UNIVERSITETET FOR MILJØ- OG BIOVITENSKAP
NORWEGIAN UNIVERSITY OF LIFE SCIENCES

DOCTOR SCIENTIARUM (DR. SCIENT.) THESIS 2008:5

ESSAYS ON THE MULTIFUNCTIONALITY OF AGRICULTURE AND POLICY OPTIONS

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AVHANDLING NR. 2008:5

DEPARTMENT OF ECONOMICS AND RECOURSE MANAGEMENT
NORWEGIAN UNIVERSITY OF LIFE SCIENCES
THESIS NO. 2008:5

Sammendrag

Jordbruket produserer mer enn bare varer som kan omsettes i markeder. I tillegg produseres en lang rekke goder, onder og tjenester som ikke kan omsettes i markeder. Jordbruket kan på grunn av dette gi bidra til ulike samfunnsmessige mål samtidig. Dette er essensen i det multifunksjonelle landbruket.

Mengdene av de "produktene" som ikke kan omsettes i markedet vil ikke være samfunnsmessig optimale siden produsentene, dvs. bøndene, ikke får de rette signalene gjennom markende. En måte å korrigere for disse eksternalitetene på, som er hovedtema i avhandlingen, er å betale/skattlegge bøndene direkte basert på hvor mye de produserer av de ulike godene, ondene og tjenestene. Imidlertid, dette er ikke den eneste muligheten, og i en del tilfeller er dette ikke den optimale løsningen.

Mange av "produktene" fra jordbruket er koblet i den forstand at dersom en endrer mengden av ett endres også mengden av ett eller flere andre. Dette, som kalles koblet produksjon eller jointness på engelsk, skyldes enten tekniske og biologiske prosesser eller økonomiske faktorer som faste allokerbare innsatsfaktorer. Dersom vi kjenner disse sammenhengen, vil ulike kombinasjoner av skatlegging/subsidiering av innsatsfaktorer, "produkter" og praksiser føre til de ønskede mengdene sett fra samfunnets side. I en slik situasjon vil den optimale politikken være den som fører til de laveste administrasjonskostnadene.

To av artiklene i denne avhandlingen omhandler virkemidler for å redusere nitrogenforurensingen fra jordbruket. Siden forurensingen fra hver gård eller hvert skifte ikke kan måles eller er veldig kostbar å måle, vil ikke direkte skattlegging av forurensingen være mulig/fornuftig. Den første artikkelen analyserer effekten av private transaksjonskostnader i et marked for omsettelige gjødselkvoter. Det blir vist at transaksjonskostnadene i liten grad påvirker handelen i kvotemarkedet, og at omsettelige kvoter har den forventede miljøeffekten. Den andre artikkelen analyserer en mulighet for å fjerne noe av usikkerheten knyttet til hva som er optimal gjødsling det enkelte år. Det foreslåtte virkemidlet er et system med delte kvoter. Den første delen av kvoten blir tildelt om våren og er lik hvert år, mens den andre delen blir tildelt senere basert på hva som anses som optimal gjødsling hvert enkelt år. Resultatene indikerer at virkemidlet gir reduksjoner i forurensingen til en lavere kostnad (både for samfunnet og for bonden) enn en avgift på gjødsel.

De to andre artiklene er knyttet til transaksjonskostnader og optimal politikk når produksjonen er koblet. Transaksjonskostnadene er mye lavere når virkemidlene er knyttet til varer enn når de er knyttet til andre objekter. Dersom koblingen er slikt at bonden ikke kan påvirke den, er virkemidler knyttet til varer helt klart det optimale for å korrigere for eksternaliteter. Dersom koblingen er mer fleksibel, er det ikke mulig å trekke generelle konklusjoner. Forskjellene i transaksjonskostnader mellom ulike mulige virkemidler vil imidlertid fortsatt være avgjørende.

Analysene viser også at transaksjonskostnadene kan reduseres betydelig gjennom å redusere antallet virkemidler. Dette er ikke overraskende, men det er overraskende hvor fort transaksjonskostnadene øker når en øker antallet virkemidler (og holder den totale overføringen konstant).

For et land som ikke er konkurransedyktig på verdensmarkedene, som Norge, indikerer analysene at den optimale politikken er å bruke prisstøtte (direkte og indirekte) for å sikre produksjon på et vist nivå, og å supplere dette med andre virkemidler som for eksempel direkte støtte for å produsere miljøgoder. Det første vil føre til et vist nivå av de kollektive godene, mens det siste kan brukes for å finjustere produksjonen av dem.

Abstract

Agriculture produces more than just commodities that can be and are traded in markets. In addition, agriculture provides a large range of non-market outputs in the form of goods, bads and services. These multiple outputs may contribute to different societal objectives at once, which is the essence of the concept of multifunctional agriculture.

The quantities of the non-market goods, bads and services may not be socially optimal since the producers do not receive the right signals through the markets. One option for correcting for these externalities is to use direct payments/taxes based on level of the non-market outputs. However, this is not the only options, and in some cases this is definitely not the optimal option.

Many of the outputs in agriculture are linked in such a way that a change in the level of one will affect the levels of the others. This, termed jointness, is due to technical and biological processes and economic factors like fixed allocable inputs. If these relationships are known, different combinations of taxes/subsidies on inputs, outputs and practices may be used to induce the socially desirable levels of the agricultural outputs. In this setting the optimal policy mix is the mix that results in lowest administrative costs.

Two of the papers in this thesis discuss policy measures to reduce nitrogen pollution from agriculture. Since pollution at farm or field level is not observable or very costly to monitor, taxing emissions directly is not a viable option. The first paper analyzes the effect of private transaction costs in a market for fertilizer quotas. It is shown that transaction costs do not influence trade much, and that tradable fertilizer quotas have the expected environmental effects. The second paper analyzes one option for resolving some of the uncertainty about the growing conditions a given year. The proposed instrument is a two-round quota system: a year independent amount is awarded in the spring while the quota in the second (later) round is awarded based on the expected optimal fertilization level the given year. Results indicate that abatement costs (both private and social) are lower for the proposed instrument than for a nitrogen tax. More research is needed in order to investigate the possibility and costs of estimating the yearly optimal fertilization levels ex ante.

The two other papers concern transaction costs and optimal policies under jointness. Transaction costs are much lower for polices targeting commodities than for polices targeting other objects. If jointness is such that it is not possible for the farmer to influence the proportions of the different outputs it is clearly optimal to target the commodity. For more flexible forms of jointness it is not possible to draw a general conclusion. Still, the differences in transaction costs between policy options are of great importance.

The analysis also shows that transaction costs can be reduced substantially by reducing the number of schemes. It is not surprising that merging schemes would result in lower administrative costs, but it is surprising how fast the total transaction costs increase as the number of schemes increases (given a total transfer to farmers).

For a country that is not competitive on the world market, like Norway, the analysis suggests that the optimal policy is to use commodity based support to induce production up to a certain level and to supplement this with other measures like direct payment for the production of public goods. The first will insure a certain level of public goods production wile the latter may be used for fine-tuning public goods production.

Preface and Acknowledgements

> "I may be wrong and you may be right, and by an effort, we may get nearer to the truth" (Karl R. Popper)

This thesis marks the end of a long journey. The thesis would not have been possible without the help and inspiration of many people. Too many to mention them all, but a few deserves a special thanks. First and foremost the co-authors of the papers (in alphabetical order): Arild Vatn, Eirik Romstad and Valborg Kvakkestad. In addition to the concrete contributions, I have also had the pleasure of working with them in various projects. Eirik deserves a second thanks for being my (long time) supervisor.

Over the years I have also worked with many other nice persons in various projects. I have in almost all my academic career work with Helge Lundekvam (who unfortunately passed away in 2007), Marina A. Bleken, Lars Bakken and Lars Egil Haugen. They have taught me all I know about agro-ecology. Of course I do not hold them responsible – in any way – for errors I may have committed in this thesis.

I am also grateful to the faculty and staff of the Department of Economics and Resource Management. Despite – or maybe due to – opposing views we have had many enlightening and entertaining discussions over the years.

The main aim of my research has been to be applied, i.e. trying to apply economics to real world problems in agriculture. In this respect, linking economics and natural sciences is a necessity. Since the work is related to public policy analysis, a dash of institutional economics has also been necessary. In my own view, my head is (neo-classical) economic, I have my feet on the ground (i.e. in natural sciences) and one arm is institutional. The rest of the body is concerned about the environment.

This thesis contains one controversial issue: the use of commodity based support in agriculture. There is a long tradition for using price support – not only in Norway – and it is easy to find distortive effects of this type of support. This will lead to inefficiencies in commodity markets, but my major concern is more ethical than ideological. If surplus production is dumped on the world market this will lead to lower prices. Poor people may benefit from this – if they get access to this cheap food. However, this will prevent developing countries from developing an efficient agricultural sector. It is therefore important to underline that this type of support should not be used as general income support in competitive countries. One main point in this thesis is that the use of commodity base support is an efficient way to insure the production of public goods in some situations, but not all.

Finally and not the least, this project would not have been possible without the support of my family: Grethe, Martha and Eyvinn. They have been patiently awaiting the finish. I love you!

Ås, May 2008

Per Kristian K.L. Rørstad

Contents

Linking the pieces together

1. Introduction

The main aim of this first part of the thesis is to put the different papers into a wider perspective. The main theme of the papers in this thesis concerns correcting externalities in agriculture. Since the production of positive and negative externalities is interlinked with commodity production, one cannot analyze externalities in isolation from the production of commodities. It is therefore necessary to discuss the characteristics of the outputs from agriculture and the possible implications for regulation (Section 2). This is followed by a discussion about some of the policy options (Section 3). In Section 4 the Norwegian agricultural policy is briefly presented and discussed. The current policy in Norway is rather complex with a large number of schemes. Hence, a complete treatment would be a thesis in itself. Only a limited number of issues will therefore be discussed. The focus will be on the main types of policy instruments used and the level of support. Next, abstracts of the papers in this thesis will presented (Section 5), and in Section 6 the relevance of the papers will be discussed.

2. Characteristics of agricultural goods

2.1. Multifunctional agriculture

Agriculture produces more than just commodities that can be and are traded in markets. Agriculture also provides a large range of goods, bads and services[1] that are not traded in markets. The fact that agriculture produces multiple outputs is closely linked to the concept of multifunctionality, and OECD (2001:11) gives the following description of the concept:

> "Multifunctionality refers to the fact that an economic activity may have multiple outputs and, by virtue of this, may contribute to several societal objectives at once. Multifunctionality is thus an activity oriented concept that refers to specific properties of the production process and its multiple outputs."

The different outputs may have no (i.e. zero), positive or negative value to society, reflecting their contribution to different societal objectives. These values may change over time.

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[1] A good is an object that when "consumed" increases the utility of the consumer. A bad is the opposite of a good, i.e. when "consumed" it decreases the utility of the consumer. Finally, a service is the non-material counterpart to a good. Even though they differ in characteristics, they have in common a non-zero value. Unless explicitly stated, the term good refers to any of the three types of outputs.

Technological development may in the future enable the production of biofuel from straw (so-called second generation biofuel), and thereby increasing the value of straw from almost zero. Preferences may also change over time, leading to changes in valuation. This means that multifunctionality is not a static concept.

As in all other production processes, multiple outputs in agriculture are unavoidable (Faber et al., 1998:131). This can be inferred from two of the laws of thermodynamics: conservation of mass and energy, and non-decreasing entropy. If follows (almost) directly form this that there is a dependency between output levels for some goods, i.e. if the level of one output changes, the output level of some other good will also change. This interlinkage between output levels is termed jointness. In addition to the technical reason mentioned above jointness may be due to economic factors like fixed allocable resources (land, capital and labor). Paper 3 gives a more detailed discussion about these issues, but we will return to the possible implications of jointness below.

With the concepts of multifunctionality and jointness in place, we move on to look at the different outputs of agriculture. The most central non-commodity elements of Norwegian multifunctional agriculture, i.e. elements with non-zero value, are (Romstad et al., 2000:1):

- *landscape*: biodiversity, cultural heritage, amenity values of landscape, recreation and access, scientific and educational value,
- *food related issues*: food security, food safety and food quality,
- *rural concerns*: rural settlement and rural economic activity, and
- *pollution*: losses of nutrients to water and air (e.g. nitrate and N_2O), erosion, and pesticide residues in food, soil and water.

Since multifunctionality is defined in terms of policy objectives, the list may vary from country to country. For example, rural concerns may not be an issue at all in some countries, while other issues not in the list might be important. Since natural conditions (climate, soil types, topography, etc) vary, flood control or desertification, for example, may be important issues related to agriculture in some countries. This means that the concrete content of multifunctional agriculture is “site” specific, but the meaning of the concept is universal.

Some of the goods may be provided also by other sectors than agriculture, and this is termed separate production below and in Paper 3. Agriculture is not necessarily the cheapest provider of all of the goods in the list above. However, since the outputs from agriculture are linked, i.e. joint, we need to compare the whole bundle when comparing. Simply put, agricultural production will affect all the four main categories of goods in the list above. Some of the goods may be relational in the sense that the value depends on the level of other goods, i.e. is context dependent. For example the value (to the public) of an old farm building may be higher if it is part of an active agricultural environment than in a museum. Likewise, the value of a natural cultural landscape may be higher than an artificial landscape. This does not mean that separate production never is optimal, but that the values of the goods are different. Or more precise, separate production may result in a (slightly) different good.

2.2. Market vs. non-market outputs

From economic theory we know that in a competitive[2] economy the market outcome will be Pareto optimal (Hanley et al., 1997:24), i.e. it is not possible to increase the welfare of one person without reducing the welfare of at least one other. This is know as the first theorem of welfare economics, and it basically means that as long as markets are competitive there is no need to do anything, the market will maximize total welfare[3]. However, for many goods produced in agriculture there exist no markets at all. The main reason emphasized in the literature is that property rights are not complete for these goods. Property rights are complete when they are well-defined, transferable, secure and that all the benefits and costs accrue to the agent (Kolstad, 2000:60). The landscape goods in the list above are linked to the land, and the property rights for land (as land) can be said to be complete, but it is hard for the farmer to capture all benefits e.g. from people benefiting from the scenic beauty of the landscape. In the case of pollution, it is hard to confront the individual farmers with the costs of pollution since most pollution in agriculture is hard to trace back to the emitter. For the two last groups of goods in the list, it is even harder to envision a (normal) market where the farmers can be paid for providing the goods.

The notion of externalities is closely linked to incomplete property rights and transaction costs[4]. An externality exists if the consumption or production decision of one person or firm affects the utility or production function of another person or firm without permission or compensation. Clearly, in the absence of any regulation most of the non-commodities produced in agriculture may be viewed as externalities, both positive (goods and services)

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[2] The conditions for a competitive market are: complete property rights, atomistic participants, complete information and no transaction costs. No transaction costs will lead to complete property rights and complete information, i.e. the requirements may be reduced to atomistic participants and no transaction costs.

[3] There may be distributional issues, and they can be large, but these may be dealt with outside the market.

[4] The notion of transaction costs is discussed in more details in Papers 1, 3 and 4. Here it will suffice to define transaction costs as "…the costs of arranging a contract ex ante and monitoring and enforcing ex post" (Matthews, 1986:906).

and negative (bads). Since the effects (positive or negative) are not taken into account in the decision making process, the outcome will not be optimal.

If it is possible and costless (zero transaction costs) to bargain over an externality, bargaining will lead to an efficient outcome, regardless of the initial allocation of property rights. This is known as the Coase theorem, attributed to Coase (1960). Without transaction costs, initial allocation of property rights will only have a distributional effect. If transaction costs are positive, the initial property rights and the distribution of transaction costs will influence both the outcome of the bargaining, i.e. the total benefits, and the distribution of benefits (Vatn, 2005). If transaction costs are large enough and known a priori, there will be no bargain at all. In this case, given the institutions, status quo is the efficient allocation. Hence, the externality is Pareto irrelevant.

Since externalities can be bargained out when transaction costs are zero, this implies that transaction costs is the main reason for the existence of externalities[5]. If there are many agents involved on one or both sides of the table, bargaining costs will be large and possibly block a solution that otherwise would be beneficial for all parties. Even with few agents involved there is no guarantee that the bargaining will lead to an efficient outcome. Asymmetric information can lead to strategic behavior in the bargaining, and incomplete property rights can lead to that the agreement is not enforceable. As mentioned above, pollution in agriculture is hard to trace back to the emitter. Due to this, the farmers have incentives to not reveal their real preferences or costs in the bargaining, i.e. this is a principal-agent type of problem. In the case of landscape provision consumers have incentives to not state their real willingness to pay since there is the possibility to free ride.

Complete property rights would eliminate all externalities. There could still be some uncompensated losses, but complete property rights implies acceptance. For example, if the farmers have the right to pollute and this right is complete, this means that society has recognized farmers' right to pollute. If the farmers pollute without compensating the victims, this would still be Pareto optimal, but as implied by the Coase theorem, there is a potential Pareto improvement in this situation. If transaction costs are not too high, both parties would benefit from trading rights. In the case the consumers have the right to a clean environment, they could force the farmers to not start polluting (or force them to stop). This would impose

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[5] The terms externality and external effects are often used also for cases where the externality is corrected for, but here the term is used according to the definition above. If the externalities are corrected for, they can be said to be internalized.

costs on farmers, but still be Pareto optimal. Hence, the distribution of property rights given that they are complete, will determine which Pareto optimal allocation would be the starting point of the bargaining or the final allocation if transaction costs are too large. However, as we will see in the next section, the nature of these goods, services and bads is such that it is hard to envision complete property rights.

2.3. Private vs. public goods and bads

Yet another way of analyzing the reason that some goods are non-marketable is to look at two specific characteristics of the goods: rivalry and excludability in consumption. A good is rival if one person's consumption of a unit of the good diminishes the amount available for other to consume, and a good is excludable if it is feasible and practical to selectively allow consumers to consume the good (Kolstad, 2000). Goods that are not rival are termed non-rival and goods that are not excludable are termed non-excludable. However, rivalry and excludability is in reality more relative than the definitions suggest. The "consumption" of a road can be said to be non-rival if traffic is low, but as congestion sets in, the "consumption" becomes rival. Likewise for excludability: for example, there is a (physical) limit on the number of consumers that can enjoy the same landscape. If there are many people at a view point, additional persons will be excluded since there is no room for them, while if there are few, the view is non-excludable. The degree of rivalry and the degree of excludability are therefore better descriptions of the real world. Table 1 shows a commonly used classification of goods along these two dimensions.

Table 1.Classification of goods.

		Degree of excludability	
		High	Low
Degree of rivalry	High	Private goods	Common pool resources
	Low	Club goods	Public goods/bads

Source: adapted from Randall (1983).

Most of the public goods, bads and services in agriculture have a low degree of rivalry and low degree of excludability, i.e. they are public goods or public bads[6]. The classification in the table above does not take into account the spatial dimension. The goods and bads may be provided and "consumed" at different spatial scales, e.g. they may be local, regional, national

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[6] One may argue that the bads ends up in common pool resources like water and air and that the term bad in itself indicates rivalry in consumption. However, here we will use the conventional terminilogy.

or global public goods and bads. In some cases this distinction may be important. It is of little value to society to produce a local public good like a landscape in a place where there are none to enjoy the landscape.

If a good is a pure public good, i.e. consumption is completely non-rival and non-excludable, a market is not Pareto efficient if the price will exclude anyone who derives positive marginal benefit from this public good (Hanley et al. 1997:43). This is so since non-rivalry implies zero marginal social costs. A private firm cannot profit by providing a good for free, hence a market will not lead a Pareto optimal allocation.

Few goods in agriculture are pure public good, in the strict sense, but a low degree of excludability still represents a problem in a market (if it exists) regarding resource allocation. If people cannot be excluded from consuming the good, there is a possibility for free riding. Free riders consume the good without paying for it, i.e. the market will provide less of the good than social desirable. The other group of goods with low degree of excludability (common pool resources) seems less relevant for agriculture (but see footnote 6). However, also there markets may fail to allocate resources efficiently (Hanley et al. 1997:37).

Some of the goods/services, i.e. the food related issues, may also be provided in the form of private goods or by private actions, at least to some degree. Some use the term collective goods for public provision of such goods. The form of the good/service may be different when provided by society compared to the private case. At the national level food security is related to keeping agricultural resources (land, capital and knowledge) in production – or at least possible to bring back into production – storage and securing import possibilities in the case of crisis. At the private level, people can store food for the time of crisis.

Regarding private provision of the two other food related issues, food safety and food quality, this is closely related to information (transaction costs). The consumers need reliable information about the quality of the food in order to choose the right food. Public provision of such information (or public food control) will probably result in lower total costs than private information gathering.

To what extent the public should provide information about food safety and food control or support the agricultural sector directly for providing food safety[7] will remain unanswered in

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[7] This does not mean that domestic products have to be “cleaner” than imported food, but some illnesses common in other countries are absent in Norway. For example, salmonella is (almost) absent in domestically produced agricultural products, while frequently found in other countries (Norwegian Institute of Public Health, 2007).

this thesis. Still, since food security and food safety is produced jointly with commodity production, these services will be produced in agriculture as long as there is food production.

In this section we have seen that agriculture produces a number of public goods, services and bads, and that in the absence of regulation, they will not be produced at optimal levels. In the next section we will discuss how to regulate agriculture.

3. The regulation of public goods and bads

If markets are well-functioning there is no need to regulate the market outputs. However, we observe that there are many commodity support programs in place, even though the number is reducing. Such policies will lead to inefficiencies in the commodity markets. Still, there are some arguments that could justify the use of commodity support. First, efficiency is a purely economic (resource allocation) notion and as such it is amoral. This means that society may be willing to carry the costs of being inefficient in some markets if this leads to the fulfillment of e.g. some moral obligation. It is hard to see that this applies to agriculture, but should not be ruled out. Second, since agriculture contributes to several objectives, the use of commodity support may increase the overall efficiency by reducing the total costs of regulation (transaction costs). This will be discussed below and in Paper 3.

3.1. Non-point source pollutions

Most of the public bads in agriculture are in the form of non-point source pollutions. Substances are inevitably lost from the farm fields to the environment. These losses include ammonia losses to air, nitrate, pesticides and phosphorus losses to watercourses (including groundwater) and erosion (losses of particulates). A certain level of these losses may not be harmful, but above this level they may make the watercourses unsuitable for human use (e.g. as drinking water), increase the costs of utilizing the water (e.g. increased costs of water treatment) or reduce the benefits of other “water based” resources (e.g. fishing and recreation). The damages or reduced quality/value of the water may be a direct consequence of the pollution, i.e. contamination, or indirectly by e.g. increased oxygen demand in water or more generally, eutrophication.

