilizer is 55 percent, violation profits from manure are added to the violation profits from fertilizer. Violation profits from fertilizer arise only when the reduction is 87 percent. The results are shown in Table 6.6.

Table 6.6: Profits from violating alternative policy instruments, millions of SEK.

Reduction in fertilizer is:	Quotas	Charges	Permit market
55 %	22.9	24.5	12.7
87 %	41.2	17.6	12.2

It is interesting to note that the profits from violating the charge and permit market systems are higher when the reduction in fertilizer is 55 percent than when it is 87 percent. This may be explained by the higher marginal violation cost when 87 percent of the fertilizer is reduced. Under a quota system, where the marginal violation cost is independent of the size of the reduction, the violation profits are higher when the reduction in fertilizer is 87 percent.

The quantity of illegal use of nitrogen differs among the policy instruments and also depends on the desired reduction in the use of fertilizer. When the desired reduction is 55 percent the illegal use of nitrogen consists of both smuggled fertilizer and violation of rules regarding cultivation of cover crops. The latter type of illegal use corresponds to 950 tons of N for all policy instruments. Smuggling of fertilizer from the mainland is the only type of illegal use when the desired reduction in fertilizer is 87 percent. The amount of smuggled nitrogen is then largest under a charge system when the desired reduction in the use of fertilizer is 55 percent. The actual reduction is then only 18 percent. The quantities of illegal use of nitrogen under all policies are given in Table 6.7.

Table 6.7: Illegal use of nitrogen under alternative policies, tons of N

Reduction of fertilizer is:	Quotas	Charges	Permit market
55 %	3939	5760	3137
87 %	4867	4198	3440

It may be recalled from Chapter 4 that the violation profits and the quantity of illegal use of nitrogen under a permit market were determined by the price of nitrogen. In Tables 6.6 and 6.7, violation profits and illegal use of nitrogen under a permit market are calculated for the case where farmers smuggle only in excess of their initial ration. It is also assumed that the price of permits equals the charge under a charge system. If all of the nitrogen required were smuggled, the violation profits and illegal use of nitrogen would be of the same size as under a charge system.

6.4 Summary and Conclusions

The purpose of this chapter has been to estimate the social value of yield losses, income distribution effects and violation profits, which were analyzed in Chapters 3 and 4. We began by determining cost efficient reductions in the use of fertilizer and manure, respectively. Two different leakage effects of manure were considered. The leakage of nitrogen from manure was assumed to be either the same or twice as high as from fertilizer. Cultivation of cover crops as a means of reducing the leakage from manure applied in autumn was found to be a cost efficient measure only when the leakage from manure is twice as high as from fertilizer. When the leakages of fertilizer and manure are assumed to be the same, no regulation on the treatment of manure turned out to be cost efficient. Two sizes of reductions in the use of fertilizer were therefore considered, 55 and 87 percent.

The social value of yield losses and income effects may be calculated as some integrals of the demand function of nitrogen, as shown in Chapter 3. The results show that the social values of yield losses under the charge and permit market systems are not only the same, but also lower than under a quota system. It was also found that the ranking of the charge and quota systems with respect to income distribution effects depends on the size of the reduction in fertilizer. When the reduction is 55 percent the income distribution effects are largest under a charge system. When the reduction in the use of fertilizer is 87 percent, the efficiency losses due to a quota system exceed the charge payments under a charge system, which implies that a quota system is more costly to the farmers.

Actual implementation of environmental protection legislation is used as a basis when calculating the profits from violating different policy instruments. It turns out that the ranking of the policies with respect to violation profits is similar to the ranking with respect to income effects. Thus, profits from violating a permit market system are always lowest when farmers smuggle only in excess of their initial rations. When the reduction in the use of fertilizer is 55 percent, the profits from violating a charge system are highest; they are twice as high as under a permit market. The profits from violating a quota system are largest - three times larger than a permit market - when the reduction in fertilizer is 87 percent.

APPENDIX

Cost Estimates

A:1 Marginal costs of regulation on manure

The marginal costs of drying manure aχf chicken and cattle are calculated as the retailer's price to the consumers (Weibulls). For a description of estimates of all other marginal costs, see Kindt (1988).