Let us now briefly look at the processes that determine the damages. For the sake of exposition, let us assume that all natural processes are known with certainty (full knowledge and no stochastic processes). We may now divide the “problem” in two. First there is the part that the farmer can control directly (to some extent), i.e. the losses that leave the fields, and second the part that the farmer cannot control, i.e. the fate of the losses that leave the fields. The latter is determined by a number of different processes from the farm field to the recipients, where the damages will depend on the "supply" of compounds from all farmers in the drainage basin (and other sources). The damages will also depend on the characteristics of the recipient (like size, depths, water flow, etc). On the way from the field to the recipient the amounts may be reduces by processes like sedimentation and dentrification. This means that what leaves the field is not necessarily what enters the recipient. Regarding the losses from a field, these are determined by interactions between the actions of the farmer and processes in the soil - plant system. For example, losses will depend on the type of crop, tillage practice, the amount of nutrients applied and the soil type, etc. Since the processes in the soil and waterways are influenced by the weather, they are clearly stochastic, adding complexity.

Incentives to achieve the so-called first-best allocation[8], e.g. taxing the farmers according to the resulting marginal damages from their losses, are clearly unrealistic. Even though it is possible to measure the ambient concentrations of the different pollutants, it is impossible to measure the individual contributions.

In the following some of the options aimed at reducing the negative externalities from agriculture will be discussed. The discussion will not be exhaustible, and only economic instruments are discussed. Non-economic options are for example information and education programs, economic support to research and development, and direct regulations. All these policy options are to some degree present in the Norwegian agricultural policy. For a more complete review of economic policy options, the reader is referred to Shortle and Horan (2001) and Horan and Ribaudo (1999).

When designing policy instrument there are three important issues that need attention: who to target, what to target (what compliance measure to use or where to place the incentives) and how to target (how to induce the desired changes or mechanism). Regarding the first issue, farmers are clearly the polluters, but as argued above, it is uncertainty about the contributions of individual farmers. Both individual farmers and groups of farmers may be targeted, dependent on the compliance measure. When choosing what to target, the compliance measure should be correlated with the environmental problem at hand, enforceable and targetable (in practical terms). The literature in this field has focused three different general

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[8] The first-best allocation is defined in the absence of transaction costs. As noted above, externalities exist due to transaction costs. This means that the so-called first-best allocation is defined for a situation that does not exist. Still, we will use first-best as a reference point.

options: ambient concentration, emission proxies and inputs/practices (Shortle and Horan, 2001). Regarding how to target, Shortle and Horan (2001) list the following options: taxes/subsides, standards, markets, contracts/bonds and liability rules. In this thesis standards and markets will be termed non-tradable quotas/permits and tradable quotas/permits, respectively. In theory it is possible to use permits to regulate practices, however, this option is normally used on inputs. We will see below that also outputs may be targeted, and should therefore also be added to the list. Relevant options are shown in Table 2.

Table 2. Non-point pollution control instruments.

	Compliance measure		
Mechanism	Inputs/Outputs/Practices	Emission proxies	Ambient concentration
Taxes/Subsidies	X	X	X
Non-tradable permits	X	X	
Tradable permits	X	X	
Contracts/Bonds	X		
Liability rules	X		X

Source: adapted from Shortle and Horan (2001:258).

Inputs/outputs/practices and ambient concentration are rather straight forward in the sense that these compliance measures are directly based on observable objects or actions. Emission proxies are a collection of different approaches that approximate emissions. For example, the proxy may be based on modeled losses or nutrient balances. Regarding the latter, if both the input use and the amounts of nutrients removed with harvest are measured (or modeled), it is possible to estimate the amount of the applied nutrients that remain in the soil after harvest, i.e. the nutrient surplus. This surplus is correlated with the emissions. In the following we will focus on the first compliance measure (inputs/outputs/practices).

Griffin and Bromley (1982) develop what they call a nonpoint externality theory. They show that if the relationships between the different inputs and outputs and emission (they call these relationships nonpoint production functions) are known with certainty, it is possible to set up an efficient (first-best) system of taxes/subsidies or permits. Taxes are levied on inputs and outputs that are negatively related to emissions, while subsidies are used if the input or output reduces emissions. Unless all farms are equal, this means that the efficient policy, i.e. permit levels or tax/subside rates, is farm specific. If uncertainty is added to the model, Shortle et al. (1998) show that this policy still can result in the first-best solution. However, Shortle and Horan (2001:266) note that this tax/subsidy system "…is a nice theoretical prescription for obtaining the first-best allocation, but unrealistic. The scheme is exceptionally information intensive and complex…". The discussion about transaction costs is almost absent in this literature, but it is evident that as the precision increases, i.e. loosely speaking the "distance" to the first-best allocation, the costs of information increase. In other words, there is a need to balance precision and transaction costs.

One issue related to this is information asymmetries. They pose challenges in all types of transactions, including public regulations. For example, abatement costs (costs of reducing pollution) differ from farm to farm, but this is in most cases private information. This may cause moral hazard and adverse selection problems, especially if the regulation is farm specific. In general, private information will lead to uncertainty about the outcome (reduction of damages) since the regulator does not know the response to incentives. In terms of a tax on inputs, there are uncertainties about the tax level that would lead to the wanted reduction in pollution (or the optimal reduction). Griffin and Bromley (1982) note that this problem can be solved by an iterative process where the tax rate is changed (by trial and error) until the goal is met. If the goal is linked to ambient standards, this may in reality not be as easy at it seems. Since processes are stochastic, mainly due to the weather, changes in the ambient concentrations are due to both changes in the weather and the induced changes in farming practice. Hence, it is close to impossible to use the iterative procedure. If reductions are defined in terms of input use, output levels or practices, the iterative procedure may work. However, it adds another type of uncertainty that may affect farmers' response: policy uncertainty. Since it is not costless for farmers to adjust to new and/or changed polices, they may respond differently if they expect the change to last than when they expect the policy to change in the near future. This is discussed in Paper 1.

There are methods that may reveal (at least some) private information, e.g. screening, signaling and auctions. However, it is outside the scope to discuss this issue further. The reader is referred to the rather a large literature on contract design, e.g. the seminal works of Akerlof (1970), Spence (1973) and Stiglitz (1975). In addition, Shortle and Horan (2001) review the literature relevant for non-point source pollution, and Latacz-Lohmann and van der Hamsvoort (1998) discuss auctions for public goods provision.

The choice between targeting inputs, outputs or practices will of course depend on correlation with the environmental problem and tractability. Losses of soil are mainly dependent on management choices (especially tillage practice and crop cover in winter), since the main drivers are surface processes. Hence, regulating input use will have little or no effect. In stead one could tax practices that increases erosion, subsidize practices that reduces erosion or both. All three will be equally efficient in the short run if we assume zero transaction costs. This since the choice of the farmers is determined by the relative profitability of the different practices. In the long run taxes and subsidies yield different entry and exit incentives, hence the short and long run effects may differ. The costs of control may, however, vary. In the case of a subsidy, at most only those who apply for a subsidy on certain practices will have to be controlled, while in the case of a tax (and the combination of tax and subsidy) all farmers may be controlled. Even though there are costs of processing applications for subsidies, total transaction costs are probably lower in the subsidy case than for the other two options.

Regarding losses of nitrogen and pesticides, targeting input use is in most cases the preferable option. Practices are in general less correlated with the losses.

As is shown in Papers 3 and 4, transaction costs are lowest for uniform input taxes, and these costs are almost negligible. The reason is that the tax is levied on a good that is traded in a (well-functioning) market. This requires only one piece of information, the amount traded. If the scheme is implemented at an aggregate level, i.e. wholesale dealers, importers or producers, the number of point to collect information from will be low. The disadvantages are that it is blunt, in the sense that it does not discriminate according to marginal damage, and that the income effect is larger than alternative instruments (as discussed in Papers 1 and 2). It is possible to decrease the income effect by a lump sum reimbursement, but this will increase transaction costs.

One alternative to input taxes is input quotas, either tradable or non-tradable (Papers 1 and 2). This means that each farmer is granted the right to use or purchase a certain amount of a given input. If the quota is tradable, he/she might sell some of his/her quota to others or buy additional rights in the quota market. If the farmer is free to trade with whoever he/she likes, this will reduce the need for control, but at the same time it may change the environmental effect since quotas can be traded from less to more polluting farms (or vice versa). Tradable quotas will also result in lower income effects than comparable non-tradable quotas and a uniform input tax. Both types of quotas will have a lower income effect than a tax since there is no tax to be paid and the input use is roughly the same. Trade will only take place if both buyer and seller benefit from the trade. Hence, making quotas tradable will reduce the income effect. Transaction costs may reduce trade (Paper 1), and they are linked to the rules of trade. If the income effects (or abatement costs) are important, there should be few restrictions on trade. If there are large differences in how the different sources influence the recipient, a non-tradable quota might be better.

Theoretically it is not hard to set up a “perfect” incentive structure, but the world is not “perfect”. In my view, it is better to use an imprecise policy measure that is transparent – in the sense that everyone can understand what is going on – and easy to implement than a overly complex instrument that is costly to implement.[9]

3.2. Public goods

We will now turn to public goods and different policy options. Public goods and public bads are clearly different in their appearance, but as (hopefully) will become clear, there are no large differences when it comes to sensible policy options.

The major difference between public goods and public bads is that the value of the former is positive and the latter is negative. Does this mean that (private) bads cannot be traded? This may be a matter of definition, but e.g. industrial waste may change “owner” more times before the final treatment. In stead of paying for the waste, one is paid to take care of the waste. Thus, not even the sign of the value seems to not matter much.

In most cases pollution from agriculture cannot be traded, in physical terms, since it is diffuse and often dissolved in water. Even though pollution rights may be traded (implicitly), the impossibility to trade the pollution directly means that there is a difference between point and non-point externalities. However, even here the difference with respect to efficient allocations is not as large as it might seem. Recall from above that Griffin and Bromley (1982) show that a set of input and output taxes/subsidies would result in an efficient allocation in the case of non-point pollution, given knowledge about the nonpoint production function. The latter is a representation of the relationship between different inputs and outputs and emission. Emission is just another output, and the partitioning of the inputs and outputs is really arbitrary. Hence, if input taxes/subsidies can lead to efficient allocations in the case of non-point outputs the same type of policy instrument can also result in efficient allocations in the case of point outputs. It should be kept in mind that transaction costs are assumed away in the model. Thus, their policy instrument may not be the optimal when regulating a point output.

The most important difference between point and non-point outputs is the possibility to

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[9] This applies for the major types of pollutants in agriculture. If there is a large variation in emission between sources or damages are sensitive to extremes in emission, increased precision may be justified.

measure them. Commodities are well-defined, and since they are traded in a market they must be easy to measure. Hence targeting commodities are easy and the cost of doing so is low. As the outputs get more diffuse, our (current) ability to measure them becomes poorer and the targeting costs increase. The important question in this respect is: are the public goods produced in agriculture point or non-point goods?

The correct answer, at least semantically, is neither. Loosely speaking, if they were point outputs they could be traded in markets, i.e. they would be private goods. At the same time they are more observable and measureable than non-point source pollutions. This means that "pointness" is relative.

This does not mean that the distinctions between goods and bads and between point and non-point sources are meaningless, but for policy prescriptions they are only important to the degree they affect transaction costs. Hence, most of what is said for the case of non-point pollution applies also for public goods.

Most of the public goods jointly produced with commodities in agriculture are 'diffuse'. Not in the same sense as for diffuse pollution, but in the sense that they are not as well-defined as commodities. For example, what constitutes a cultural landscape? Is it topography, the crops grown, the size of the fields, grazing animals, border elements or everything? Unless we know this, valuation of the cultural landscape becomes very challenging. Valuation is necessary if we want to devise first-best policies. Still, we know that people value the agricultural landscape, but we do not know enough about how these values are formed. The conclusion is that the precision of any landscape policy cannot be very high. Similar argument may be used for the other public goods. It should be noted that some public goods may be more well-defined than others, for example some elements of cultural heritage, and for such goods it is possible to reach a high level of precision.

Regarding policy options, we may target the public goods directly or utilize jointness and target inputs, outputs or practices that are correlated with the public good in question. As is shown in Papers 3 and 4 there are large differences in transaction costs, with commodity support yielding (dramatically) lower transaction costs. On the other hand, commodity support may for some goods result in lower precision which also must be taken into account. If many public goods are jointly produced with commodities, the likelihood that the reduction in transaction costs is larger than the losses due to reduced precision increases.

Jointness is due to either physical/biological processes or economic factors like fixed allocable inputs. Setting the relative prices at the right levels is the main challenge in the latter case. This means that subsides/taxes on inputs, outputs and practices (or technology) is a viable option to secure optimal production of public goods. Transaction costs are important also in this setting.

Paper 3 deals with the other source of jointness, jointness due to biological and/or physical processes. This type may be divided into two sub-types: fixed and flexible. If jointness is fixed it is not possible alter the proportions of the two (or more) outputs, given the level of the outputs. Since the jointness is "locked" the optimal policy is to target the output that results in lowest administrative costs. If the jointness is flexible the policy that maximizes welfare will depend on more factors than just transaction costs. Flexibility implies that it is possible to increase the output of the e.g. non-commodity for a given level of the commodity output. However, if only commodity output support is used, there are no incentives for farmers to increase the level of the non-commodity output. This may (or may not) be optimal, dependent on the welfare function, the costs of increasing the non-commodity output, the budget (or scale of production) and the difference in transaction costs between the policy options. This means that it is not possible to draw a general conclusion with respect to the optimal policy option – precision (and the implied costs) needs to be balanced against the costs of regulation.

Even though the use of commodity price support, set at the right levels, can be shown to be efficient, it is not without problems. Commodity support can clearly be seen as trade distorting. It is also possible to view this from the opposite angle: free trade is distorting optimal polices for public goods provision. This is clearly a matter of rights, in which economics not necessarily should play the main role. Global efficiency reasoning seems more important than the discussion about rights in the trade-talks. As a WTO member we should of course abide by the rules, but we should be aware of the consequences.

4. The agricultural policy in Norway

Agriculture occupies 3.4% of the total mainland area of Norway (2.8 of the total area), and agriculture must thus be said to be a marginal land use activity. Due to the length of the country – from about 57° 57' to about 71° 11' northern latitude – and a varied topography, conditions for agricultural production vary throughout the country.

According to Statistics Norway (2008a) there were 51200 agricultural holdings in 2005, and a total agricultural area of about 1 million hectares. This means that the average holding is about 20 hectares. The average holding size in EU-25 is about 16.6 hectares (calculated from Eurostat, 2007b). The difference is even larger when we look at the distribution by holding size (Table 3). From the table we see that almost half of the farms in the EU-25 are less than 5 hectares, and that the enlargement (form 15 to 25 member states) has lead to a large increase in the share of very small farms. According to Eurostat (2007a:35) more than 90% of farms with over 10 hectares are located in the old member states. Without going into a lengthy discussion, this implies that the diversity in the EU is larger than in Norway, despite the large variation in climatic and topographic conditions in Norway.

Table 3. Agricultural holdings (%) in the EU and Norway by holding size, 2005.

	<5 ha	5-10 ha	10-30 ha	30-50 ha	>50 ha
EU-25$^{1)}$	45	18	20	6	10
EU-15$^{1)}$	37	30	26	4	3
Norway$^{2)}$	12	19	51	13	5

Sources: $^{1)}$ Eurostat (2007a), $^{2)}$ Statistics Norway, 2008b.

If we compare the farm size in Europe with other countries, agriculture in Europe must be said to be small scale. For example, the average holding size in Australia in 1997 was about 3200 hectares (calculated from Bureau of Rural Sciences, 2001). Scale is important for the profitability and thereby competiveness, and is therefore one factor that may affect the “need” for support.

The total support in 2006 to producers in the OECD countries is estimated to € 214 billion, which is about 27% of total farm receipts (OECD, 2007). The latter is termed producer support estimate, PSE. However, there is a large variation between the different OECD countries. The PSE for some selected countries are shown in Figure 1.

There are two other countries with about the same level of percentage PSE as Norway and Switzerland: Iceland and South-Korea. The figure indicates that the agricultural policy has been fairly stable in Norway over the last 20 years. Except for New Zealand, which reduced support to almost zero in the late 80ies, there have been few large changes, while in general the support level is declining (in percentage terms). Still, the PSE for Norway (65%) is almost 2.5 times the OECD average (27%). In absolute terms, the PSE for Norway were about the same for the periods 2004-06 and 1986-88, the latter estimated at NOK 19083 million (OECD, 2007).

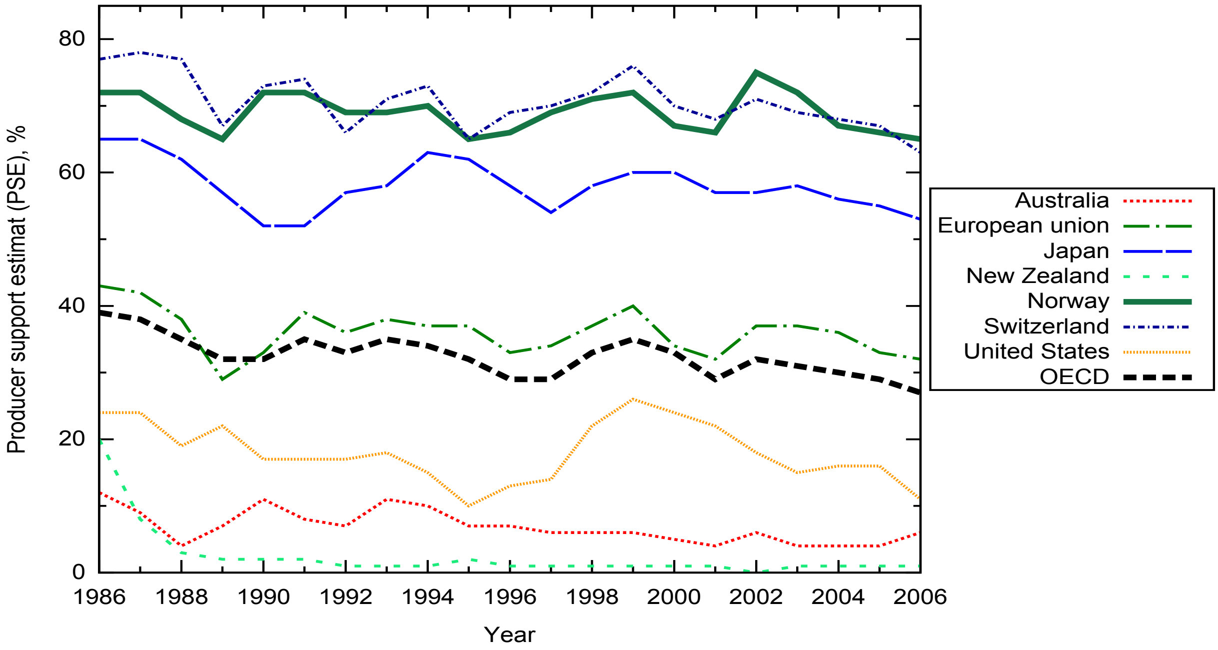

Figure 1. Producer support estimate, in %, for selected countries. Source: OECD (2007).

The PSE includes both budgetary support and indirect support like border measures (tariffs, import quotas, etc.) combined with target prices. The indirect support and payments based on outputs leads to a gap between the prices farmers receive and border prices. In 2006 the market price support was about 44% of the PSE, and the ratio between the average price received by the farmer and the border price (producer NPC) was 2.25. Even though support based on commodity output (in % terms) has declined over time, producer NPC is still significantly higher than the OECD average.

In Norway commodity output based support is complemented by a variety of other support measures, e.g. based on acreage and headage. Most of these other payments and target prices are set in annual negotiations between the government and farmers' organizations. A large share of the measures not based on commodity outputs are differentiated by geographical location (regions) and farm size (acreage and number of animals).

Only few large payment schemes target the production of public goods and bads directly: cultural landscape payment and taxes on pesticides. Other agri-environmental programs are handled regionally/locally, hence, measures vary throughout the country. Measures include support for reduced tillage, constructed wetlands/retention ponds, buffer strips and hydro technical installations. All are aimed at reducing erosion and losses of phosphorus. No economic measures are used to reduce the losses of nitrogen. Until the late 90ies there was a tax on nitrogen (and phosphorus) in fertilizers, but it was removed in favor for other measures. The main argument was the negative income effect (Ministry of Finance, 1999).

One measure that was introduced was mandatory fertilization plans, but the regulation does not contain any quantitative restrictions on the use of fertilizers. Some areas in Norway are defined as nitrate sensitive areas where the nitrogen application restrictions of the EUs nitrate directive apply.

The total support estimate (TSE), which measures the overall agricultural support financed by consumers, was about NOK 20.7 billion in 2006. This is about 1% of GDP, which is about the same as the OECD average (OECD, 2007).

The farm gate value of production (NOK 18.8 billion) is less than the support (PSE = NOK 19.1 billion and TSE = NOK 20.7 billion). However, the total value of production is larger since the OECD estimate only includes commodities. Politically the value of the non-commodity outputs can be said to be large since the agricultural policy has been supported by various governments and parliaments during the last 20 – 30 years. If we are concerned about the resource allocations, this is however not a satisfactory observation.

The high level of support is not a large problem for Norway per se. Norway is a rich country, and spending about 1% of GDP on agricultural support is accepted by a large majority of the population. Still, 20 billion is a large sum, and the money may be used more effectively (in terms of welfare) in other sectors. Unfortunately, reliable estimates of the non-commodity values necessary to estimate the optimal “size” of Norwegian agriculture and the optimal policy mix are missing.

Even if we utilize economies of scale, i.e. increase the size of Norwegian farms, support is needed in order for agriculture to “survive” given current world market prices. Flaten (2003) uses a partial equilibrium model (JORDMOD) to estimate the effects on Norwegian agriculture from removing support completely and removing “only” border measures. Without any support Norwegian agriculture will vanish (almost completely). Only potato production and a very small grain area will “survive”. In the case only border measures are removed, the agricultural area will be reduced by about 87%. Only production of sheep meat will increase, while other productions will decrease dramatically compared to the base situation (1998). Flaten (2003) emphasizes that the results should not be taken literally, but they indicate that the competitiveness of Norwegian agriculture is (very) low (even if allowed to utilize economies of scale).

Brunstad el al. (1999; 2005) are attempts to include public goods production in a partial equilibrium framework by including cultural landscape and food security in the model.

Landscape is included by using a willingness to pay function. In Brunstad et al. (1999:542) they present a table over the willingness to pay to prevent a reduction in the agricultural landscape by one-half. The willingness to pay varies with the parameters of the function, and ranges from NOK 0.5 billion to about 3.0 billion. They stress that the estimates are uncertain, but still use them in their policy evaluations. If we take their approach to the extreme and use their willingness to pay function (and using the same parameter values as used in Brunstad et al., 2005), the total value of the Norwegian agricultural landscape is larger than NOK 20 billion. Hence, the current Norwegian agricultural policy would pass a benefit – cost test.