A:2 Yield losses and enforcement costs for different groups of farmers

The use of nitrogen is allocated among the six groups as shown in Table 1. The farmers are divided into groups according to their average holdings of land.

Table 1: Use of nitrogen by different groups of farmers, tons of N

<30	30-40	40-50	50-60	60-70	>70	Total
1533	741	1000	776	670	1157	5877

Source; Yearbook of Agricultural Statistics 1985, individual data from SCB, Örebro

These quantities are used as weights in estimating the average nitrogen price elasticity from the group specific estimates in Table 5.3, Chapter 5. The average price elasticity is 4.33 in absolute value. The elasticities in Table 5.3 are then transformed into new elasticities where the average elasticity is 0.5 in absolute value. The results are listed in Table 2.

Table 2: Nitrogen price elasticities for different groups of farmers

<30	30-40	40-50	50-60	60-70	>70 ha
0.20	0.80	0.35	0.42	0.15	1.09

These elasticities constitute the basis for estimating values of both yield losses and violation profits. The price of nitrogen is SEK 6/kg N. The results are presented in Table 3.

Table 3: Value of yield losses for different groups of farmers, millions of SEK

Fertilizer reduction is:	<30	30-40	40-50	50-60	60-70	>70	Total
55 %	7.0	0.8	2.6	1.7	4.1	1.0	17.2
87 %	17.4	2.1	6.5	4.2	10.1	2.4	42.7

Violation profits are estimated in a way similar to the value of yield losses. For all groups, the initial price of nitrogen is SEK 6/kg N, the transport cost is SEK 0.06/kg N, the fine is SEK 1.57/kg N and the detection rate is 0.25. Quantities of smuggled fertilizer and violation profits for each group are given in Table 4.

Table 4: Violation profits and quantities of smuggled fertilizer, millions of SEK and tons of N, respectively

Reduction in fertilizer is:	<30	30-40	40-50	50-60	60-70	>70	Total
55 %:							
Smuggled quantity	786	364	524	403	361	548	2989
Violation profits	5.8	0.9	2.0	1.2	3.6	0.3	11.8
87 %:							
Smuggled quantity	1277	601	844	651	575	919	4867
Violation profits	16.5	1.8	6.1	3.9	9.9	3.0	41.2

A:3 Social value of yield losses

The net value of yield losses in Table 3 (Appendix A:2) are expressed in the prices received by the farmers. These prices include the cost of exporting barley, wheat, rye and oats. The social value of yield losses excludes the cost of exports. Barley, wheat, rye and oats comprise approximately 35 percent of the value of total yield in 1985 measured in farmers' prices (Yearbook of Agricultural Statistics, 1986). The costs of exports above amount an average of 40 percent of the farmers' price. That is, the social value of total yield amounts to 80 percent of the yield measured in farmers' prices.

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See Chapter 1 for the remaining references.

SUMMARY OF THE RESULTS

The purpose of this thesis has been to estimate and compare cost efficiency, income distribution effects, technological change and violation incentives with respect to different policy instruments aimed at reducing farmers' use of nitrogen in Gotland. The policy instruments under study were quota, charge and permit market systems. The background for this objective is attributable to results from an interdisciplinary research on Gotland, which showed that the content of nitrogen in drinking water is high. Large reductions in farmers' use of nitrogen were recommended.

Chapter 1 focused on the fact that the use of nitrogen should decrease by 60 percent in order to restore the quality of drinking water in Gotland. It was noted that the leakage of nitrogen from manure is uncertain so that calculations for two different leakage effects were required in Chapter 6. Farmers' production decisions were also described in Chapter 1. Factors which influence their decision-making turned out to be uncertainty about yield due to weather conditions and a relatively high cost share for nitrogen. These factors subsequently served as inputs when a decision rule for farmers' use of nitrogen was modeled in Chapter 2. The results showed that farmers' revealed use of nitrogen is consistent with the use obtained by maximizing the expected utility of profits under risk aversion when manure is regarded as a disposal problem.