I fully agree that the parameters are highly uncertain, and that results form using then should be treated with great care. Nevertheless, Brunstad et al. (2005) conclude that at most 40% of the current support level can be defended by the production of the two public goods in question. The reduction in support would reduce the agricultural area by 36%. They also acknowledge that other public goods may affect (increase) the optimal support level.

More research is needed in order to find the optimal policy mix and level of support. Better estimates of the values of the public goods produced in agriculture are essential in this respect. As argued above, using commodity support to secure public goods production is clearly a viable option resulting in very low transaction costs, but more research on the (physical) relationship between private and public outputs is needed in order to device the optimal policy.

5. Abstracts of the papers

5.1. Paper 1: The effects of private transaction costs on tradable fertilizer quota markets

Private transaction costs may reduce trade in a fertilizer quota market since they reduce the net gain from trade. Transaction costs may influence both the decision to enter the quota market and the amount traded. A micro economic model is developed in the paper in order to analyze how fixed and variable transaction costs affect these two decisions.

The theoretical model is used to simulate fertilizer quota markets in four Norwegian regions under the assumption of a well functioning quota market, i.e. only variable transaction costs are included. The model is run for a wide range of transaction costs and quota levels.

The results show that transaction costs have a modest effect on trade, even at extremely high levels. Trade will increase if allowed between regions, but this has only a small effect on the aggregate nitrate loss. The effects within each region are larger.

The differences in aggregate environmental effects between tradable quotas, non-tradable quotas and a (comparable) fertilizer tax are very small. This implies that the aggregate nitrogen losses are mainly governed by total nitrogen use. If the income effect is a concern, this implies that the regulator should implement a tradable quota system with as low as possible transaction costs. Hence, a scheme with few, if any, constraints on trade is preferable.

5.2. Paper 2: Policy measures to induce split application of fertilizers

This paper is coauthored with Eirik Romstad.

The effects of pollution from nature based productions – like agriculture – do not only depend on the production decisions made. Nature, or more specifically the weather, is the main driving force in such productions. If possible, policies to reduce the environmental damages should therefore also seek to incorporate "the game nature plays".

The characteristics of nature based productions vary. Consequently, policy instruments needs to be tailored to the specific production and environmental problems. In grain production growing conditions vary considerably between years. This variation carries over to the environmental damages. Research indicates that split fertilization is a promising measure to reduce nutrient leaching from agriculture since this opens up for utilizing information as it becomes available during the growing season. Split application of fertilizers in grain is rarely used, indicating higher profits from fertilizing only at the beginning of the growing season.

This paper looks at policy measures to induce farmers to practice split fertilization. These measures include a two-tiered input tax and a two period system of fertilizer quotas. It is demonstrated that a two-tiered tax will not work, due to the necessarily large difference in tax level between the two periods and the possibility to store fertilizers from one year to the next.

We have analyzed the effects of split fertilizer quotas and taxes on fertilizer nitrogen in southeastern Norway under current climatic conditions and under a possible future climate (2010 – 2048). The results show that the split quota will reduce losses to the environment at lower costs (both private and social) than a tax. Further research is needed to investigate if these promising results also hold in other regions in Norway.

5.3. Paper 3: Multifunctional agriculture – the policy implications of jointness and positive transaction costs

This paper is coauthored with Arild Vatn.

In a transaction cost free economy, jointness is of little interest since providing the incentives to farmers for producing all goods at the optimal levels is costless. However, regulation is not costless, and the paper shows that transaction costs are much lower for polices targeting commodities than polices targeting other goods. Also, the analysis shows that transaction costs can be reduced dramatically by reducing the number of support schemes.

If a non-market good is linked to a commodity in a way that cannot be altered by the farmer, what we term fixed proportions, targeting the commodity is the optimal policy, since it results in lowest transaction costs.

One property of (physical) joint production is that it exhibits economies of scope. This means that separate production of non-market goods and imports of commodities is optimal only if the difference between domestic costs and the world market price is large.

In the case of flexible proportions, i.e. it is possible to alter the relationship between outputs, it is not possible to draw universal conclusions regarding what type of output to target. The recommendation will depend on the trade-off between reducing transaction costs and securing precise delivery of the public good.

For a small country that is not competitive at world market prices, like Norway, we suggest, to use commodity support up to a certain point and to combine this with specific support schemes more directly targeted at the non-market goods to increase precision.

5.4. Paper 4: Why do transaction costs of agricultural policies vary?

This paper is coauthored with Arild Vatn and Valborg Kvakkestad and is published in *Agricultural Economics* **36**(1):1-11.

Policy related transaction costs (TCs) is an important issue when evaluating different policy options. However, TCs are often not taken into account in policy evaluations, but may be as important for efficiency as the direct production costs. Different policies may result in different TCs, and the main aim of the paper is to explore possible reasons for these differences. We compare the level of TCs for 12 different agricultural policy measures in Norway, and we analyze the causes of the differences along three different dimensions: asset specificity, frequency, and point of policy application. At the national level we find that all three dimensions are of importance when explaining the differences, while variation in TCs incurred by farmers are mainly due to differences in point of policy application and asset specificity. Data show that direct price support has the lowest TCs, while more direct payments for environmental amenities have the highest.

6. The relevance of the papers

It is argued above that there are no large fundamental differences between public goods and public bads in the sense that the same type of policy instrument may be used in both cases. However, in terms of scale there is a difference. Pollution (public bads) is foremost linked to intensity (input use and practices) while public goods are more linked to the presence of agricultural production and the structure of the agricultural sector. While public bads may be regulated at the micro level, public goods may be dealt with more effectively at the more aggregate level – that is, the more general agricultural policy.

Regarding public bads in Norway, economic instruments are only used to regulate pesticide use. As mentioned above, taxes were used earlier on nitrogen and phosphorus, but replaced by compulsory fertilizer plans without quantitative restrictions on nutrient use. This will raise awareness about the problem, but the precision of this instrument must be said to be poor. One disadvantage of a tax is the negative income effect, and two of the papers in this thesis (Papers 1 and 2) discuss two alternatives with lower negative income effects: tradable fertilizer quotas and split application of fertilizers (in the form of quotas in two rounds). The former is clearly a viable option, both in Norway and elsewhere. Regarding the latter, more research is needed before a definite conclusion can be drawn. The results from the simulations are promising. However, this instrument uses the expected yearly optimal fertilization level, and more research is needed to investigate the possibility, accuracy and costs of estimating this.

Public goods are jointly produced with commodities. Due to the high cost level and unfavorable growth conditions in Norway, agriculture is not competitive given current world market prices. Without any support Norwegian agriculture will (almost) vanish (Flaten, 2003) or at least, the levels of public goods will fall short of the demand (Brunstad et al., 2005:484). This is also the situation in other countries like Iceland, Finland and Switzerland. Papers 3 and 4 are very relevant in this respect. The results from the papers support in principle the current Norwegian agricultural policy regarding the types of policy instruments used, i.e. support base on commodity output combined with other measures. However, the analyses clearly show that policy costs can be reduced substantially by reducing the number of policy schemes. Transaction costs in Norway can be reduced by using few and large commodity based support schemes, supplemented by smaller schemes targeting public goods production more directly. The first would induce a certain level of production, while the latter may be use to fine-tuning public good production. If the agricultural sector is competitive and self-sufficient, output based policies will in most cases have distortive effects and should be avoided.

The efficient policy mix will differ from country to country due to differences in the links between commodities and public goods and bads. This means that efficiency in the international commodity markets may lead to inefficiencies in public goods/bads production in some countries.

7. References

Akerlof, G. (1970). The market for “Lemons”: Quality uncertainty and the market mechanism. *Quarterly Journal of Economics*, **84**(3):488-500.

Brunstad, R.J, I. Gaasland & E. Vårdal (1999). Agricultural production and the optimal level of landscape preservation. *Land Economics*, **75**(4):538-546.

Brunstad, R.J, I. Gaasland & E. Vårdal (2005). Multifunctional agriculture: an inquiry into the complementarily between landscape preservation and food security. *European Review of Agricultural Economics*, **32**(4):469-488.

Bureau of Rural Sciences (2001). *Land use change, productivity and diversification. Final report of theme 5.1 to the National Land & Water Resources Audit*. Bureau of Rural Sciences, Kingston, Australia.

Coase, R.H. (1960). The Problem of Social Cost. *Journal of Law and Economics*, **3**(1):1-44.

Eurostat (2007a). *Agricultural statistics. Data 1995 – 2005.* Eurostat Pocketbooks. Office for Official Publications of the European Communities, Luxembourg.

Eurostat (2007b). *Europe in figures. Eurostat yearbook 2006-07.* Eurostat Statistical books. Office for Official Publications of the European Communities, Luxembourg.

Flaten, O. (2003). Norsk mjølkeproduksjons konkurranseevne i forhold til andre land. *Landbruksøkonomisk forum*, **20**(2): 5-15.

Hanley, N, J.F. Shogren & B. White (1997). *Environmental economics in theory and practice*. Macmillan Press.

Horan, R.D & M.O. Ribaudo (1999). Policy objectives and economic incentives for controlling agricultural sources of nonpoint pollution. *Journal of the American Water Resources Association*, **35**(3):1023-1035.

Kolstad, C.D. (2000). *Environmental economics*. Oxford University Press.

Latacz-Lohmann U. & C.P.C.M. van der Hamsvoort (1998). Auctions as a means of creating a market for public goods from agriculture. *Journal of Agricultural Economics* **49**(3):334–345.

Matthews, R.C.O. (1986). The Economics of Institutions and the Sources of Growth. *The Economic Journal*, **96**:903-918.

Ministry of Finance (1999). *St.prp. nr. 67 (1998-99) Omprioriteringer og tilleggsbevilgninger på statsbudsjettet 1999.* Norwegian Ministry of Fincance, Oslo.

Norwegian Institute of Public Health (2007). *Salmonellose. Smittsomme sykdommer fra a-å.* Available at (accessed May 2008): http://fhi.no/dav/84fb65458f.pdf

OECD (2001). *Multifunctionality: Towards an analytical framework.* OECD, Paris.

OECD (2007). *Agricultural policies in OECD countries: Monitoring and evaluation 2007.* OECD, Paris.

Romstad, E., A. Vatn, P.K. Rørstad & V. Søyland (2000). Multifunctional Agriculture - Implication for Policy Design. *Report No. 21*. Department of Economics and Social Sciences, Agricultural University of Norway. Available at (accessed May 2008): http://www.umb.no/ios/Publikasjoner/melding/m-21.pdf

Shortle, J.S & R.D. Horan (2001). The economics of nonpoint pollution control. *Journal of Economics Surveys* **15**(3):255-289.

Shortle, J.S, R.D. Horan & D.G. Abler (1998) Research Issues in Nonpoint Pollution Control. *Environmental and Resource Economics* **11(**3–4**):** 571–585.

Spence, A.M. (1973). Job Market Signaling. *Quarterly Journal of Economics*, **87**(3):355-77.

Statistics Norway (2008a). Focus on farming. Available at (accessed May 2008): http://www.ssb.no/english/subjects/10/04/10/jordbruk_en/

Statistics Norway (2008b). Sample survey of agriculture and forestry 2007. Available at (accessed May 2008): http://www.ssb.no/lu_en/

Stiglitz, J.E. (1975). The Theory of "Screening," Education, and the Distribution of Income. *The American Economic Review*, **65**(3): 283-300.

Vatn, A. (2005). *Institutions and the Environment*. Edward Elgar, Cheltenham UK, Northampton USA.

PAPER 1

The effects of private transaction costs on tradable fertilizer quota markets

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Abstract

Private transaction costs may reduce trade in a fertilizer quota market since they reduce the net gain from trade. Transaction costs may influence both the decision to enter the quota market and the amount traded. A micro economic model is developed to analyze how fixed and variable transaction costs affect these two decisions.

The theoretical model is used to simulate fertilizer quota markets in four Norwegian regions under the assumption of a well functioning quota market, i.e. only variable transaction costs are included. The model is run for a wide range of transaction costs and quota levels.

The results show that transaction costs have a modest effect on trade, even at extremely high levels. Trade will increase if allowed between regions, but this has only a small effect on the aggregate nitrate loss. The effects within each region are larger.

The differences in aggregate environmental effects between tradable quotas, non-tradable quotas and a (comparable) fertilizer tax are very small. This implies that the aggregate nitrogen losses are governed by total nitrogen use. If the income effect is a concern, this implies that the regulator should implement a tradable quota system with as low as possible transaction costs. Hence, a scheme with few, if any, constraints on trade is preferable.

Key words: tradable permits, transaction costs, trade, leaching of nitrogen

1. Introduction

1.1. The environmental problem

Agricultural production inevitably leads to different losses to the environment. Some of these losses are harmless, some have negative consequences for society and/or the environment and in some cases the effects may be positive. These effects are normally not taken into account when farmers make their decisions, thus they are externalities. If the aim of society is to maximize (or at least improve) welfare we may need to correct for these externalities.

Nitrogen is one compound that is lost from agriculture, and it is lost to water courses mainly in the form of nitrate. The main challenge when controlling losses of nitrogen from agriculture is the diffuse or non-point nature of the losses. This means that it is technically hard and/or (very) costly to regulate the losses directly. In practice this means that we need to use a proxy for the losses. One approach is to form a common liability among the involved farmers for the ambient quality in a water course (see Segerson, 1988; Romstad, 2003;

Hansen and Romstad, 2007), but this will not be discussed in this paper. Another approach is to target factors that are closely linked to the losses of nitrogen. In most cases this means that the input use, i.e. the use of fertilizers or the utilization of animal manure, is targeted. The logic is that reduced input use will lead to reduced losses to the environment. Two policy instruments are analyzed in this paper: fertilizer nitrogen quotas and taxes on fertilizer nitrogen. The main focus will be on the former.

A uniform input regulation (e.g. tax or input quota) will in general not be efficiency (i.e. minimize total costs) with respect to pollution reduction. The simple reason is that the relationship between input use and losses to the environment vary for different farms and differs even more between individual farm fields. They are mainly due to farm specific factors like climate, crop, soil type, etc. If regulation is costless, an efficient regulation should capture these differences in losses. However, we know that regulation is not costless, and the costs will increase as the precision (or complexity) of the policy instrument increases. This means that a less precise policy may be the least cost option.

1.2. Transaction costs

There is a plethora of transaction costs definitions. One of the most open definitions is: "In the broadest sense transaction costs encompass all those costs that cannot be conceived to exist in a Robinson Crusoe economy where neither property rights, nor transactions, nor any kind of economic organization can be found….. In short, they comprise all those costs not directly incurred in the physical process of production." (Cheung, 1987:56).

This definition is clearly too broad to be operational, especially since it is not defined in terms of transactions but their absence. A useful operationalization of the concept is to split transaction costs into three elements: the cost of information gathering, the cost of contracting, and finally the cost of monitoring and enforcement (Dahlman, 1979; Stavins, 1995).

Since all transactions require (at least) two actors, there will be costs on both sides, e.g. time spent on negotiating a deal. However, this does not necessarily mean that both pay their own costs. One, maybe somewhat farfetched, example is the court ruling where one party is liable for the other party's legal fees. Also, there is no symmetry regarding what type and the size of transaction costs the different actors involved in a transaction bear. This is especially important when analyzing policy instruments since the distribution of transaction costs may vary substantially between different policy options.

If a tax is levied on fertilizers, farmers will not incur any transaction costs[1]. In this case the policy is normally implemented at producer/importer, wholesaler or retailer level, and they, in addition to the regulatory agency, bear all transaction costs. In the case of tradable permits both the regulatory agency and the farmers bear transaction costs. The regulatory agency must award the permits and control that trades are according to the rules. The farmers must find information about the trade system, search for potential partners to trade with, negotiate contracts, etc. Clearly, the size and distribution of transaction costs is closely linked to the design of the policy.

Private transactions costs, i.e. those incurred by farmers, may play an important role for the trades in a quota market. If they are large they will prevent trades, since the gain from trade is less than the costs of trading. As will be shown below, transaction costs may influence both the decision to enter the quota market and how much to trade. Gangadharan (2000) finds that transaction costs reduce the probability of trade by 32% in an emission trading program in Los Angles. Stavins (1995) uses a theoretical emission permit model to show that the number of trades is negatively affected by transaction costs. Some if his hypotheses are “confirmed” by laboratory experiments (emission permit trading) by Cason and Gangadharan (2003).

If there are no transaction costs, the allocation of initial permits has only equity or distributional effects. Stavins (1995) and Cason and Gangadharan (2003) show that if marginal transaction costs are constant (or proportional to the value of the trade, e.g. broker fee), the initial allocation of permits still has no effect on abatement costs and the price in the permit market. Other types of transaction costs (non-constant marginal and fixed transaction costs) will have an effect. Montero (1997) finds that if participants have discrete technology choices, abatement costs and the permit price are sensitive to the initial allocation even in the case with constant marginal transaction costs.

These findings indicate that “…the supposed symmetry of taxes and permits become questionable, and the need to compare these instruments on a case-by-case basis becomes more compelling” (Stavins 1995:146).

1.3. The proposed quota system

If the efficiency of the market is important, the "market creator" should somehow seek to minimize these costs. Two aspects in this respect is that the system should be easy for the

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[1] The tax will change the optimal level of input use and the farmers will adapt to the new prices. However, this is part of his/her normal decision making process and represents hence no extra costs.

agents, here farmers, to understand and that the institution that takes care of the trade should be working "well". The system proposed here is as follows:

1. Each farm is awarded (for free) the right to purchase a certain amount of fertilizer nitrogen (the initial quota) a given year.
2. The nitrogen rights are tradable and the farmers may sell some or all of his/her rights or buy additional rights in a quota market. This means that the quota is fully divisible.
3. The physical fertilizer is bought in a separate market at a given price (v).

Compared to the case of non-tradable quotas, the proposed system will have lower or equal effect on farm income (given the same distribution of quotas). The reason is simple: trade will only take place if both parties gain from trade, i.e. all trades will increase the profits of the involved farmers. However, the effects on the environment (losses of nutrients) are generally not known apriori since the relationship between input use and pollution differs for the different farms.

The distribution of quotas will affect the individual income (an endowment effect). However, in the case of a tradable quota this is mainly an equity issue. This since the net surplus in the quota market will remain in the sector. In the case of a tax, the producer surplus will always be reduced. This means that at the aggregate level, a tax will lead to larger income effects than permits, given that both result in the same aggregate fertilizer use.

The difference may be substantial. Hansen (2004) estimates that the farm profit loss is about 18 times higher for a tax than for tradable quotas, both set to achieve a 10% reduction in nitrogen application. The difference in profit loss between non-tradable and tradable quotas is about 8%, if baseline use is known with certainty.

1.4. Aims and organization of the paper

On this background, the aims of the paper are as follows:

- Develop a theoretical model for the effects of transactions costs on farmers' behavior in a fertilizer quota market.
- Apply the theory developed to investigate to what extent transactions costs influence trade and the effect of this on the environment (leaching).
- Compare the effects on leaching of the proposed quota system to the effects of non-tradable quota and a comparable tax on fertilizer nitrogen.

In the first part of the paper a micro economic model is developed to analyze how different types of transaction costs (fixed and variable) affect farmers' behavior in the quota market. As with other types of fixed costs, fixed transaction costs do not affect the amount traded, but the decision to trade or not. Variable transaction costs affect both decisions, and it is therefore important to analyze them separately.

The results from the theoretical part are used in market simulations. Due to lack of data, results from another simulation model, ECECMOD (Vatn et al., 2006) is used to generate the necessary data: nitrogen demand and leaching functions. As such, the simulations may be viewed as a meta analysis and results should be taken as indications of the effects and not proof. With this said, the model has proven well in simulating farmers choices (see Vatn et al., 2006 for details).

2. Tradable permits in a profit maximizing framework

2.1. Introduction

Before we enter the analysis it is important to clarify the assumptions. We will assume that the farmers are maximizing expected profits. This recognizes that there are uncertainties involved. The weather during the growth season is the most important factor for variations in crop growth between years. Since the weather is unknown at the time the farmer makes the most the important decisions, he/she must base his/her decisions on expectations about the crop's response to controllable input factors. The uncertainty and variability in yields may, in addition to demand side uncertainties, lead to price uncertainties. While (input and output) price uncertainties may play an important role, it is outside the scope of this paper to include them in the analysis. Prices are therefore assumed to be known with certainty and fixed, i.e. do not vary with the level of the permits.

Regarding yield uncertainty, we will for simplicity assume that farmers are risk neutral, implying that only the mean matters. All production functions should therefore be read as functions for expected yields. Farmers are further assumed to be price takers in all markets, i.e. there is no strategic behavior in the quota market.

Since the main aim of this paper is to analyze the effects of transaction costs on tradable mineral nitrogen permits, other factors will be assumed to be constant. The nitrogen price in the quota market may affect other choices than mineral nitrogen. Since nitrogen utilization differs between crops, an increase in the nitrogen price or value (due to a reduction of the quotas) may change the crop rotation towards more "effective" crops. This may affect farm nitrogen demand, but it will not influence the way transaction costs affect trade in the permit market. Simulations (Vatn et al., 2006) indicate that crop rotations are affected by the N price, but the effects seem to be modest. Animal manure is also assumed away in the theoretical section. Finally, technology is assumed to be invariant to the size of the permits (and permit price). In the long run this may not hold since the quotas will affect the profitability of the farms, and investment decisions, exit from and entry into the sector, etc. are closely linked to profitability. This is linked to the permit as a policy instruments, and again it does not affect the way transaction costs influence the quota market.

2.2. No transaction costs

2.2.1. The maximization problem

Under the assumptions above, the short run maximization problem for a farmer participating in the quota scheme may be stated as[2]:

$$\underset{N_1,\dots,N_J,N^s,N^{cu}}{\mathrm{Max}} E\left[\pi(N_1,..,N_J,N^s,N^{cu})\right]=\sum_{i=1}^{J}a_ip_if_i(N_i)-vN^{cu}+v_mN^s-FC \qquad [1]$$

subject to

$$N^{cu}-N^s-\sum_{i=1}^{J}a_iN_i=0 \qquad [2]$$

$$0\le N^{cu}\le N^c \qquad [3]$$

$$N_i\ge 0\ \forall i \qquad [4]$$

where

a_i	area of field i, assumed to be larger than zero,
p_i	price of crop on field i,
$f_i(N_i)$	expected yield function for a given crop on field i[3],
N_i	amount of nitrogen (N) applied to field i,
v	base price on N,
N^s	amount of N sold (negative if purchase) from the farm,
v_m	effective price (base + premium) of N traded in the quota market,
N^c	total quota for the farm,
N^{cu}	amount of quota used, and
FC	fixed costs.