When the policy instruments were compared with respect to cost efficiency, income distribuition effects, technological change and violation profits in Chapters 3 and 4, it was assumed that the farmers' decision rule regarding the use of nitrogen can be represented by maximization of the expected utility of profits under risk aversion. Income distribution effects were defined as the total decrease in farmers' profits due to an implemented reduction in the use of nitrogen. The performance of the policy instruments with respect to technological change was measured as their ability to encourage technological change. The ability to encourage technological change was defined as the difference in income distribution effects between the old and the new nitrogen-abatement technology. So-called violation profits, which were assumed to be a measure of the incentives to violate the various policy instruments, were defined as the expected utility of violation costs less the expected utility of violation gains.

The main analytical results from the comparisons of policy instruments in Chapters 3 and 4 are listed in Table 1. The symbols ">", "≥" and "=" should be interpreted as "better than", "better than or as good as" and "as good as".

Table 1: Criteria of comparison and rankings of quotas, Q, charges, C, and permit market, PM

Cost efficiency	C = PM > Q
Income distribution effects	PM > Q (C) > C (Q)
Technological change	C ⩾ PM ⩾ Q or Q ⩾ C ⩾ PM
Violation profits	PM > Q (C) > C (Q) or C (Q) > Q (C) > PM

When comparing policy instruments with respect to cost efficiency, it was found that the charge and permit market systems are both better than a quota system. This is a common result of studies when policy instruments are compared, which can be traced back to the mid-1960s; see Kneese (1964 and 1968) in Chapter 3. The reason why a quota system yields higher nitrogen-abatement costs is that quotas are distributed in an inefficient way, which gives rise to what may be termed efficiency losses.

It is assumed that the initial permits under a permit market system are distributed to the farmers free of charge. The income effects are then lowest for a permit market. Under a charge system, the farmers must pay a higher price for all nitrogen they use. The income effects of a charge system exceed the income effects of a quota system if the charge payments are higher than the efficiency losses.

All three policy instruments were found to encourage technological change. When it was assumed that quotas are distributed efficiently, the incentives for technological adjustment are highest for the charge and permit market systems. This result also required the assumption of a given price of permits. However, a switch to a nitrogen-saving technology may reduce the demand for permits. This, in turn, would bring about a fall in the price of permits, which implies that the incentives for further technological change are reduced. In this case, the incentives for technological change may be higher under the quota and charge systems.

As mentioned above, violation profits were defined as the expected utility of violation gains less the expected utility of violation costs. Under a quota system, violation gains were regarded as the increase in the net value of yield due to use of nitrogen in excess of the quotas. Violation gains under the charge and permit market systems consisted of charge payments and the price of permits which are evaded by the farmers. For all policy systems, the violation cost was defined as the cost of for smuggling fertilizer from the mainland plus the expected fine. Two types of fines were considered: a variable fine which varies with the quantity of smuggled nitrogen and a fixed fine which is the same for all policy instruments.

Under a variable fine system, the expected fine under the permit market and charge systems was assumed to include the price of permits and the charge, respectively, which the farmer tried to evade. These items were not included in the expected fine under a quota system, which implies that the expected fine is lower. When the efficiency losses of a quota system exceed the charge payments of a quota system, the profits from violating a quota system exceed the profits from violating a charge system for a sufficiently high charge. If a system of fixed fines were used, the profits from violating a charge system are higher than the profits from violating a quota system because violation costs are then the same for the two policy instruments.

Under a permit market system, it was taken into account that the occurrence of smuggling reduces the demand for permits, which in turn lowers the price of permits. This implies that violation profits decline. In the extreme cases, the profits from violating a permit market system can be either the same as under a charge system or smaller than under the other two policy systems.

However, the results presented in Table 1 may be changed if the assumption regarding the initial distribution of permits is changed. In our case it was assumed the permits were distributed free of charge. If the permits instead were sold by an auction, results regarding most of the criteria of comparison may be changed. An interesting issue for future research is therefore to analyse to what extent the results of this thesis are affected when the distribution of initial permits is changed.

When analysing profits from violating a permit market no difference was made regarding sellers and buyers of permits. Buyers of permits would not make protests against the fall in the price of permits which is brought about by the occurrence of smuggling. But the sellers of permits may try to inhibit reductions in the price of permits. Farmers could then start to supervise each other in order to prevent a decrease in the permit price. Another interesting topic for future research is therefore to analyse whether and, if so, to what extent "self-policing" occurs under a permit market system.