Equation [1] is the farmer's short run objective, i.e. maximizing expected profit given that other inputs than N are fixed. Equation [2] just states that what the farmer uses plus what he sells equals the quota he uses. This amount must be greater or equal to zero and less or equal to the total quota awarded to the farm ([3]). The last constraint ([4]) insures mass-balance for

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[2] The expectation operator will be omitted in the subsequent analysis. All references to profits should be taken to mean expected profit.

[3] It is certainly restrictive to assume that yield is only affected by nitrogen application in addition to crop type and field characteristics (e.g. soil type). Factors like tillage practice, the use of other nutrients than nitrogen and pest management will affect yield. As discussed in the previous section such factors are assumed to be invariant to the nitrogen price and hence are captured by the yield function.

fertilizers, i.e. prevents the theoretical possibility of applying a negative amount of nitrogen and selling it on the permit market.

Since the maximization problem is linear in the choice variables in all parts but the yield function, we know that the solution to the first order conditions (N_1^*,.., N_J^*, N^{cu*}, N^{s*}) is a maximum if the J production functions, $f_i(N_i)$, are concave in the optimal point. If they are strictly concave for positive nitrogen levels, the maximum is global (and unique). Since this is a biological process, the production functions may have a sigmoid-like shape, i.e. monotonically increasing, one inflexion point and convex at $N_i = 0$. In such a case the optimal solution is to the right of the point of inflexion or zero (corner solution). This is discussed in the appendix.

If we substitute [2] in [1] and [3] we can rewrite the problem as:

$$\underset{N_1,\ldots,N_J,N^s}{\text{Max}}\ \pi(N_1,..,N_J,N^s) = \sum_{i=1}^{J} a_i p_i f_i(N_i) - v\left(N^s + \sum_{i=1}^{J} a_i N_i\right) + v_m N^s - FC \tag{5}$$

subject to[4]

$$0 \le N^s + \sum_{i=1}^{J} a_i N_i \le N^c \tag{6}$$

$$a_i N_i \ge 0\ \forall i \tag{7}$$

The Lagrangian for this problem:

$$\begin{aligned} L = {} & \sum_{i=1}^{J} a_i p_i f_i(N_i) - v\left(N^s + \sum_{i=1}^{J} a_i N_i\right) + v_m N^s - FC + \mu\left(N^c - N^s - \sum_{i=1}^{J} a_i N_i\right) \\ & + \tau\left(N^s + \sum_{i=1}^{J} a_i N_i\right) + \sum_{i=1}^{J} \rho_i a_i N_i \end{aligned} \tag{8}$$

The first order conditions are:

$$\frac{\partial L}{\partial N_i} = a_i\left(p_i \frac{\partial f_i(N_i)}{\partial N_i} - v - \mu + \tau + \rho_i\right) = 0 \quad \forall i \tag{9}$$

$$\frac{\partial L}{\partial N^s} = -v + v_m - \mu + \tau = 0 \tag{10}$$

and the complementary slackness conditions are:

$$\rho_i \ge 0, a_i N_i \ge 0, \rho_i a_i N_i = 0 \quad \forall i \tag{11}$$

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[4] The non-negativity constraint on N_i is rewritten in order to ease the derivation of the optimality conditions. This does not change the optimality conditions since a_i is always strictly positive and the right hand side is zero. Of course, the value of the associated Lagrangian multiplier will change, i.e. be scaled, but this does not matter in our case.

$$\tau \geq 0,\ N^s + \sum_{i=1}^{J} a_i N_i \geq 0,\ \tau\left(N^s + \sum_{i=1}^{J} a_i N_i\right) = 0 \qquad [12]$$

$$\mu \geq 0,\ N^c - N^s - \sum_{i=1}^{J} a_i N_i \geq 0,\ \mu\left(N^c - N^s - \sum_{i=1}^{J} a_i N_i\right) = 0 \qquad [13]$$

As a start of analyzing the problem, let us have a look at the non-negative constraint on the input. Since $a_i>0$, we know from [11] that $\rho_i > 0$ when it is optimal to apply no nitrogen to field i. It is shown in the appendix that under normal conditions constraint [7] holds as a strict inequality (i.e. $N_i > 0$ and $\rho_i = 0$).

τ is zero if the sum of what is sold and what is used on-farm is positive. Recall from [2] that this equals the amount of the quota used (N^{cu}). N^{cu} may be zero in only two situations. First: if the farmer is not using nitrogen at all and selling nothing (N_i's and N^s are all equal zero). He is using no N if the price is very high, but when the price is high he should sell the quota. Therefore, we can rule out this situation. The second case is when all fertilizer the farmer is using is bought in the quota market. This will be profitable if the price in the market is less or equal to the base price ($v_m \leq v$). However, the price in the quota market (v_m) must be greater than or equal to the base price (v). The reasoning behind this is that no one will buy at one price and then sell at a lower price. This situation can therefore also be ruled out. Hence, the middle expression in equation [12] must hold as a strict inequality, i.e. $\tau = 0$.

The last multiplier, μ, is the shadow price of the total quota. From [13] we see that when the total quota is nonbinding $\mu = 0$ implying that $v_m = v$ (eq. [10]). Since v_m is the quota market price, this must hold for all farms in the market. Since the marginal value of the total quota is zero this means that the sum of all individual quotas is equal to or larger than the total optimal use of nitrogen at the price v. If the aim of the quota system is to reduce the total use of nitrogen, the total amount in the market should be less than what would be without the regulation. This means that the quotas are binding[5], i.e. $\mu > 0$ and $N^{cu} = N^c$.

The optimality conditions (eq. [9]) may now be restated as:

$$p_i \frac{\partial f(N_i)}{\partial N_i} - (v + \mu) = 0 \quad \forall i \qquad [14]$$

or by combing [9] and [10]:

$$p_i \frac{\partial f(N_i)}{\partial N_i} - v_m = 0 \quad \forall i \qquad [15]$$

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[5] This does not mean that all the individual quotas must be less than the use at the price equal v.

This is a standard optimality condition, i.e., value of marginal product equals marginal cost.

We have seen that $N_i > 0$ (and $\rho = 0$), and we may therefore drop equation [4]. If we assume that the quota is binding, we have from [3] that $N^{cu} = N^c$, since $N^{cu} > 0$ ($\tau = 0$). If we use [2] in [1] and substitute N^c for N^{cu}, the optimization problem ([1] – [4]) may be written as:

$$\underset{N_1,\ldots,N_J}{\mathrm{Max}}\,\pi(N_1,..,N_J;N^c) = \sum_{i=1}^{J} a_i p_i f_i(N_i) + (v_m - v)N^c - v_m \sum_{i=1}^{J} a_i N_i - FC \qquad [16]$$

It is straight forward to show that the first order conditions of [16] are identical to [15].

2.2.2. Nitrogen demand and supply

It is now possible to solve [15] with respect to N_i and find the nitrogen demand for each field as a function of the prices (p_i and v_m) and the parameters of the yield functions, $N^*_i(v_m, p_i;\beta)$. It is rather easy to show that the N-demand functions are falling in the input price, as long the yield function is concave (see the appendix).

If we assume that the yield functions are polynomials of third degree:

$$f_i(N_i) = \beta_{0i} + \beta_{1i}N_i + \beta_{2i}N_i^2 + \beta_{3i}N_i^3 \qquad [17]$$

equation [15] may be written as

$$3\beta_{3i}N_i^2 + 2\beta_{2i}N_i + \beta_{1i} - \frac{v_m}{p_i} = 0 \qquad [18]$$

Solving [18] yields the N-demand (or optimal N-use) for a field[6]:

$$N_i^*(v_m,p_i;\beta) = \frac{-\beta_{2i} \pm \sqrt{\beta_{2i}^2 - 3\beta_{3i}\left(\beta_{1i} - \frac{v_m}{p_i}\right)}}{3\beta_{3i}} \qquad [19]$$

If the yield functions are second degree polynomials, the N-demand is:

$$N_i^*(v_m,p_i;\alpha) = \left(\frac{v_m}{p_i} - \alpha_{1i}\right)\frac{1}{2\beta_{2i}} \qquad [20]$$

where α_{1i} and α_{2i} are parameters of the yield function.

The next step is to calculate the amount sold or bought in the quota market. Rearranging [2] we get:

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[6] Since we are solving a second order polynomial, there are two roots (solutions). We know from the second order conditions that the yield function is concave around the right root, i.e. the one that maximizes the objective. For admissible product functions, it can be shown that if the inflection point is positive, the sign in front of the square root term is minus (-) for the right root. The sign is plus (+) if the inflection point is negative.

$$N^s\left(v_m,p_i,N^c;\beta\right)=N^c-\sum_{i=1}^{I}a_iN_i^*\left(v_m,p_i;\beta\right) \quad [21]$$

Since the $N_i^*(\bullet)$ functions are falling functions of v_m, $N^s(\bullet)$ must be an increasing function in v_m, as is shown in the figure below. At the price v^0, the farmer is not trading, i.e. total use of nitrogen at the farm equals the quota. If the price is below v^0, the farmer will buy additional nitrogen in the quota market ($N^s(\bullet) < 0$), while for higher prices the farmer will sell some of his quota on the market.

If the quota is reduced, v^0 will shift to the right. This since $N^s(\bullet)$ shifts down when N^c is reduced (see [21]). The intuitive explanation to this is that when nitrogen gets more constrained, the farmer will be willing to buy more or sell less at a given quota price (v_m).

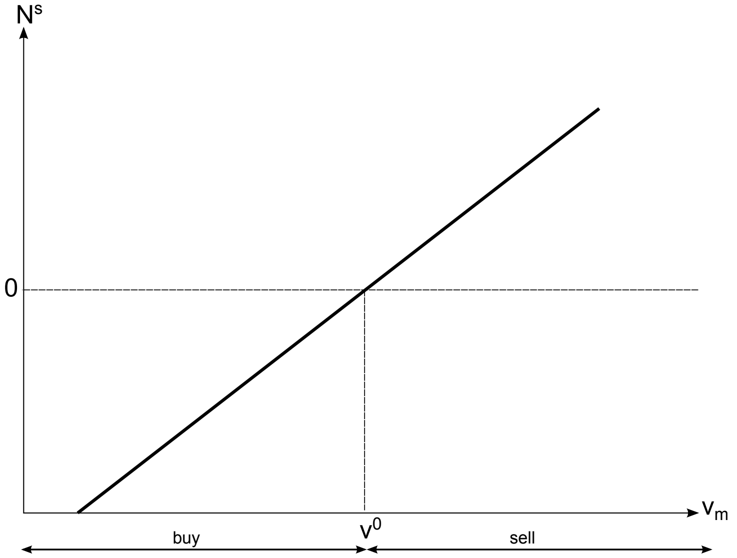

Figure 1. Net sales as a function of market price in the case of no transaction costs and under the assumption that demand functions are linear[7].

Let π^T denote the indirect profit function for a farmer that is trading in the quota market. Using the envelope theorem on [8] gives:

$$\frac{\partial\pi^T(\bullet)}{\partial v_m}=\frac{\partial L^*(\bullet)}{\partial v_m}=N^s(\bullet) \quad [22]$$

Since $N^S(\bullet)$ is the derivative of the indirect profit function, the curvature properties of the profit function can be read from Figure 1. Since $N^S(\bullet)$ is increasing in v_m, the indirect profit function must be convex in v_m. $N^S(\bullet) < 0$ to the left of v^0 and positive to the right, hence, the

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[7] It will be assumed in the rest of the paper that demand is linear in the nitrogen price. This implies that the yield function is or can be approximated by a second order polynomial in the relevant nitrogen range. The error due to this assumption is an empirical question and will depend on the range.

indirect profit function must be U-shaped, with at minimum at v^0 ($N^s = 0$). This is shown in the figure below.

The shape of the indirect profit function may be given an economic explanation. Since the farmer will only trade when he/she expects to gains, it follows directly that the minimum profit is obtained when not trading. (We have assumed that the farmer is rational and maximizes profits.) For some nitrogen price (v^0) it is optimal for the farmer to use only the quota allotted. This would also be the optima choice without the quota scheme and a nitrogen price of v^0. Without the quota system, lower prices would induce the farmer to buy more nitrogen and increase the profits, while higher prices would lead to lower N-use and lower profits. With the quota system, a higher price than v^0 would induce the farmer to sell nitrogen since the loss due to lower yield (lower on farm N-use) is less than the revenue from selling nitrogen.

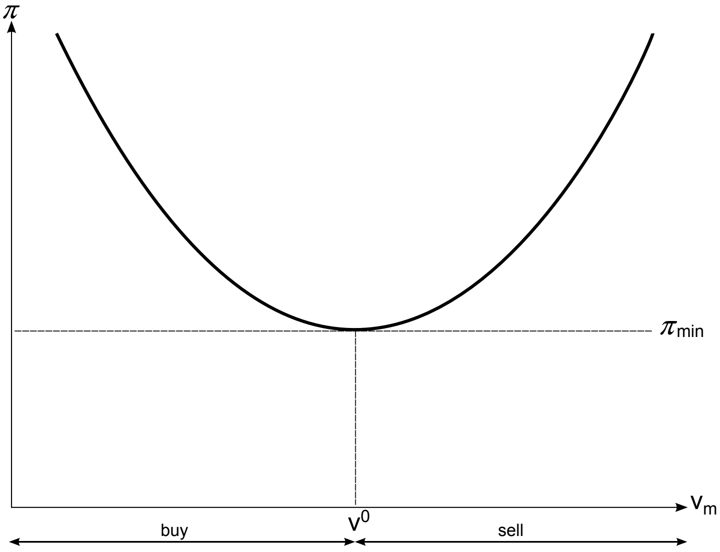

Figure 2. The indirect profit function. [8]

It was shown above that a decrease in the quota will move v^0 to the right. Therefore, also the profit function shifts to the right. A reduction of the quota will lead to a reduction of π_{min} and therefore also the indirect profit function in Figure 2 will shift down.

We have so far assumed that it is costless for the farmers to trade. However, there will always be costs when transacting in a market, e.g. the cost of information gathering and the costs of contracting. These costs may be real costs or opportunity costs, but they will nevertheless exist. Transaction costs may of course be so small that they are negligible, but it is still important to understand how these costs affect the choices of the farmer and the quota market.

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[8] It should be noted that the figures should not be read literately. The scales on the axis are arbitrary. For example, π_{min} may be negative.

In the following we will divide transaction costs into fixed and variable transaction costs. While the former is invariant to the amount traded, the latter varies with the amount traded. They will be analyzed separately because they affect the choices in different ways. Fixed costs will not affect the marginal decision, loosely speaking the slope of the demand curve, but variable costs will. The fixed costs are only incurred if the farmer is trading[9], and the farmer will only enter trade if the gain is lager than the fixed costs. Hence, fixed costs will only affect the trade not-trade decision. Variable transaction costs may also influence this decision, in addition to the decision about how much to trade when trading.

We will first look at the situation with (only) fixed transaction costs, followed by variable transaction costs and finally a discussion about the situation with both types of costs.

2.3. Fixed transaction costs

A full treatment of fixed transaction costs is given in the appendix. Here the focus will be on the more intuitive understanding.

In the presence of transactions costs the farmer has the choice of entering the market or not, in addition to how much to trade. The farmer will trade if and only if $\pi^T(v,v_m,TC,N^c) > \pi^N(v,N^c)$, where $\pi^T(\bullet)$ is the profits from trading, TC is transaction costs and $\pi^N(\bullet)$ is the profits from not trading. For a given quota and base price (v) we know that $\pi^N(\bullet)$ is constant with respect to v_m (equal to π_{min} in the Figure 2). For $\pi^T(\bullet)$ we know that fixed transaction costs just shifts the indirect profit curve down compared to the situation without any transaction costs. This means that fixed TC does not affect the curvature. Since $\pi^N(\bullet)$ is the minimum profit level when there are no transaction costs, parts of $\pi^T(\bullet)$ will lie below $\pi^N(\bullet)$ (Figure 3).

In a certain range of the market price for permits π^T is below π^N, hence the farmer is not trading. To the left of this region he/she buys fertilizer in the market, to the right he/she sells.

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[9] Gathering information about the scheme, decision-make, etc. is not costless. These costs are not known ex ante. Thus, the farmer must base the decision about “investing” in information gathering etc. on expectations about the costs and benefits. A farmer may therefore decide to not “participate” (i.e. not trade) if the expected cost of information etc. is too large. This decision is not included in the model, but will be discussed in the concluding section.

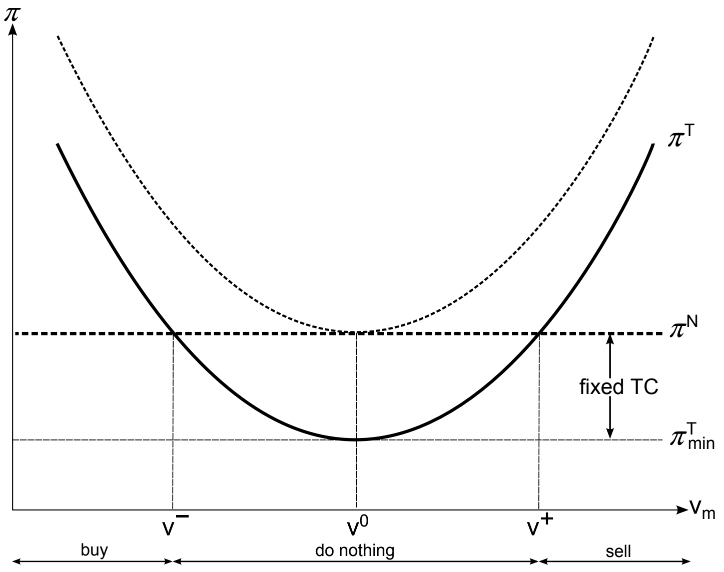

Figure 3. The profit in the case of fixed transaction costs.

The net supply curve is shown in Figure 4. As mentioned above, the fixed cost does not affect the marginal decision. This means that in the price region where the farmer takes part in trade the net sales function is the same as for the case without transaction costs.

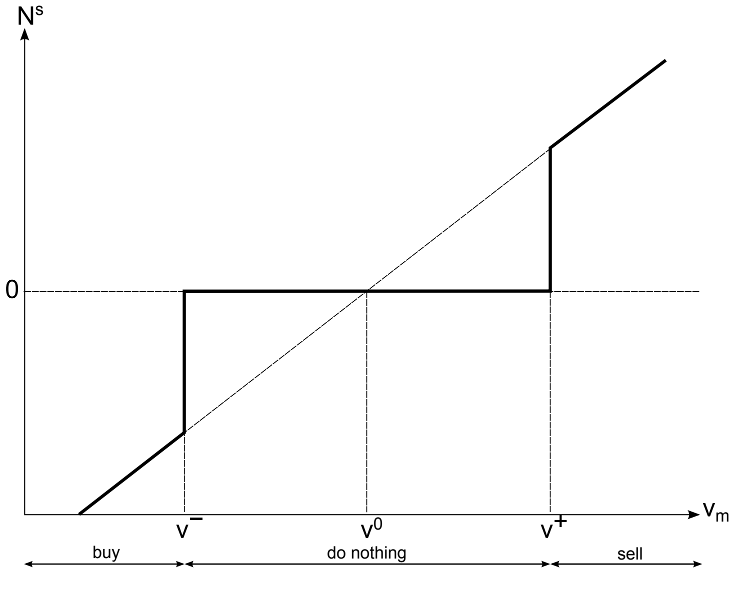

Figure 4. Net sales when transactions costs are fixed and demand for nitrogen is linear in the price.

The width of the non-trade price region depends on the curvature of the profit function and the size of the fixed transaction cost. It is shown in the appendix that if demand functions are linear:

$$\sum_{i=1}^{J} a_i N_i^*(v_m, p_i; \beta) = c_0 + c_1 v_m \qquad [23]$$

the width of the non-trade region can be approximated by:

$$v^{+} - v^{-} = \sqrt{8\frac{TC}{-c_1}} \qquad [24]$$

The non-trade region increases when fixed transaction costs, TC, increases. This can easily be seen from Figure 3. From the figure we also see that the flatter the profit curve is the larger is the non-trade region, cet. par.. The slope of the profit curve is determined by slope of the demand curve (c_1), and therefore the non-trade region will decrease as the slope of the demand curve increases in absolute terms, i.e. c_1 becomes more negative.

2.4. Variable transaction costs

Let us now turn to the situation with variable transaction costs. The objective of a profit maximizing farmer may be stated as:

$$\underset{N_1,\ldots,N_J,N^s}{\mathrm{Max}}\ \pi(N_1,\ldots,N_J,N^s;N^c) = \sum_{i=1}^{J} a_i p_i f_i(N_i) - vN^c + v_m N^s - TC(N^s) - FC \qquad [25]$$

subject to

$$N^c - N^s - \sum_{i=1}^{J} a_i N_i = 0 \qquad [26]$$

where TC(N^S) is the transaction costs function with TC(0) = 0, and the rest of the variables are as earlier defined.

The Langrangian for this problem is:

$$L = \sum_{i=1}^{J} a_i p_i f_i(N_i) - vN^c + v_m N^s - TC(N^s) - FC + \lambda\left[N^c - N^s - \sum_{i=1}^{J} a_i N_i\right] \qquad [27]$$

with the following first order conditions:

$$\frac{\partial L}{\partial N_i} = a_i\left\{p_i\frac{\partial f_i(N_i)}{\partial N_i} - \lambda\right\} = 0 \quad \forall i \qquad [28]$$

$$\frac{\partial L}{\partial N^s} = v_m - \frac{\partial TC(N^s)}{\partial N^s} - \lambda = 0 \qquad [29]$$

The optimal level of nitrogen use and thereby the trade decision is governed by [28], and λ is the key to analyze the problem further. Solving [29] for λ yields:

$$\lambda = v_m - \frac{\partial TC(N^s)}{\partial N^s} \qquad [30]$$

It is reasonable to assume that transaction costs is a non-decreasing function in the amount traded[10] (the absolute value of N^s). It also seems reasonable to assume that transaction costs are concave. If there are no fixed transaction costs and the TC(•) is convex one could reduce transaction costs by splitting the trade into smaller pieces (see the appendix). In the limit we would end up with an infinite number of trades each of infinitesimal size and zero transaction costs (as long as permits are divisible). This is clearly not plausible.

Since we are looking at only variable transaction costs they must be zero when the farmer is not trading. Marginal transaction costs are negative when the farmer is buying permits ($N^s < 0$) and positive when the farmer is selling ($N^s > 0$). This means that the marginal transaction costs switch from negative to positive at $N^s = 0$. Figure 5 illustrates the general shape of the transaction costs function.

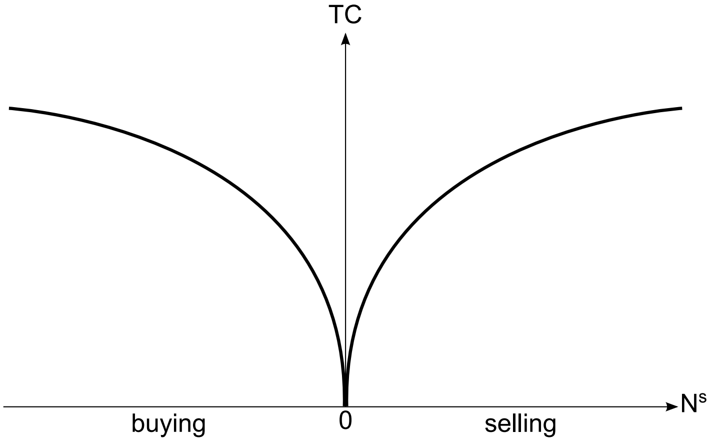

Figure 5. Transaction costs as a function of the amount traded (N^s).

Let us start to analyze the problem round $N^s = 0$. From the previous sections we know that $v_m = v^0$ is such a point and that the profit level is π_{min} (see Figure 1 and Figure 2). The farmer will trade only if the profit from doing so is larger than π_{min}. If we interpret λ in [30] as the marginal nitrogen price (= v_m minus marginal transaction costs), this must be larger than v^0 for it to optimal to sell permits and smaller than v^0 for buying permits. Since marginal transaction costs are non-zero, there is a region around $v_m = v^0$ where the farmer is not trading.

Let λ^b denotes the shadow value of the total quota when the farmer is a buyer, we then have from [30] that $\lambda^b \geq v_m$. Likewise, if the farmer is a net supplier of N in the quota market the marginal transaction costs are larger or equal to zero, hence $\lambda^s \leq v_m$. This means that $\lambda^s \leq v_m \leq$

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[10] It is possible that transaction costs differ for sellers and buyers, e.g. the buyer is paying all the transaction costs. For simplicity we will assume that transaction costs are the same for both sellers and buyers.

λ^b. Since $\lambda^b > \lambda^s$ and λ is non-decreasing in v_m there must be a region where λ is constant. In this region the farmer will not enter trade and $\lambda = v^0$. Graphically this is shown in Figure 6.

There are many transaction costs functions that have the properties discussed above. The simplest is when TC(•) is linear in the absolute value of N^s, e.g. $TC(\bullet) = \gamma\,|N^s|$ (Figure 6 panel A). If the cost is proportional to the value of the trade (e.g., broker fee), $TC(\bullet) = \beta\, v_m\, |N^s|$ (Figure 6 panel B).

For both these simple functions it is rather easy to find the width of the no-trade interval. In the case of linear transaction costs, the slopes of all the λ-lines are equal to one (parallel lines). The vertical distance between the upper and lower λ-lines equals 2γ, and width of the non-trade region is the same. If transaction costs are a fraction of the value of the traded amount, the width of the non-trade region is $2\beta v^0/(1-\beta^2)$.

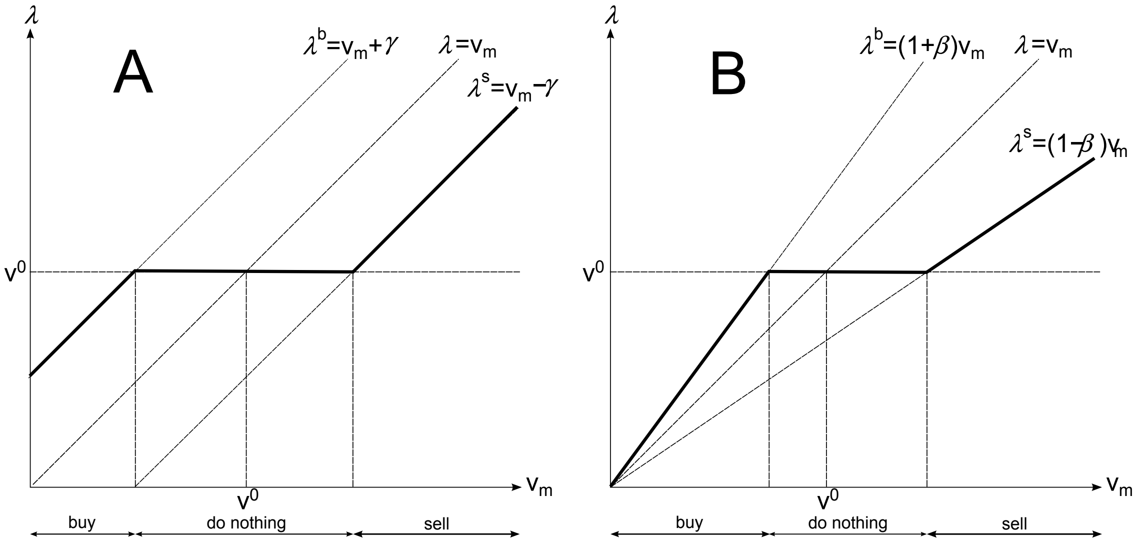

Figure 6. Market price and shadow value of quota for two different transaction costs functions.

The next step is to analyze how variable transaction costs affect trade. If the farmer is buying permits we have that $\lambda > v_m$. The yield fuction, $f_i(N_i)$, is concave which means that the optimal use of nitrogen for all fields is smaller than in a situation without transaction costs (equation [28]). When the total use of nitrogen is smaller, the amount bought in the permit market is also smaller (equation [26]). Similarly, if the farmer sells permits, he/she would sell less than without transaction costs. This means that variable transaction costs affect both the decision about entering trade and the amount traded in the case the farmer trade permits in the market. This is shown in Figure 7. The transaction cost function is assumed to be strictly concave. The hatched line is demand-supply when there are no transaction costs.

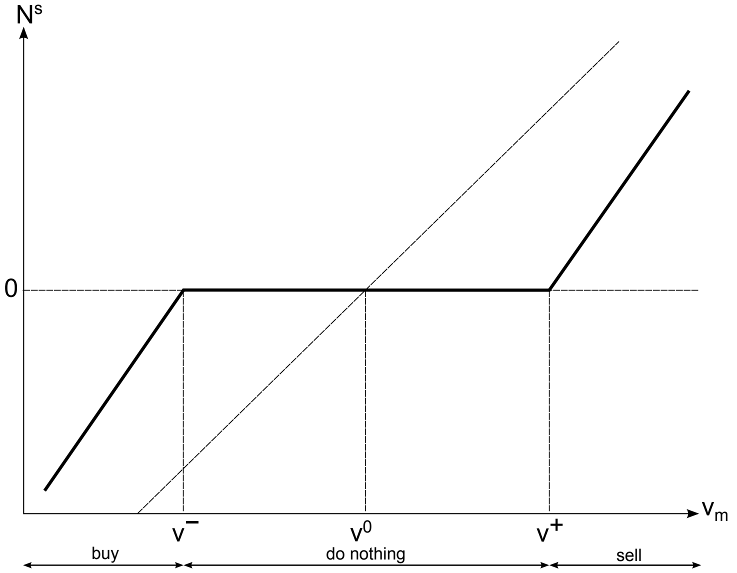

Figure 7. Net sales when the transactions costs function is strictly concave in the amount traded and demand is linear in the nitrogen price.

Transaction costs will shift the profit function down compared to a situation without transaction costs. In addition it will shift to the left for prices below v^- and to the right for prices above v^+. This is illustrated in the figure below.

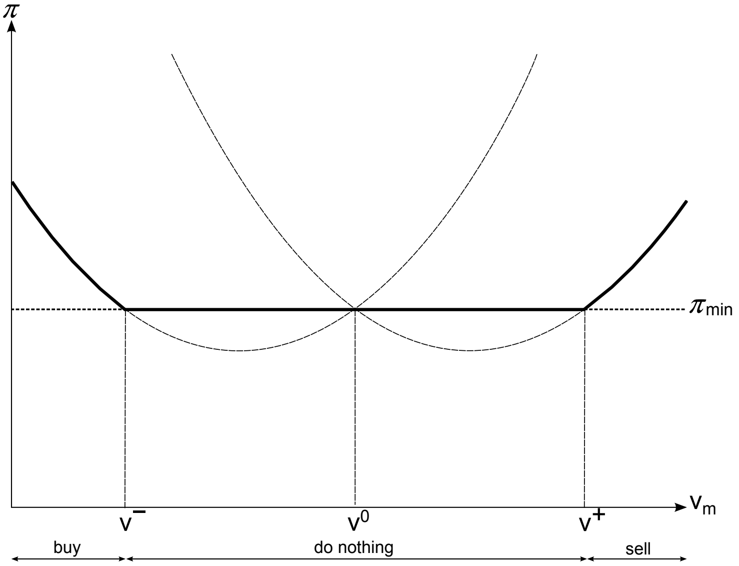

Figure 8. Profit with variable transaction costs.

If we now combine the two previous sections, we can analyze the situation with both fixed and variable transaction costs.

2.5. Fixed and variable transaction costs

As mentioned above, fixed costs do not affect the marginal decisions, i.e. how much to buy or sell given that the farmer is trading. We will therefore use the analysis for the case with variable transactions costs as a starting point.

In the case of variable transactions costs, the profit function is u-shaped with a horizontal part where the farmer does not trade. Fixed transaction costs will shift this curve downward vertically. This means that a part of the profit function will be below the profit level with no trade (equal to the horizontal part of the profit function with variables transaction costs). Since the farmer only has to carry these costs if he enters the market, there will be a larger price range where the farmer decides not to trade.

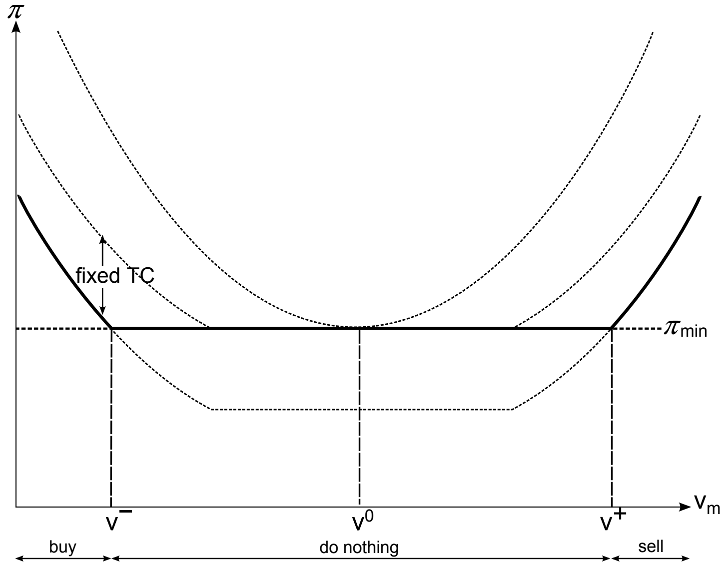

Figure 9. Profit for variable and variable plus fixed transactions costs.

The demand-supply curve will be similar to the one with only fixed transactions costs. The main difference is that, as mentioned above, fixed transaction costs will result in a larger non-trade region.

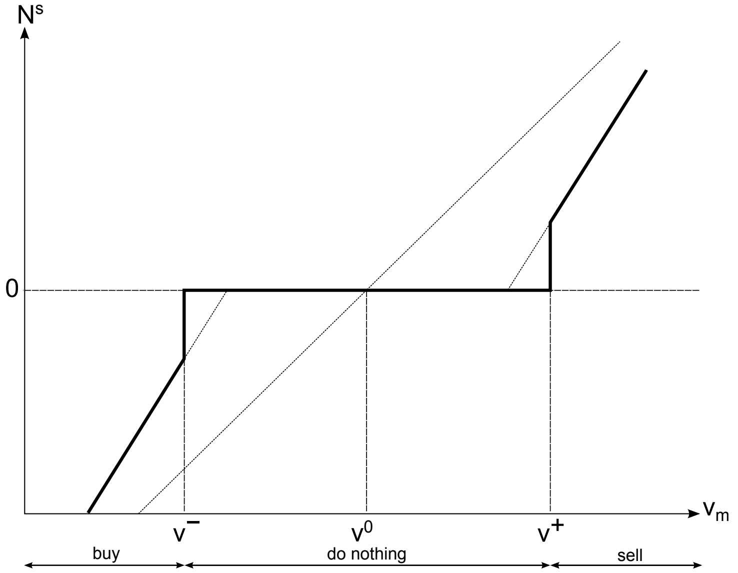

Figure 10. Net sales with both fixed and variable transaction costs.

If we assume that nitrogen demand is linear in nitrogen price (equation [23]), and that transaction costs are a linear function in traded amount, i.e.:

$$TC(N^s) = \gamma_0 + \gamma_1 \left| N^s \right| \qquad [31]$$

the non-trade region can be approximated by (see the appendix for the derivation):

$$v^+ - v^- = \gamma_1 + \sqrt{\gamma_1^2 - 8\frac{\gamma_0}{c_1}} \qquad [32]$$

We have so far analyzed the effects of transaction costs on the farmer's choices. Two main conclusions may be drawn from the theoretical model developed: a) fixed transaction costs affect the decision of entering the market or not, but not the traded amount if the farmer enters the permit market and b) variable transaction costs affects both decision of entering the market and the amount traded. Without transaction costs the farmer will trade for all prices in the quota market, except for a certain price (v^0) for which the farms nitrogen demand equals the quota. When transaction costs are non-zero there will be a price region where the farmer is not trading.

2.6. The permit market

In a market demand must equal supply in order to clear. Since the farmers may be both buyers and sellers in the market, depending on the price, the farmers cannot be identical for trade to occur. If all farms (or more precisely: their demand-supply-functions for permits) are identical there would be no differences to trade out in the market. In our case there are two differences between the farms: the response to the price in the quota market which is due to the demand function for nitrogen, and the non-trade price region. As shown above, the latter may depend on the former (in the case of fixed transaction costs). The placement of the non-trade region will depend on the size of the permit and the demand function. The figure below shows a hypothetical outcome of a market with only two farms.

If the non-trade price regions are overlapping, there will be no trade. This indicates that trade reduces as transaction costs increases. However, the analysis above only shows that transaction cost will affect trade, not how large the effects are.

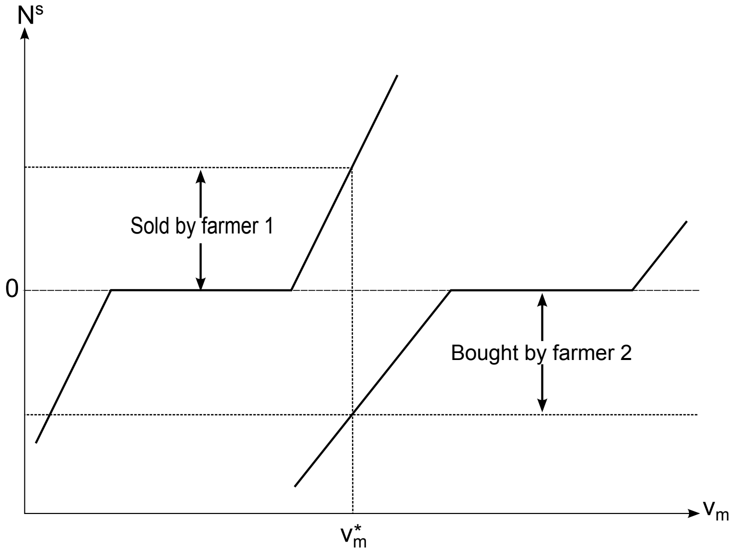

Figure 11. Trade in a market with two farmers.

Ideally, real world data should be used when testing the hypothesis implied by the theoretical model. This requires that a tradable fertilizer quota system is implemented and that transaction costs could be varied (or at least varies between farms with similar characteristics). Real world data does not exist, meaning that we have to use other methods. One option could be to simulate the quota marked in lab and let (real) farmers trade in this (hypothetical) market. This is an appealing idea, but outside the scope of this paper to investigate further. An alternative is to simulate the farmers and let these model farmers trade in the market. The next section will show how this can be done and presents some results from this type of market simulation.

3. Simulations

3.1. Simulating the market

Farm level nitrogen demand is the core element in the theoretical analysis above. Farmer’s response function (net sale as a function of quota market price) is the quota minus on farm nitrogen demand “corrected” for the effects of transaction costs (see Figure 1, Figure 4, Figure 7 and Figure 10). With such demand functions, simulations of the quota market are rather straight forward[11]. Data on farm level fertilizer use is to some extent available, but due to small nitrogen price variation, we would get reliable estimates for a too small price range. Hence, we need to rely on another method for estimating nitrogen demand.

The data used in this paper is taken from simulations using ECECMOD (Vatn et al., 2006). ECECMOD is a model cluster aimed at studying the economic and environmental effects of

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[11] At least under the assumptions made in this paper.

different agri-environmental policy instruments. The model operates at different levels: from farm fields to regions, with the farm as the main managerial unit. Different choices are simulated in the model (e.g. crop rotation, fertilization, tillage practice and manure handling) and environmental effects (e.g. nitrate loss, ammonia loss and erosion) are calculated as a consequence of these choices. Choices are based on economic conditions (prices and polices) and farm characteristics (main type of production, size, climate and soil type distribution).

The current version of ECECMOD covers four regions in Norway: South-eastern region (covering areas south east of Oslo), Hedmark (in the central part of south Norway), Trøndelag (in the middle part of Norway) and Jæren (in the south west). Jæren is dominated by animal husbandry (mainly milk and beef), Hedmark and the South-eastern region are dominated by crop production (grain), while Trøndelag represents a mixed case. The climate and soil types differ substantially between the regions.

Each region is represented by about 10 type farms. These model farms were created from farm data, and each type farm represents about 100 – 150 real farms. When grouping the (real) farms, size, type of production and manure intensity were used as criteria. Since acreage of each farm was available it is possible to scale the results from the model farms to the whole region. For more information about the regions and the performance of ECECMOD, see Vatn et al. (2006).

Since ECECMOD operates at farm level and the nitrogen price is an exogenous variable in the model, it is possible to estimate farm level nitrogen demand functions. The model was run with three different nitrogen prices: base price and two levels of a tax on nitrogen in synthetic fertilizers (50%, 100%)[12]. Linear farm level nitrogen demand functions are estimated based on the results from ECECMOD. Only nitrogen price was used as independent variable. The estimated functions fit the "observations" (very) well, except for nine type farms (out of 51). These type farms are excluded from the rest of the analysis. However, they represent a rather small fractions of the total areas in the regions: 4.0% in the South-eastern region, 0.5% in Hedmark, 3.1% in Trøndelag and 7.8% in Jæren. For the model farms included in the analysis, the residuals of the estimated functions are less than 2% of the "observed" nitrogen demand.

In the quota market simulations each model farm is awarded a quota equal to a fraction (equal for all farms) of base line fertilizer use. The latter is nitrogen demand when the nitrogen price

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[12] In the model there are no differences in the calculations of private costs and incomes from changing the nitrogen prices directly and using a tax. The differences lie in how societal costs and benefits are calculated.

equals the base price (called v in the theoretical model above). The market is simulated for different quota levels: 70%, 80%, 90% and 100% of base line use.

Two different trading rules are analyzed. Under the first, trades are only allowed within the regions while under the other, nitrogen may also be traded between regions. Since there are rather large differences between the regions one would expect that trade will increase when opening up for trade between the regions. The environmental situation in the different regions may vary, and it may thereby be desirable to set different reduction targets (i.e. different quota levels) in the different regions. However, if trade is allowed between regions, the effects of the differentiation will be reduced. Quotas are not differentiated in the simulations, but the results will still give insights into the flows of nitrogen between regions.

Regarding transaction costs, only variable transaction costs are included in the simulations. Further, transaction costs are assumed to be linear in the amount traded. Fixed transaction costs could easily be included, using the approximation given in equation [32], and non-constant marginal costs could be assumed. Transaction costs seem to decline over time (Falconer and Whitby, 1999 and Gangadharan, 2000) probably due to a learning effect. As the farmers gain experience in trading in the market, this reduces the overall transaction costs and the likelihood of large fixed costs. Cason and Gangadharan (2003) find that in the long run constant marginal transaction costs are more important than decreasing marginal costs. This means that the market simulated in this paper may be viewed as a mature market.

Transaction costs are assumed to be equal for both buyers and sellers and the same for all farmers. This assumption means that the non-trade region will be symmetric round the price where the farmer is not trading in the absence of transaction costs, i.e. v^0 (see for example Figure 10). The sum of buyer and seller transaction costs are be expressed in percentage terms of the base nitrogen price, and is varied from 0 to about 50%.

The main objective of quotas is to reduce the overall nitrogen use and thereby also reduce the loss of nitrogen to the environment. The loss of nitrate to drainage is estimated in ECECMOD and these results from ECECMOD are used to estimate farm level leaching functions (second order polynomials with fertilizer nitrogen as argument). This way it is possible to estimate the environmental effects of the tradable quotas. The results from the quota market simulations are also compared to the effects of a uniform tax on nitrogen. The tax is set such that the sum of the nitrogen demand in all regions equals the sum of the quotas in the regions, i.e. total nitrogen use are the same in both cases.

3.2. Results

Figure 12 shows the effects on trade of transaction costs and the size of the quota. The upper part shows results for the case when trade between the regions is not allowed, while the lower part is for the case when trade between regions is allowed. The results from simulations of a 100% quota are included just to show that the model produces sensible results for the base line case, i.e. no trade.