Empirical calculations were used to examine the performance of the policy instruments with respect to cost efficiency, income distribution effects and violation profits. The basis for these calculations was the series of nitrogen demand functions estimated in Chapter 5. An estimation of the aggregated nitrogen demand function was required in the calculations for the charge and permit market systems. In order to measure the effects of a quota system, it was necessary to estimate nitrogen demand functions for different groups of farmers. The result from estimations of the aggregate demand function shows that the nitrogen-price elasticity amounts to 0.5 in absolute value. The estimations of nitrogen-price elasticities for different groups of farmers turned out to vary between 0.15 and 1.05 in absolute values. However, the quality of the data underlying the estimates of elasticities for different groups of farmers was poor.

The leakage of nitrogen from manure was considered on two levels: i) the same as or ii) twice as high as from fertilizer. Optimal allocations of reductions in manure and fertilizer, respectively, were determined for both levels of leakage. Reductions in the application of both manure and fertilizer turned out to be optimal when the leakage from manure is high. When the leakage of nitrogen from manure is assumed to be low, the optimal solution only involves reduction in the application of fertilizer. The results of the empirical calculations for both amounts of leakage from manure are shown in Table 2. Violations profits are calculated for a system of variable fines.

Table 2: Social value of yield losses, income distribution effects and profits from violating policy instruments, millions of SEK

	Quotas		Charges		Permit market	
Manure leakage is	high	low	high	low	high	low
Social value of yield losses	19.3	34.2	13.9	21.2	13.9	21.2
Income distribution effects	23.9	42.7	33.6	34.4	16.3	26.5
Violation profits	22.9	41.2	24.5	17.6	12.7	12.2

It should be noted that we did not consider the effects of a change in the price of permits when estimating violation profits. It was assumed that farmers smuggle only in excess of their initial permits. At one extreme, if no smuggling occurred under a permit market system, the violation profits would be the same as under a charge system.

Performance with respect to cost efficiency was measured as the social value of yield losses due to a reduction in the use of nitrogen under the policy instruments. According to Table 2, the social value of yield losses is lowest and of the same size under the charge and permit market systems. For a low leakage of nitrogen from manure, the social value of yield losses under a quota system is 50 percent higher than under the other two systems.

Farmers' subsidies were included in the calculations of income distribution effects. Table 2 indicates that the income effects of a permit market system are lowest regardless of the size of the leakage from manure. Initial permits were assumed to be distributed free of charge. Under a quota system, the income distribution effects may be 90 percent higher than under a permit market system. Note that the income distribution effects under a charge system are higher than under a quota system when the leakage of nitrogen from manure is high. When the leakage from manure is low, the efficiency losses under a quota system exceed the charge payments under a charge system.

The ranking of policy instruments with respect to violation profits is similar to that of income effects. Violation profits are always lowest under a permit market system. They are highest under a charge system when leakage of nitrogen from manure is high and largest under a quota system when the leakage from manure is high. Note that profits from violating the charge and permit market systems are larger when the leakage of nitrogen from manure is low than when it is high. This occurs because the charge and price of permits, respectively, increase when the desired reduction in the use of fertilizer increases from 55 to 87 percent. This, in turn, increases the violation cost, thereby reducing the violation profits.

Thus, according to Table 2, a permit market system performs best with respect to all criteria, when it is assumed that the price of permits does not change. As indicated in Table 1, this result may change if the assumption is relaxed. A quota system is better than a charge system with respect to income effects and violation profits when the leakage of nitrogen from manure is high. When leakage is high, the income effects and violation profits under a charge system are smaller than under a quota system.

When making the empirical calculations it was assumed that the structure of the nitrogen demand function is the same during the period of estimation, i.e., 1948-1984. During this period farmers' production technologies have been subjected to great changes, which, if taken into account, may affect the results of the estimated nitrogen-price elasticities. It should also be kept in mind that the calculations with respect to a quota system are more uncertain than any of the others due to poor estimations of the demand functions for different groups of farmers. The results in Table 2 should therefore be interpreted with caution.

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