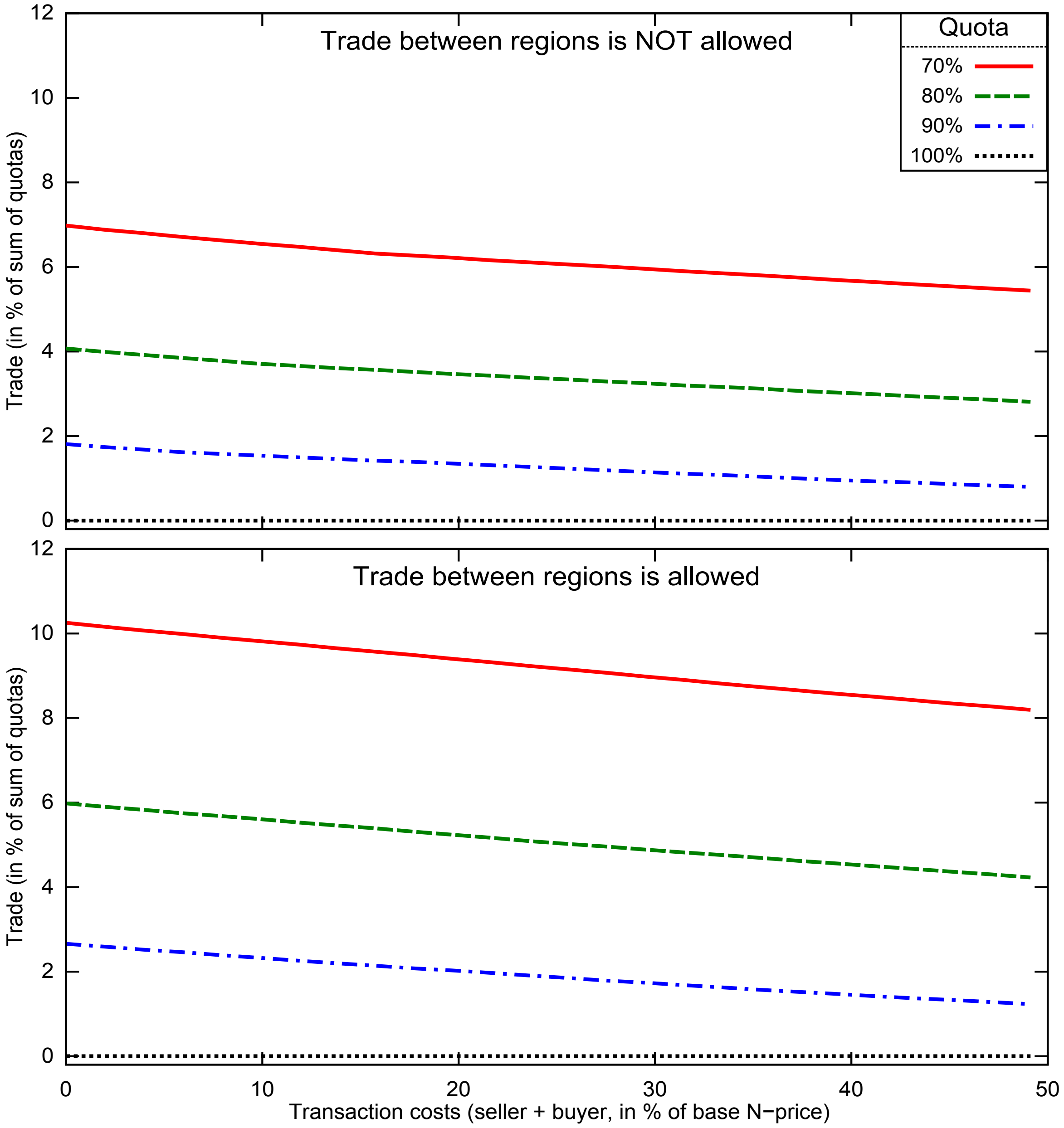

Figure 12. Amount traded (in % of sum of all quotas) for different levels of transaction costs and quota size. Quotas are in % of base line use.

Under both trading rules we see that the effect of transaction costs is rather modest. In the case trade is not allowed between regions, the difference in trade between the largest level of transaction costs and no transaction costs is between 1.0 and 1.5 percentage points. When trade is allowed between regions the difference is larger, but still rather modest (1.4 – 2.1 percentage points). We will return to the trade between regions below.

Trade increases as the quota reduces, as expected. As nitrogen gets more constrained the marginal value of nitrogen increases (due to concavity of the production functions). This means that the farmer is willing to pay more at a given price, and since the farmer may also be a supplier, supply will increase. Technically, a reduction in the quota shifts the demand-supply curves (see e.g. Figure 7) to the right and thereby increases both supply and demand for a given price. Hence, both the price in the quota market and trade increase.

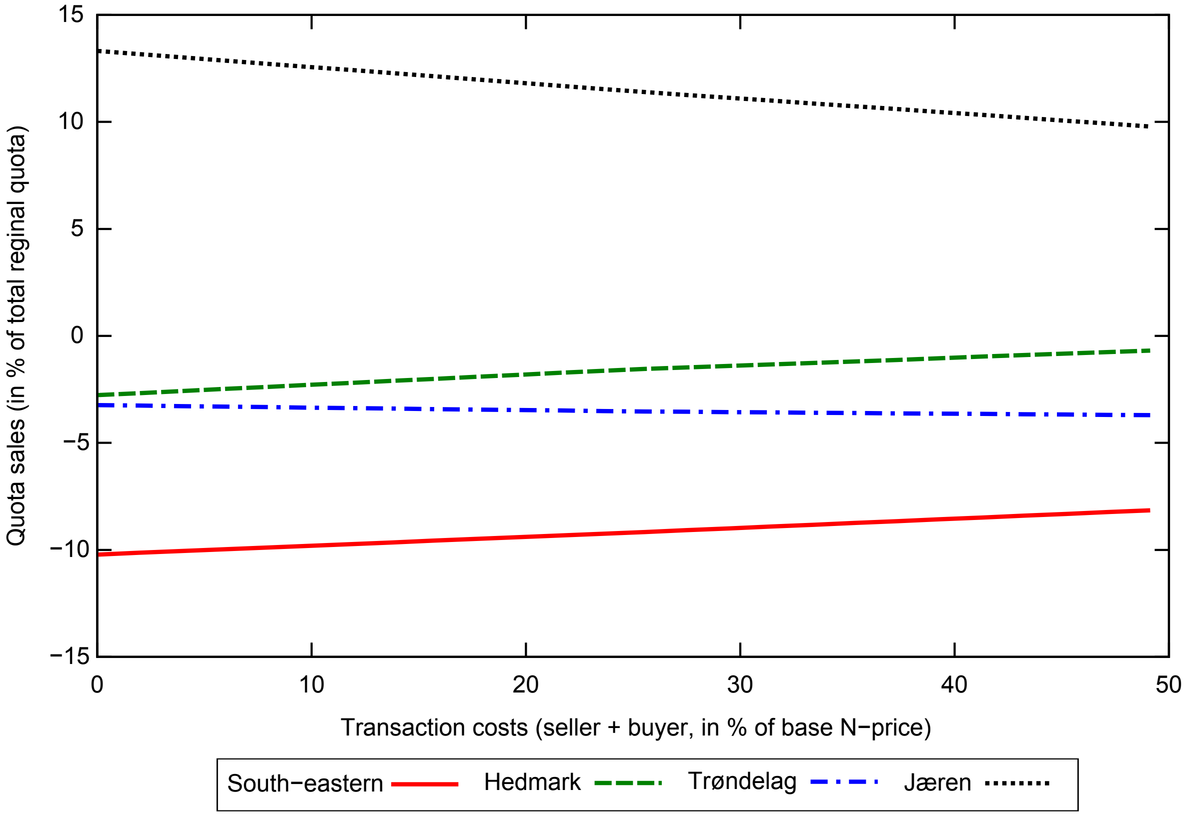

Figure 13. Trade between regions (in % of regional quota). Negative values means import of quotas. Quota is 80% of base line use.

The effect on trade of allowing trade between the regions is rather large. Trade is about 50% larger when trade between regions is allowed. As mentioned above, there are rather large differences between the regions regarding e.g. type of production and climate. This means that there are differences in nitrogen demand and these differences are larger between than within regions. Loosely speaking, trade is about trading out differences, and by increasing the difference trade will increase. The figure above shows the net trade in and out of the different regions for the case of an 80% quota. The results for the other quota levels are similar, but the levels differs somewhat.

Jæren is the largest exporter of permits. The region is dominated by grassland (> 85%). Due to this and the climate, the production functions are rather flat. This means that the yield loss from reducing N-application is rather low. Combined with the lower value of grass compared to e.g. grains, the "costs" of reducing N-use is lower than in the other regions, hence the region is exporting permits.

The southeastern region, dominated by grain (about 90%), is the largest importer. The yield functions are steeper than for grassland and the price of grain is larger than grass. This results in higher willingness to pay for nitrogen and import of permits.

The next issue is the environmental effects of the quotas and transaction costs (Figure 14).

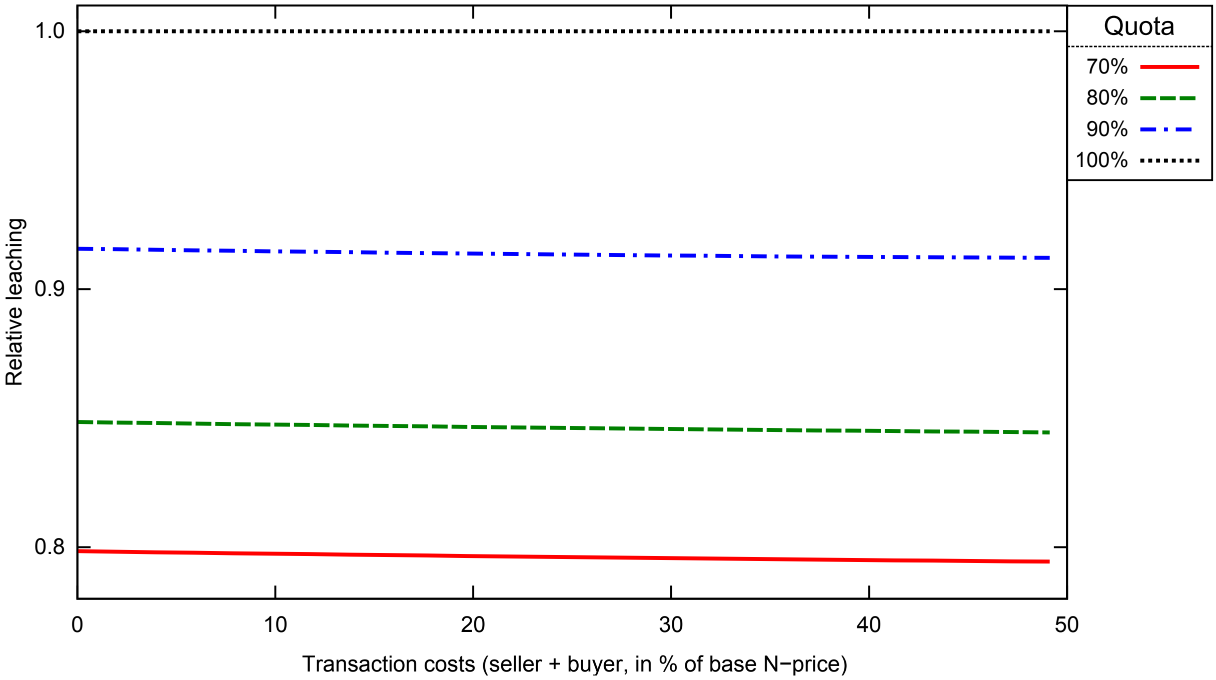

Figure 14. Relative leaching. Ratio between leaching under tradable quotas and base line leaching. Trade is allowed between regions. Quotas are in % of base line use.

Reduced quotas should in general result in reduced leaching, at least if the reduction is large enough. The figure shows that this is the case. The results for the case where trade is not allowed between regions are almost identical to the ones in the figure above, and is therefore not shown. As will be shown below, this does not mean that the trading rule does not influence regional results.

Transaction costs seem to have almost no effect on leaching. This together with the fact that the effect of the trading rule is also very small seems to suggest that leaching is mainly determined by the quota size[13]. This again means that total nitrogen use is the main factor regarding the total leaching at the aggregate level. This is confirmed if we look at the ratio between leaching under tradable and non-tradable quotas (Figure 15).

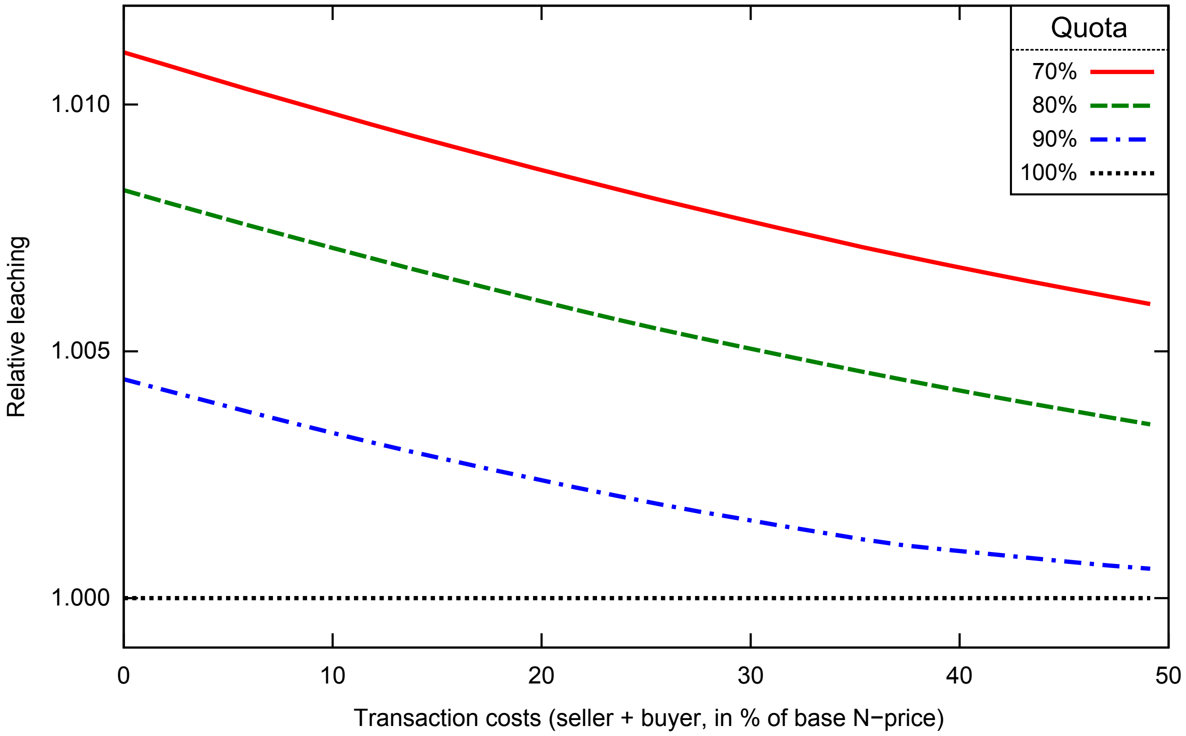

Figure 15. Relative leaching: ratio between leaching under tradable and non-tradable quotas. Trade is allowed between regions.

One alternative to tradable permits is a tax on nitrogen in synthetic fertilizers. The tax is set such that total nitrogen use is the same in both cases, and the results show that the differences in leaching between the two alternative policy measures are small (Figure 16). At the highest transaction costs level the difference in leaching is about 2%. Given the uncertainties involved we can conclude that there is no difference between the two policy instruments.

The reason why relative leaching is increasing in Jæren and decreasing in the other regions is the effect of transaction costs on trade. The denominator of the ratio (leaching under a uniform tax) is constant. Jæren is reducing its export when transaction costs increases, this leads to increased nitrogen use and thereby increased leaching. For the other regions, imports decrease and thereby also total nitrogen use which leads to lower leaching. The total effect is a small decrease in relative leaching.

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[13] Leaching at the micro level is determined by a rather complex interplay between different physical and biological processes and managerial choices. However, at the aggregate level, micro level differences seem to be averaged out.

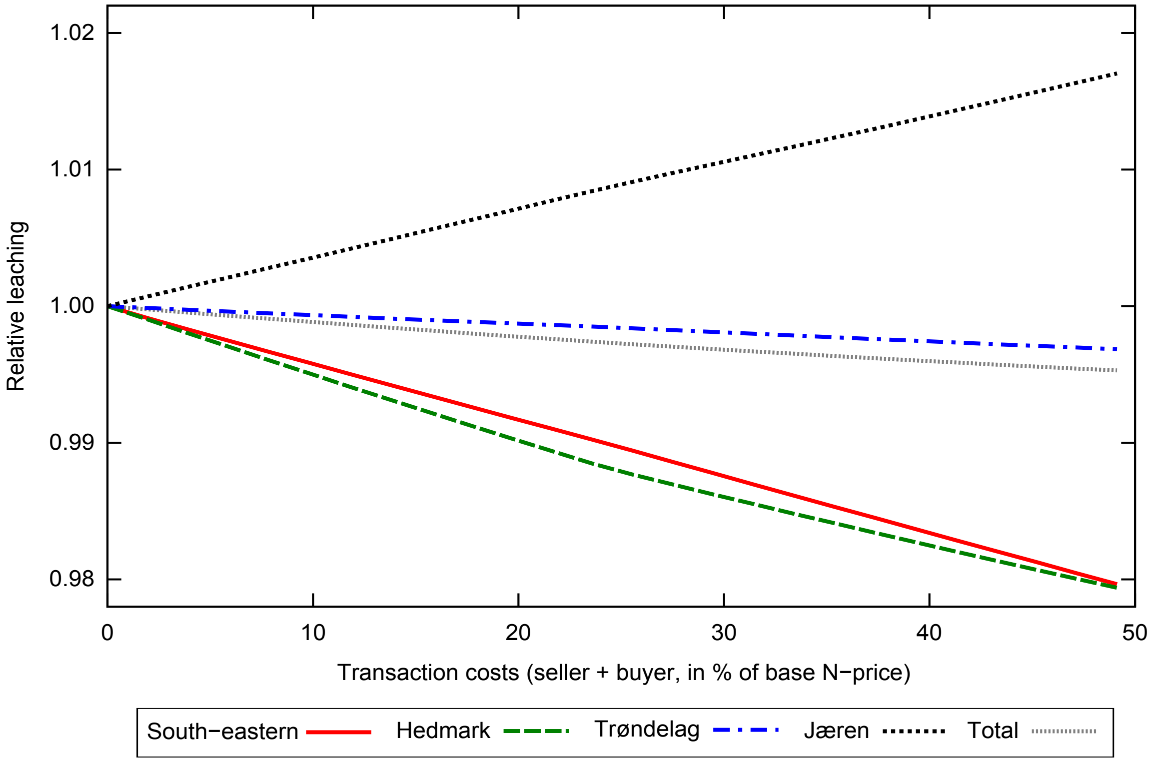

Figure 16. Relative leaching. Ratio between leaching under tradable quotas and a uniform tax. Trade is allowed between regions. Quota is 80% of base line use.

At the aggregate level the trading rule have almost no effect on leaching. However, we have seen that if trade is allowed between regions, there will be trade between regions and this will influence leaching in the different regions.

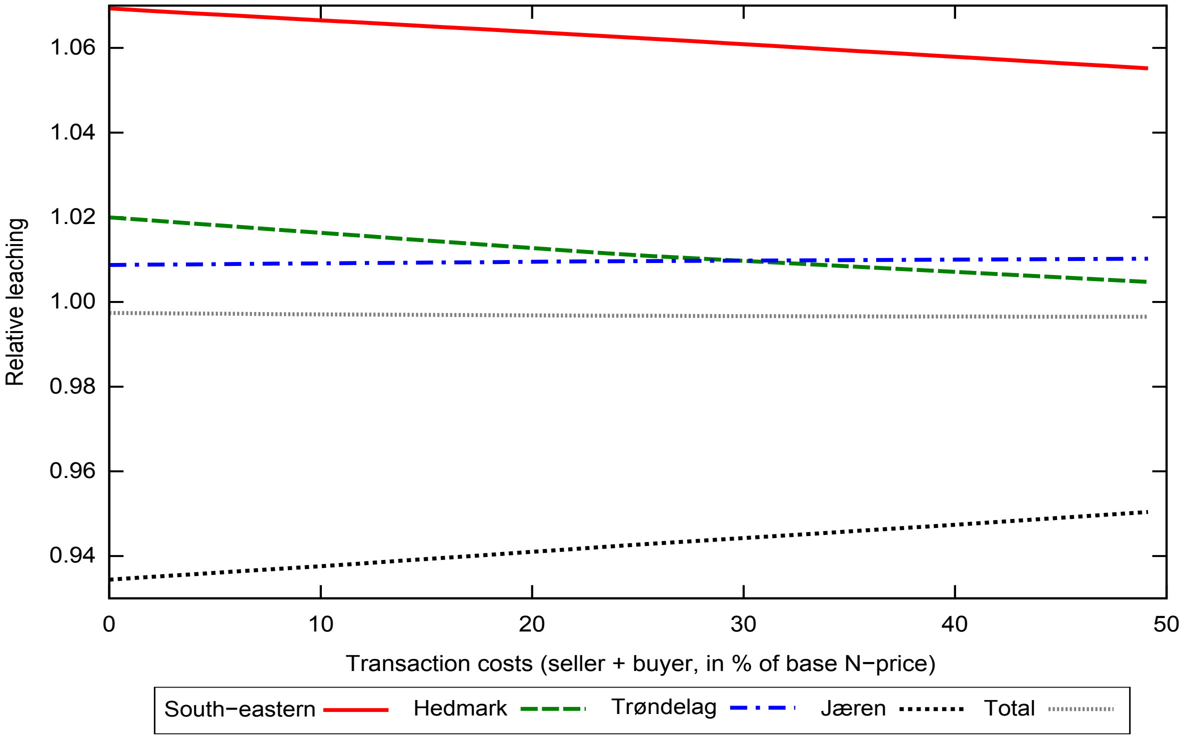

Figure 17. Relative leaching: ratio between leaching with and without trade between regions. Quota is 80% of base line use.

The figure above shows the ratio between leaching when trade is allowed between regions and not. For two of the regions the effects are significant: the largest exporter of quotas (Jæren) and the largest importer (South-eastern). For the other regions (and total) the effect is modest. Since transaction costs decreases trade, the effect of trade between regions reduces when transaction costs increases.

4. Discussions and conclusions

The theoretical model developed in this paper shows that private transaction costs will affect trade in the quota market. However, results from market simulations show that the effect is modest, although larger at the regional level than when all regions are seen together. It should be noted that only variable transaction costs are included in the analysis and that further research should look into the effects of fixed transaction cost.

If a reduction in total leaching is the aim of the policy, all three policy options studied (tradable quotas, non-tradable quotas and a uniform fertilizer nitrogen tax) may yield the desired result. However, the income effects and public transaction costs will be different. Quotas will yield lower income effects than input taxes, at least if the quotas (i.e. the right to buy fertilizers) are awarded for free. The reason is that while the input use is about the same in both cases, the input price is larger in the case of a tax. The tax will therefore lead to lower revenues. If the quotas are tradable, the income effect will be lower (or at least not larger) than non-tradable quotas since trade will only take place if both seller and buyer gain from trade. The larger income effect of the tax may lead to more farms exiting the sector, hence having a larger structural effect than quotas.

Public transaction costs are (very) small for a fertilizer tax (Rørstad et al., 2007). In the case of quotas the public transaction costs will depend on how the system is set up, especially how quotas are awarded, and the trading rules (e.g. if trade is allowed between regions or not). The latter will influence the control and enforcement costs, and will in general increase as the rules get tighter. Regarding the costs linked to how quotas are awarded, these are mainly linked to how much information that is needed to set the individual quotas. The more detailed the needed information is, the larger will transaction costs be. Since transaction costs related to the trades do not affect the trades much, the distribution of quotas among farmers will most likely not influence the outcome of the market. This means that all permits may be awarded to one farmer with the same degree of efficiency as dividing them among farmers. However, this will have large distributional effects and may therefore be viewed as unfair.

The quotas in this paper are set in percent of the base line use. The base line use is private information, and a truthful revelation mechanism is probably hard or costly to implement. A more reasonable approach would be to utilize information farmers already give in their application for subsides (e.g. acreage support). Acreage of different crops is already included in the Norwegian support system and may be used as a proxy for the nitrogen use. This is only a proxy, but clearly less expensive than using the real base line nitrogen use.

The market simulations showed that if trade between regions is allowed, permits will be sold across regions leading to higher (for regions importing permits) or lower (for exporting regions) leaching compared to a situation with no trade between regions. If the reduction target is not reached in all regions, a lowering of the quota levels may solve the problem. This will increase trade between regions, but regional leaching will still be reduced. It is of course possible to ban trade between regions, i.e. by issuing permits that can only be used within the regions, but it is costly to control the transport of (physical) fertilizers between the regions.

As implied above, policy design will influence transaction costs, both public and private. In this paper it is assumed that the quota market is working well and that farmers are experienced in using this market. Fixed transaction costs, i.e. costs invariant to the amount traded, will be low (or at least substantially lower than in the initial years). Hence, variable transaction costs is the main concern. Despite the fact that the effect of transaction costs is small, it does not mean that transaction costs are unimportant, rather to the contrary. If we only look at the aggregate level, transaction costs do not influence the environmental effect of the quota system much. Cost effectiveness will therefore be maximized if transaction costs (sum of public and private) are minimized. In the mature market the policy recommendation is to impose as few as possible restrictions on trade. The role of the regulator (e.g. governmental agency) should only be to issue quotas, to oversee that the market is working well and control that no-one is cheating.

In the dynamic perspective fixed transaction costs may play a larger role. In the initial years they will most likely be larger, due to larger information, search and negotiation costs. If these costs are known, their effect will be as derived in the theoretical part of this paper, i.e. reduce trade by increasing the non-trade price region. Again, the rules should be as simple as possible with as few restrictions as possible.

Trade invariant costs are not known apriori. For example, cost related to information gathering can not be known apriori because the optimal amount of information is unknown.

The uncertainty about the costs means that the agents must base their decision on expectations. Clearly, the more complex the scheme is, the larger the expected costs will be, reducing the probability of participation and finally trade. In addition to keeping the scheme simple, the regulator may reduce the expected costs by providing relevant information about the scheme and facilitate the creation of an efficient marketplace.

The costs in the initial year(s) may be viewed as an investment where expected costs should be compared to expected benefits over time. The latter is comprised of the expected yearly benefits from trade and the time horizon. Expected benefits are unknown since the price in the quota market is not known, but this is not related to the rules of the scheme. The time horizon may be viewed as the expected "lifetime" of the quota scheme, and the longer the time horizon is, the larger is the probability for participation, cet. par. If the farmers experience frequent changes in agricultural policy, this will shorten the time horizon. Participation therefore depends on the ability of the policy-maker to convince the farmers that the quota system will be a lasting system. Policy predictability is an important issue.

In order to utilize the income effect advantage of a tradable quota system (compared to non-tradable quotas and input taxes), the quota system should be set up as simple as possible and the regulator should facilitate the creation of an efficient quota market.

5. References

Bleken, M.A. (2001). *KONOR – a Model for Simulation of Cereal Growth. Documentations*. Report no. 2/2001, Reports from AUN. Department of Horticulture and Crop Sciences, Agricultural University of Norway.

Cason, T.N. and L. Gangadharan (2003). Transaction Costs in Tradable Permit Markets: An Experimental Study of Pollution Market Design. *Journal of Regulatory Economics* **23**(2):145-165.

Cheung, S.N.S. (1987). Economic organization and transaction costs in Eatwell J., M. Milgate, and P. Newman (eds.) *The New Palgrave: A Dictionary of Economics* London and New York: Macmillan and Stockton. v. 2, pp 55-58.

Dahlman, C. J., 1979. Problem of Externality, *Journal of Law & Economics* **22**(1):141-162.

Falconer, K. and Whitby, M., (1999). The invisible costs of scheme implementation and administration. In G. Van Huylenbroeck and M. Whitby (eds.), *Countryside Stewardship: Farmers, Policies and Markets*. Elsevier Science Ltd, pp 67-88.

Gangadharan, L. (2000). Transaction Costs in Pollution Markets: An Empirical Study. *Land Economics* **76**(4):601-614.

Hansen, L.G. (2004). Nitrogen Fertilizer Demand form Danish Crop Farms: Regulatory Implications of Heterogeneity. *Canadian Journal of Agricultural Economics* **52**:313-331.

Hansen, L.G. and E. Romstad (2007). Non-point source regulation – A self-reporting mechanism. *Ecological Economics* **62**:529-537.

Montero, J.-P. (1997). Marketable pollution permits with uncertainty and transaction costs. *Resource and Energy Economics* **20**:27-50.

Romstad, E. (2003). Team approaches to reducing non-point source pollution. *Ecological Economics* **47**:71-78.

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

Segerson, K. (1988). Uncertainty and incentives for non-point pollution control. *Journal of Environmental Economics and Management* **15**(1):87-98.

Stavins, R. (1995). Transaction Costs and Tradable Permits. *Journal of Environmental Economics and Management* **29**:133-148.

Vatn A, L. Bakken, M.A. Bleken, O.H. Baadshaug, H. Fykse, L.E. Haugen, H. Lundekvam, J. Morken, E. Romstad, P.K. Rørstad, A.O. Skjelvåg and T. Sogn (2006). A methodology for integrated economic and environmental analysis of pollution from agriculture. *Agricultural Systems* **88** (2-3): 270-293.

Appendix

Demand and sales

In the case with no transaction costs and assuming that the quota is binding, i.e. that it is optimal to use the whole quota, the maximization problem may be written as

$$\pi^N(v, v_m, p, N^c) = \underset{N_1,\dots,N_I}{\mathrm{Max}}\,\pi(N_1,..,N_I) = \sum_{i=1}^{I} a_i p_i f_i(N_i) - vN^c + v_m\left[N^c - \sum_{i=1}^{I} a_i N_i\right] - FC \qquad [33]$$

where

a_i	area of field i, assumed to be larger than zero,
p_i	price of crop on field i,
$f_i(N_i)$	expected yield function for a given crop on field i,
N_i	amount of nitrogen (N) applied to field i,
v	base price on N,
N^s	amount of N sold (negative if purchase) from the farm,
v_m	effective price (base + premium) of N traded in the quota market,
N^c	total quota for the farm, and
FC	fixed costs.

The first order conditions evaluated at optimum gives:

$$a_i \left\{ p_i \frac{\partial f_i(\bullet)}{\partial N_i} - v_m \right\} \equiv 0 \; \forall i \qquad [34]$$

If we differentiate with respect to v_m:

$$p_i \frac{\partial^2 f_i(\bullet)}{\partial N_i^2} \frac{\partial N_i^*(\bullet)}{\partial v_m} - 1 \equiv 0 \forall i \qquad [35]$$

Since $\frac{\partial^2 f_i(\bullet)}{\partial N_i^2} < 0$ we have that $\frac{\partial N_i^*(\bullet)}{\partial v_m} < 0\ \forall i$. This means that $N^{s*}(\bullet) = N^c - \sum_{i=1}^{I} a_i N_i^*(\bullet)$ must be upward sloping in v_m.

Approximating the indirect profit function

Using the envelope theorem on [33] gives:

$$\frac{\partial \pi^N(\bullet)}{\partial v_m} = N^{s*}(\bullet) = N^c - \sum_{i=1}^{I} a_i N_i^*(\bullet) \qquad [36]$$

This means that the indirect profit function may be approximated by:

$$\pi^N(\bullet) \simeq \int N^{s*}(\bullet)\, dv_m = N^c v_m - \sum_{i=1}^{I} \int a_i N_i^*(\bullet)\, dv_m \qquad [37]$$

If we assume that demand for nitrogen is linear in v_m, implicitly assuming that production functions ($f_i(\bullet)$) are (or close to) second order polynomials, an approximation of the indirect profit function is then:

$$\pi^N(\bullet) \simeq \left(N^c - c_0 - \tfrac{1}{2} c_1 v_m\right) v_m + A \qquad [38]$$

where c_0 (>0) and c_1 (<0) are parameters and A is the integration constant.

This function has it minimum value found by:

$$\frac{\partial \pi^N(\bullet)}{\partial v_m} = N^c - c_0 - c_1 v_m = 0 \Rightarrow v^0 = \frac{N^c - c_0}{c_1} \qquad [39]$$

with the value:

$$\pi^N_{\min} = \frac{1}{2}\frac{(N^c - c_0)^2}{c_1} + A \qquad [40]$$

If there are no transaction costs v^0 is the price where the farmer switch from buying to selling.

Fixed transaction costs

In the presence of fixed transactions costs the farmer has the choice of entering the market or not. The objective of the farmer is to choose the alternative that yield the highest profit:

$$\mathrm{Max}\left\{\pi^N(v, N^c), \pi^T(v, v_m, TC, N^c)\right\} \qquad [41]$$

where
$\pi^N(\bullet)$ the profit (indirect profit function) when not trading
$\pi^T(\bullet)$ the profit (indirect profit function) when trading
TC fixed transactions costs incurred by entering the market
and other terms as defined above.

In the case that the farmer does not enter the market, his objective is:

$$\pi^N(v, N^c) = \underset{N_1,\dots,N_J}{\mathrm{Max}}\, \pi(N_1,\dots,N_J) = \sum_{i=1}^{J} a_i \left(p_i f_i(N_i) - vN_i\right) - FC \qquad [42]$$

subject to the quota constraint

$$N^c - \sum_{i=1}^{J} a_i N_i = 0 \tag{43}$$

The Lagrangian for this problem is:

$$L = \sum_{i=1}^{J} a_i \left(p_i f_i(N_i) - vN_i\right) - FC + \mu\left[N^c - \sum_{i=1}^{J} a_i N_i\right] \tag{44}$$

with the following first order condition:

$$\frac{\partial L}{\partial N_i} = p_i \frac{\partial f_i(N_i)}{\partial N_i} - v - \mu = 0\ \forall i \tag{45}$$

When the quota is binding ($\mu > 0$) the total N-use on the farm will of course be reduced compared to situation without the quota, and the implication of the first order condition ([45]) is that the optimal N level for all fields will be reduced. The yield function, $f_i(\bullet)$, is concave in N_i and therefore its derivative is falling in N_i. Since $- v - \mu < - v$, the slope of the yield function at optimum is lrager. Hence, the optimal N-level for all fields must be lower with a binding quota than without.

Since the farmer does not trade, the profit level must be constant and the same as for the case with no transaction costs and $N^s = 0$, i.e. $\pi^N(\bullet) = \pi_{min}$ (see Figure 2).

In the case the farmer enters the market, his problem is:

$$\begin{aligned}\pi^T(v, v_m, TC, N^c) &= \underset{N_1,\dots,N_J}{\text{Max}}\, \pi(N_1,\dots,N_J) \\ &= \sum_{i=1}^{J} a_i p_i f_i(N_i) + (v_m - v)N^c - v_m \sum_{i=1}^{J} a_i N_i - TC - FC\end{aligned} \tag{46}$$

In addition, we also have the net sales function:

$$N^s = N^c - \sum_{i=1}^{J} a_i N_i \tag{47}$$

Since the transaction costs are fixed they do not affect the first order conditions, so the solution to this problem is the same as for the problem in section 2.2. This means that if the farmer enters the market the trade will be the same as without the transactions costs.

If the farmer does not trade his/her profit may be estimated by equation[40], while when trading, the profit may be estimated by

$$\pi^T(\bullet) = \pi^N(\bullet) - TC = \left(N^c - c_0 - \tfrac{1}{2}c_1 v_m\right)v_m - \gamma_0 + A \tag{48}$$

where γ_0 is the fixed transaction costs. Clearly, if [48] is larger than [40] it is optimal to enter trade. In order to estimate the non-trade region we need to find the prices where $\pi^T(\bullet) = \pi^N_{min}$. This may be approximated by solving:

$$\left(N^c - c_0 - \tfrac{1}{2}c_1 v_m\right)v_m - \gamma_0 + A = \frac{1}{2}\frac{(N^c - c_0)^2}{c_1} + A \tag{49}$$

The two roots of this problem are:

$$v^0 \pm \sqrt{2\frac{\gamma_0}{-c_1}} \qquad [50]$$

and the width of the non-trade price region is thus:

$$v^+ - v^- = \sqrt{8\frac{\gamma_0}{-c_1}} \qquad [51]$$

Estimating the non-trade interval with both fixed and variable transaction costs

If we combine the first order conditions for the case of variable transaction costs ([28] and [29]) we get:

$$\frac{\partial L}{\partial N_i} = a_i \left\{ p_i \frac{\partial f_i(N_i)}{\partial N_i} - \left(v_m - \frac{\partial TC(N^s)}{\partial N^s} \right) \right\} = 0 \quad \forall i \qquad [52]$$

If the term in the parentheses is less than v^0 it is optimal to not enter trade, i.e. transaction costs are larger than the gain from trade. This means that there is a price region where the farmer is not trading:

$$N^s = \begin{cases} > 0 & v_m > v^0 + \dfrac{\partial TC(0)}{\partial N^s_+} \\ < 0 & v_m < v^0 + \dfrac{\partial TC(0)}{\partial N^s_-} \\ = 0 & \text{elsewhere} \end{cases} \qquad [53]$$

The subscripts + and – indicate in what direction the derivative should be evaluated. This since the derivative of TC(•) at $N^s = 0$ is discontinuous, switching from negative to positive.

Comparing [52] and [34] we see that the only difference is the marginal transaction costs. This means that we may use the demand functions used above if we include marginal transaction costs in the “price” argument. If we assume that transaction costs are linear in trade, i.e.

$$TC(N^s) = \gamma_0 + \gamma_1 \left| N^s \right| \qquad [54]$$

demand will then be:

$$N_i = \begin{cases} c_0 + c_1(v_m + \gamma_1) & v_m < v^0 - \gamma_1 \\ c_0 + c_1(v^0) & v^0 - \gamma_1 \le v_m \le v^0 + \gamma_1 \\ c_0 + c_1(v_m - \gamma_1) & v_m > v^0 + \gamma_1 \end{cases} \qquad [55]$$

If we now integrate back we get

$$\pi = \begin{cases} \pi^b = \left(N^c - c_0 - \tfrac{1}{2}c_1\left(v_m + \gamma_1\right)\right)v_m - \gamma_0 + B^b \\ \pi^N_{min} = \left(N^c - c_0 - \tfrac{1}{2}c_1 v^0\right)v^0 + A \\ \pi^s = \left(N^c - c_0 - \tfrac{1}{2}c_1\left(v_m - \gamma_1\right)\right)v_m - \gamma_0 + B^s \end{cases} \qquad [56]$$

This is illustrated in Figure 18.

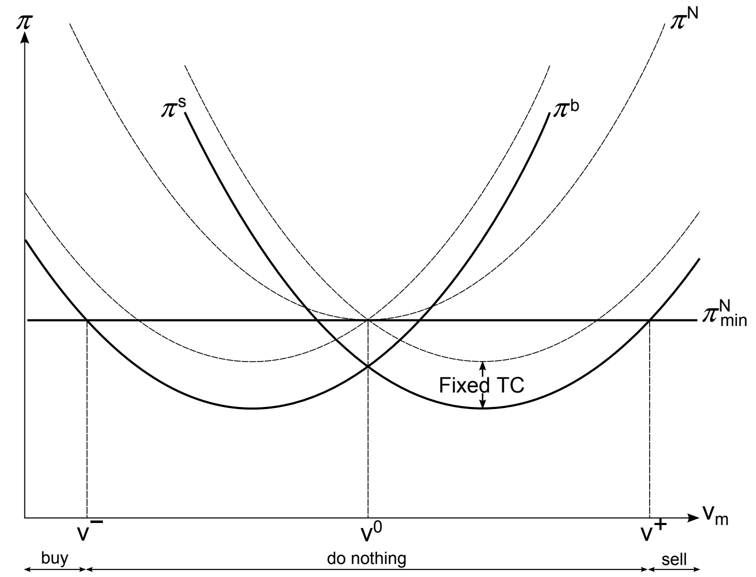

Figure 18. Profit with both fixed and variable transaction costs.

The aim now is to estimate the two points v^+ and v^-, and we need to this separately for the two points. However, the decision problem is symmetric round v^0. The profit functions are second order polynoms and we have assumed that transaction costs are the same for both purchase and sale of nitrogen in the quota marked (for a given amount). Hence, $v^+ - v^0 = v^0 - v^-$. We will therefore solve for v^+, i.e. we will use π^s and π_{min} from [56]. Since the (unknown) constants of integration (A, B^s, B^b) are closely linked to the intersections with the y-axis for the three profit functions, it is clear that they in general are different. This means that since we are solving for $\pi^s = \pi_{min}$ we have a problem with tree unknowns (v_m, A and B^s), and we need two points in order to be able to find v^+. One point is obviously $v_m=v^+$, and from [53] we know that $\pi^s + \gamma_0 = \pi_{min}$ for $v_m = v^0 + \gamma_1$ (and due to symmetry, $v_m=v^0$). Hence:

$$\left(N^c - c_0 - \tfrac{1}{2}c_1v^0\right)\left(v^0 + \gamma_1\right) + B^s = \left(N^c - c_0 - \tfrac{1}{2}c_1v^0\right)v^0 + A \qquad [57]$$

giving

$$B^s = -\gamma_1\left(N^c - c_0 - \tfrac{1}{2}c_1v^0\right) + A \qquad [58]$$

The next step is to solve the following for v_m:

$$\begin{aligned} \pi^s &= \left(N^c - c_0 - \tfrac{1}{2}c_1\left(v_m - \gamma_1\right)\right)v_m - \gamma_0 - \gamma_1\left(N^c - c_0 - \tfrac{1}{2}c_1v^0\right) + A \\ &= \\ \pi^N_{min} &= \left(N^c - c_0 - \tfrac{1}{2}c_1v^0\right)v^0 + A \end{aligned} \qquad [59]$$

By dividing through by c_1 and collecting terms, we get:

$$-\tfrac{1}{2}v_m^2 + \left(v^0 + \tfrac{1}{2}\gamma_1\right)v_m - \left(\tfrac{1}{2}v^{0^2} + \tfrac{1}{2}\gamma_1v^0 + \frac{\gamma_0}{c_1}\right) = 0 \qquad [60]$$

Since we know that v^+ is the largest root of [60] (see Figure 18):

$$v^+ = v^0 + \tfrac{1}{2}\gamma_1 + \sqrt{\tfrac{1}{4}\gamma_1^2 - 2\frac{\gamma_0}{c_1}} \qquad [61]$$

and by using the symmetry argument mentioned above:

$$v^{-} = v^{0} - \tfrac{1}{2}\gamma_1 - \sqrt{\tfrac{1}{4}\gamma_1^2 - 2\frac{\gamma_0}{c_1}} \qquad [62]$$

If we now combine these two we get the expression for the width of the non-trade region:

$$v^{+} - v^{-} = \gamma_1 + \sqrt{\gamma_1^2 - 8\frac{\gamma_0}{c_1}} \qquad [63]$$

This is consistent with the findings above.

Convex transaction costs function

In the main text it was mentioned that if the transaction costs function is convex and there are no fixed transaction costs, it would be optimal to split the transaction (i.e. trade) into smaller pieces. We will prove this, and start the proof by looking at the situation when a given trade is split into two trades of arbitrary sizes.

Let x (>0) be the total amount of nitrogen traded split into x_1 and x_2, and let f(x) be the transaction costs function. Since

$$\int_a^b \frac{\partial f}{\partial x}dx = \Big|_a^b f(x) = f(b) - f(a) \qquad [64]$$

we have:

$$d = f(x_2) + f(x_1) - f(x_1 + x_2) = \int_0^{x_2} \frac{\partial f}{\partial x}dx + f(0) - \int_{x_1}^{x_1+x_2} \frac{\partial f}{\partial x}dx \qquad [65]$$

If f(x) is convex and non-linear everywhere, the derivative of f(x) is smaller at x = 0 than at x = x_1. Since the derivative is non-decreasing and the “width” of the two integrals are the same (x_2-0 = x_1+x_2-x_1), the value of the first integral is smaller than the value of the last integral. The difference (d) is smaller than zero if f(0) is smaller than the negative of the difference between the first and last integral. Hence, if there are no fixed transaction costs (or sufficiently small), it is optimal to split the trade into two trades. Since this hold for any arbitrary split into x_1 and x_2, it must also hold for any split of x_1 and x_2 into even smaller part, and so on. This means that it is optimal to split the trade into an infinite number of small trades (zero in the limit), driving the total transaction costs down to zero (in the limit). This situation, i.e. an infinite number of trades at no cost, will not occur in the real world. We can therefore rule out the case of convex transaction costs function with no fixed transaction costs.

Convex transaction costs function may also lead to non-convexity problems. This is easily seen from the following:

$$\underset{N_1,\ldots,N_I}{\mathrm{Max}}\,\pi(N_1,\ldots,N_I) = \sum_{i=1}^{I} a_i p_i f_i(N_i) - vN^c + v_m\left[N^c - \sum_{i=1}^{I} a_i N_i\right] - TC\left(N^c - \sum_{i=1}^{I} a_i N_i\right) - FC \qquad [66]$$

For the solution of the first order conditions for this problem to be a maximum point, the objective function must be concave in the N_i. If TC(•) is convex in N^s, the negative of TC(•) is convex in N_i. Since $f_i(N_i)$ is concave and the sum of concave and convex functions may be either concave or convex, we cannot rule out the situation that it is optimal to do nothing (not trade) due to the convexity of TC(•), i.e. the solution of the first order conditions yield a minimum point.

In terms of market behavior the logic is as follows. In general, N^s is increasing in v_m. If we for simplicity only look at the situation of $N^s>0$ (i.e. $v_m>v^0$), the (marginal) gain from trade will increase as v_m increases, but so will also (marginal) transaction costs (since N^s increases). At some point the transaction costs outweighs the gains, and N^s will remain constant for larger prices in the quota market. If marginal transaction costs are large enough for $N^s=0$, the farmer will not enter trade at all. The general situation is shown in Figure 19.

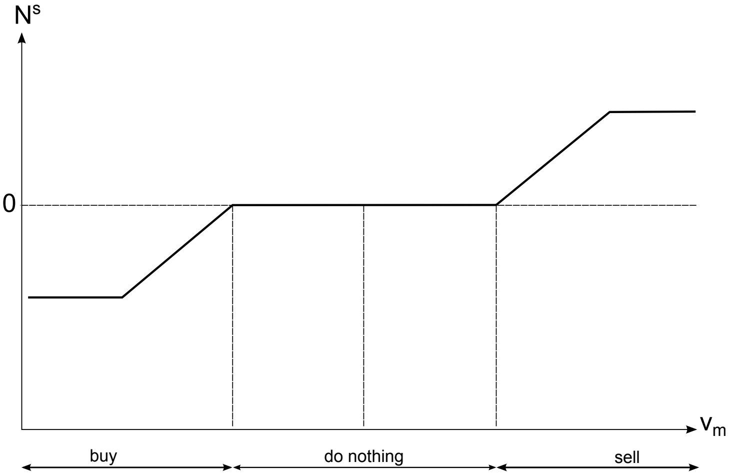

Figure 19. Sale when transaction cost function is convex.

Even though convex transaction costs functions cannot be ruled out by assumption, it seems very unlikely that they are convex.

Curvature properties of the production function

It was assumed in the main text that the production functions, i.e. crop growth, are concave in nitrogen. At high nitrogen levels this is easily justified, but at low fertilizer levels this may not be the case. If the plants are small due to low level of nitrogen, an increase in available N will lead to e.g. root development that increases nitrogen absorption larger than the increase in fertilization. This means a convex region of the production function. At high N levels the plants are closer to their maximum size and less responsive to nitrogen. This means that we need to look at the situation where the production function changes from convex to concave at some point. From [34] we have that

$$p_i \frac{\partial f_i}{\partial N_i} - v_m = 0 \Leftrightarrow p_i \frac{\partial f_i}{\partial N_i} = v_m \Leftrightarrow \frac{\partial f_i}{\partial N_i} = \frac{v_m}{p_i} \; \forall i \qquad [67]$$

If $f_i(N_i)$ is not everywhere concave (or convex) there may exist more points that satisfy [67]. The assumptions above imply one inflection point, and [67] will therefore be satisfied by two or less points. This is illustrated in Figure 20.

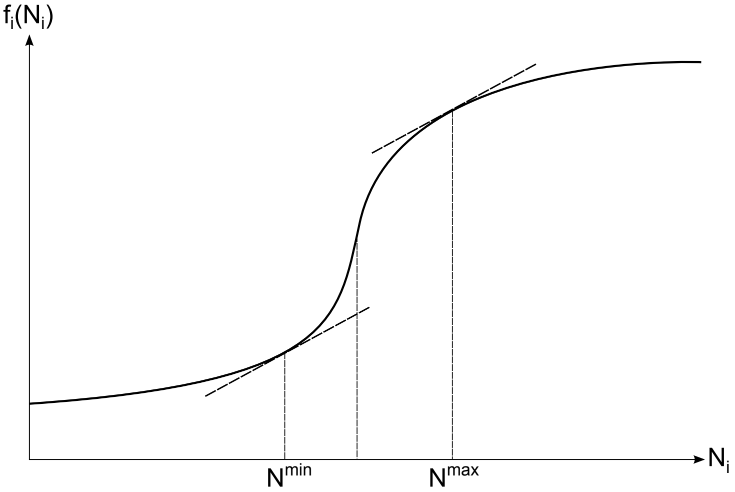

Figure 20. Extrema when the production function is both convex and concave.

The extremum to the left of the inflection point is a minimum, while the one to the right is a maximum, i.e. the solution to [33]. Equation [67] may be graphed as:

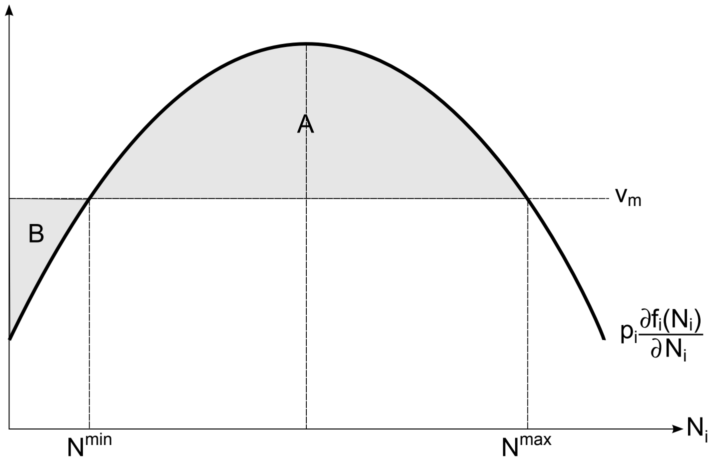

Figure 21. Extrama and profit when the yield function is sigmoid shaped.

Area A minus area B is the profit from applying N^{max} compared to using no N at all (ref. [64]). Area B is the loss from using N^{min}, hence the level that minimizes profit. If v_m increases B increases and A decreases. This means that at some level B will be larger than A and for nitrogen prices above this level it will be optimal to use no nitrogen at all (on field i). This means that the demand for nitrogen at field level in principle is discontinuous, implying that N^s also is discontinuous. However, since N^s is an aggregate for all the field of a farm and that production functions are different for the different fields, N^s will be more "smooth". Also, simulations using the Konor model (Bleken, 2001) for barley in southeastern Norway show that the level of v_m at the discontinuity is so high that only very small quotas would bring that level about in the quota market. Since the convexity is outside the relevant nitrogen and price range of this study, the potential convexity is therefore no problem.

If the yield function is strictly concave, there is only one point satisfying equation [67]. This case is illustrated in the figure below.

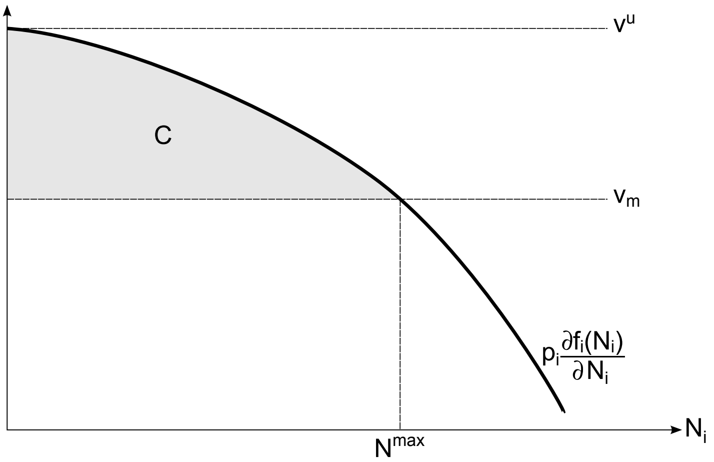

Figure 22. Extremum and profit when the yield function is concave.

Area C is the difference in profit between using N^{max} and no fertilizer. From the figure we also see that for nitrogen prices above v^u it is optimal to use no fertilizer. This price level is determined by the derivative of the yield function at zero and the ouput price. Production functions and output prices from Vatn el al. (2006) indicate that v^u is 10 – 20 times the current nitrogen price. Under a quota scheme this will only occur if the quotas are set very small.

PAPER 2

Policy measures to induce split application of fertilizers in grain production

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Abstract

The effects of pollution from nature based productions – like agriculture – do not only depend on the production decisions made. Nature, or more specifically the weather, is the main driving force in such productions. If possible, policies to reduce the environmental damages should therefore also seek to incorporate "the game nature plays".

The characteristics of nature based productions vary. Consequently, policy instruments needs to be tailored to the specific production and environmental problems. In grain production growing conditions vary considerably between years, which carry over to the environmental damages. Research indicates that split fertilization is a promising measure to reduce nutrient leaching from agriculture since this opens up for utilizing information as it becomes available during the growing season. Split application of fertilizers in grain is rarely used, indicating higher profits from fertilizing only at the beginning of the growing season.

This paper looks at policy measures to induce farmers to practice split fertilization. These measures include a two-tiered input tax and a two period system of fertilizer quotas. It is demonstrated that a two-tiered tax will not work, due to the necessarily large difference in tax level between the two periods and the possibility to store fertilizers from one year to the next.

We have analyzed the effects of split fertilizer quotas and taxes on fertilizer nitrogen in southeastern Norway under current climatic conditions and under a possible future climate (2010 – 2048). The results show that the split quota will reduce losses to the environment at lower costs (both private and social) than a tax. Further research is needed to investigate if these promising results also hold in other regions in Norway.

Key words: input taxes, split application of fertilizer, nonpoint-source pollution.

1. Introduction

Nature entails several stochastic elements. Of these the weather is the most noted factor – not only because of what it directly does (rain or shine today), but because it influences other processes, like the growth of renewable resources. From the area of bioeconomics it is well known that wise management of renewable resources under certainty differs from that under uncertainty.[1] The biosphere is also the recipient of most of the man-made waste. Polices to

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[1] Conventional wisdom suggests that "Maximum Sustainable Yield" (MSY) is a good criterion for managing renewable resources (like fisheries). Even with zero harvesting costs, MSY is not a desirable management strategy under uncertainty as it comprises an unstable equilibrium point when growth rates or stock size are not known with certainty (Conrad and Clark, 1987).

reduce the environmental damages from emissions should therefore address issues dealing with this uncertainty.

In a study to the Norwegian Ministry of Agriculture on pollution from agriculture (Simonsen, 1989), issues pertaining to uncertainty/variability were not discussed. The study indicated that taxing the polluting inputs (nitrogen and phosphorus) was the policy instrument providing least costs of reducing leaching from grain production by 50 %.[2] Vagstad (1990) was intrigued by Simonsen's findings, because the variability in the amount of N-fertilizers applied only accounted for 30 % of the variability of the measured N leaching.

Following up on Vagstad's findings, Bakken and Romstad (1992) undertook a simulation study based on data for nitrogen (N) leaching for the period 1974-1981.[3] In that particular period there was one year (1976) with drought. They showed that one could reach the same aggregate reduction in N leaching as would be the case by a 300 % N tax by reducing fertilization to 50 kilograms per hectare for that one year and keeping fertilization at the non-tax profit maximizing level the other seven years in the study period.

Split fertilization is one possibility of obtaining such fertilization levels. Its basic justification comes from a nutrient balance perspective – the nutrients that are not taken up in the plants (and removed with harvest) are "strong" candidates for leaching. Consequently, the potential leaching caused by fertilizing at a the level maximizing expected profit, i.e. constant between years, in years that display poor growing conditions can be large, while in years with good growing conditions the leaching is possibly much lower.

In the following section of this paper, the possible impacts of a split fertilization regime are investigated. Currently Norwegian grain farmers do not practice split fertilization, implying that split fertilization results in lower expected profits or that they lack information about this fertilization strategy. Policy measures to induce farmers to practice split fertilization are discussed in the ensuing sections of the paper.

2. The economics of split application

The largest possible income is obtained when all the uncertainties about the growth season is resolved, i.e. when using year specific (actual) production functions. This is in principle only possible ex post, but as we will see, split application is an attempt to approximate this

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[2] The input taxes needed to reach this target was approximately 300 % of the current fertilizer price, making it virtually impossible to implement the policy.

[3] The data set used was Uhlen's field lysimeter (Uhlen, 1985).

situation. The year specific optimal fertilization levels are found by solving the first order conditions of the following "profit function":

$$\pi_{ijt} = p_j f_{ijt}(x_{ijt}) - v x_{ijt} - FC \qquad [1]$$

where

$f_{ijt}(\bullet)$	are production functions (yield functions) for soil type i, crop j, and year t,
p_j	is the product price for grain type j,
x_{ijt}	is the year specific nitrogen fertilization level,
v	is the price of nitrogen fertilizers, and
FC	is fixed costs.

The ability of the decision maker to predict the profit maximizing fertilization level in each year is crucial for the profitability and expected effect on nutrient losses of split fertilization. Generally one would expect that as the growing season progresses, the accuracy of the decision maker's prediction increases, as indicated in Figure 1.

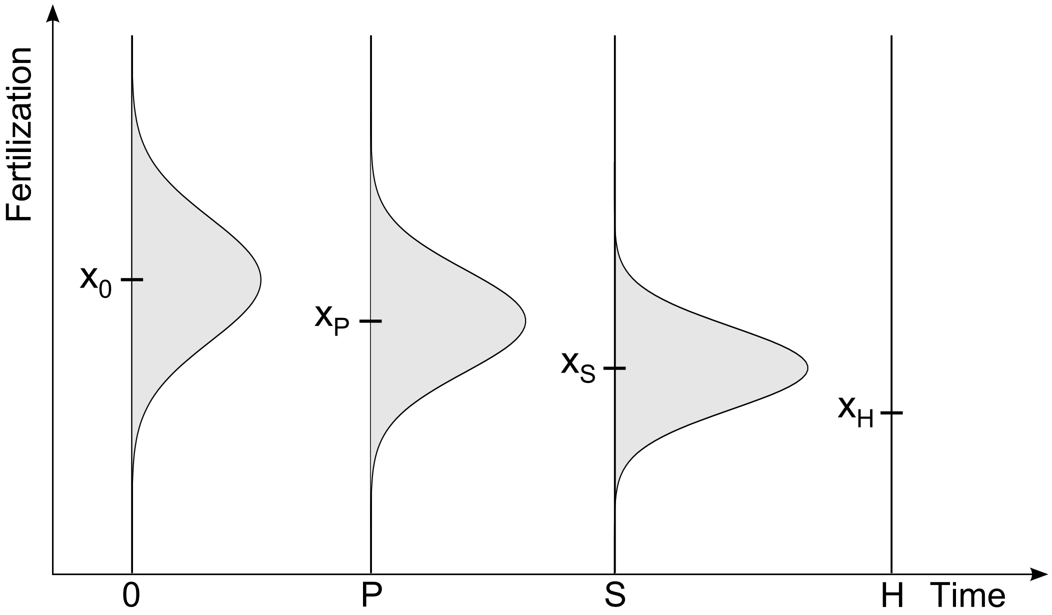

Figure 1. Forecast of the profit maximizing fertilization level (mean and distribution) as the growing season progresses (0: start of season, P: sowing, S: shooting, H: harvesting).

Split fertilization involves some additional decisions compared to fertilizing only once. The most important of these decisions is how much fertilizer to apply at the time of sowing. In this connection it is important to note that the lesser amount applied at the start of the growing season, the lesser the time before a decision on round two needs to be made.[4]

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[4] If the level applied in the first round is very low, the possibility of plant growth stagnation should not be overlooked, resulting in difficulties regaining normal plant growth later in the season.

Provided that information on the year optimal fertilization level gets more reliable as the growing season progresses, this also implies that less reliable information is gained before an (eventual) second round of fertilization.

For split fertilization to be profitable, the expected profits from split fertilization must exceed the profits of fertilizing only once. The mathematical expression for the expected profits of fertilizing once is:

$$\pi_{ij}^{1} = p_j f_{ij}(x_{ij}) - vx_{ij} - FC \qquad [2]$$

where

$f_{ij}(\bullet)$ is the expected production function for soil type i and crop j,

x_{ij} is the expected profit maximizing fertilization level for soil type i and crop j, and other terms are as earlier specified.

The mathematical expression for the expected profits of split fertilization is given by:

$$\pi_{ij}^{2} = \Sigma_{t\in T} T^{-1} E_{\Omega t}\left[p_j(1-\alpha d) f_{ijt}(x_{ijt}^{1}, x_{ijt}^{2}) - v(x_{ijt}^{1} + x_{ijt}^{2}) - FC - dC_s\right] \qquad [3]$$

where

t is the year (= 1, 2, ..., T),

$f_{ijt}(\bullet)$ are production functions for soil type i, crop j, and year t[5],

$E_{\Omega t}$ is the expectations of growing season t at the time of the second fertilization round,

α is a yield correction factor, e.g., loss from additional trafficking in the field caused by a second round of fertilization application,

x^{1}_{ijt} is the fertilization level applied in round 1,

x^{2}_{ijt} is the fertilization level applied in round 2,

d is a dummy variable, equaling one if $x^{2}_{ijt} > 0$ and zero otherwise,

C_s is additional operating costs of split fertilization, and other terms are as earlier specified.

As mentioned earlier, Norwegian farmers generally do not practices split fertilization, implying that the expected profits of fertilizing once (π^1) exceed the profits of split fertilization (π^2), or that farmers lack information about and experience in practicing split application. Consequently some policy instrument is needed for Norwegian grain farmers to practice split fertilization.

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[5] Nutrients applied in the two rounds may have different effects on yield, e.g. if much of the nutrients applied in the first round are lost due to heavy rain. However, field trials (Hoel, 2007) indicate that such effects are rather small, i.e. only total application seems to be important. For this reason we will assume an additive effect of the two rounds.

3. Choice of policy instruments

3.1. Two tiered tax

Let us for now assume that the optimal fertilization levels for the two rounds have been found, and that these amounts are given as non-tradable quotas to the farmers. To further simplify, assume that there are no yield losses or extra operating costs associated with split fertilization. The profit maximizing problem can then be posed as:

$$\pi_{ij}^2 = p_j f_{ijt}(x_{ijt}^1 + x_{ijt}^2) - v(x_{ijt}^1 + x_{ijt}^2) \qquad [4]$$

subject to

$$\begin{aligned} x_{ijt}^1 &= \bar{x}_t^1 \\ x_{ijt}^2 &= \bar{x}_t^2 \end{aligned} \qquad [5]$$

where $\bar{x}_t^1$ and $\bar{x}_t^2$ are the quotas in period 1 and 2, respectively.[6]

The first order conditions to the Lagrangian of this problem are:

$$\frac{\partial f_{ijt}(\bullet)}{\partial x_{ijt}^k} = \frac{v - \lambda^k}{p_j} \quad k = 1,2 \qquad [6]$$

where

λ^k are the Lagrangian multipliers, i.e. shadow price of the two quotas.

It is evident from Equation [6] that setting taxes equal to the Lagrangian multipliers, the resulting first order conditions under a two-tiered tax regime will equal those under split quota. Since the production functions form convex production possibility sets, it is easy to show that the tax in the first round must be equal to or larger than the tax in the second round. A two-tiered tax is unlikely to induce split fertilization because it will be more profitable to buy fertilizer in the second round (lower fertilizer tax) and store it for the next year. More specifically, the maximum difference between the taxes in the two periods cannot exceed the sum of: (i) the storage costs, (ii) the interest loss of buying fertilizers in period two and saving these fertilizers for the next year (the interest loss of dead capital), and (iii) the additional costs associated with multiple rounds of fertilizer application. Consequently the purpose of a two-tiered tax breaks down.

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[6] Note that these quotas are not crop or soil type specific, as a likely outcome of crop and soil type specific quotas would be gaming behavior on behalf of farmers, with corresponding costly monitoring being the result. The presence of quotas would, however, influence farmers' choices of crops, as the expected profit maximizing fertilization levels vary between crops and soil types.

3.2. Split quota

The other policy option we investigate is the use of fertilizer quotas. The perceived quota system has the following characteristics:

- The first round quota is sufficiently large to permit information to be gained regarding the growing conditions for the actual year (confer with Figure 1) without growth stagnation due to lack of plant nutrients.
- The second round quota is awarded based on information on how the growing season is developing in each year. Two factors determine how this year specific quota is set: (i) the regulatory agency's estimate of the year specific profit maximizing fertilization level for grains, and (ii) the agency's perceptions on what constitutes a socioeconomic and environmental desirable fertilization level, given the information that has been revealed regarding the actual growing season.
- As growing conditions on various farms may vary considerably, these quotas are transferable to allow farmers to correct their fertilization level from the agency's allotment.

Mathematically the regulatory agency will allot quotas according to the following rule:

$$\bar{x}_t^1 = \bar{x}^1 \qquad [7]$$

$$\bar{x}_t^2 = \mathrm{MIN}\left\{ I^{-1}J^{-1}\Sigma_{i\in I}\Sigma_{j\in J}\hat{x}^*_{ijt} - \bar{x}_t^1 - q_t,\ \bar{x}^2_{max} \right\} \qquad [8]$$

where

$\bar{x}^1$	is the allotment in the first round (constant between years),
I	is the number of crops used in the base calculations,
J	is the number of soil types used in the base calculations,
$\hat{x}^*_{ijt}$	is the agency's estimate of the year specific profit maximizing fertilization level for crop i on soil type j,
q_t	is the agency's estimate of needed reduction (from the year specific optimal level) in fertilization in order to reduce mean nutrient leaching to the socially desired level,
$\bar{x}^2_{max}$	is the agency's estimate of maximum desired fertilization level, and all other terms as previously defined.

Incentive compatibility and Pareto optimality are desired attributes of any environmental policy. Unfortunately both are not always possible. This is due to the problem of manipulation. The following theorem (Hurwicz, 1972) illustrates the possible impacts of manipulation:

THEOREM: Let R′ be a mechanism defined on a family of economic environments, the family of pairs of self-regarding utility functions that exhibit diminishing marginal rates of substitution everywhere. If, for every environment within this family of environments, the mechanism R′ generates equilibrium allocations that are Pareto optimal and individually rational, then it can be manipulated.

The essence of the proof of the theorem is that one agent can obtain increased utility (or profits) by manipulative behavior when all the other agents behave sincerely. Thus, each agent is led to behave manipulatively, and the outcome is not Pareto-optimal. On the other hand, Hurwicz (1959, 1973) also shows that in a dynamic market where there is uncertainty about the environment, the dominant strategy of the individual firm is to participate in the market without manipulating the market.

Applied to the suggested market for N fertilizer quotas, the insight from Hurwich's analysis implies that farmers are likely to behave like price takers in such a market, as the aggregate supply of quotas is not known with certainty by farmers (weather/plant growth dependent). Similar results have been obtained by Romstad and Bergland (1994) for emission permit markets.

There are reasons to assume that few – if any – trades will occur in the first round of quota allotments. Given perfect information we know that in "good" growing years the application in the first round is just sufficient to avoid growth stagnation before the second quota is allotted. Similarly, in "bad" growing years, the estimate of profit maximizing fertilization levels for grains are close to the first round allotment. With year specific production functions that all are rather strongly concave around this fertilization level, the expected losses of selling quotas are likely to be larger than the expected gains of buying additional quotas. The farmer is generally better off to wait with trading until the second round of quotas is available on the market.

4. Simulations

Our results are based on simulations using the SPN (soil-plant-nitrogen) model for barley on clay soil in Ås (Southeastern Norway). The results from the SPN simulations were used to estimated year specific yield, nitrate leaching and N_2O emission functions. SPN is part of a larger modeling cluster developed for the study of the interaction between agri-environmental policies, economics and ecology (Vatn et al., 2006). SPN integrates the SOILN_NO model

(Vold et al., 1999) with the dynamic plant growth model KONOR (Bleken, 2001) for the simulation of spring cereals. In addition to yield development, SPN also simulates dynamic nitrogen and carbon turn-over in the soil and the resulting nitrogen leaching. Simulation of N_2O emission is integrated by using the denitrification algorithm of the DAYCENT model (Parton et al., 2001). Heat and water transport in the soil plant system were simulated using COUP, which is a one-dimensional model driven by daily values of air temperature, relative humidity, wind speed, precipitation and cloudiness (Jansson and Karlberg, 2004). The simulated soil temperature, soil moisture, water runoff were used as input for the SPN model.

In addition to historical climate for the period 1958 – 2005, one future climate scenario was used in the simulations (for the period 2010 – 2048). A Max Planck ECHAM 4/OPYC3 global climate scenario was regionally downscaled as described by Engen-Skaugen (2007). Mean monthly precipitation and temperature are shown in Figure *2*.

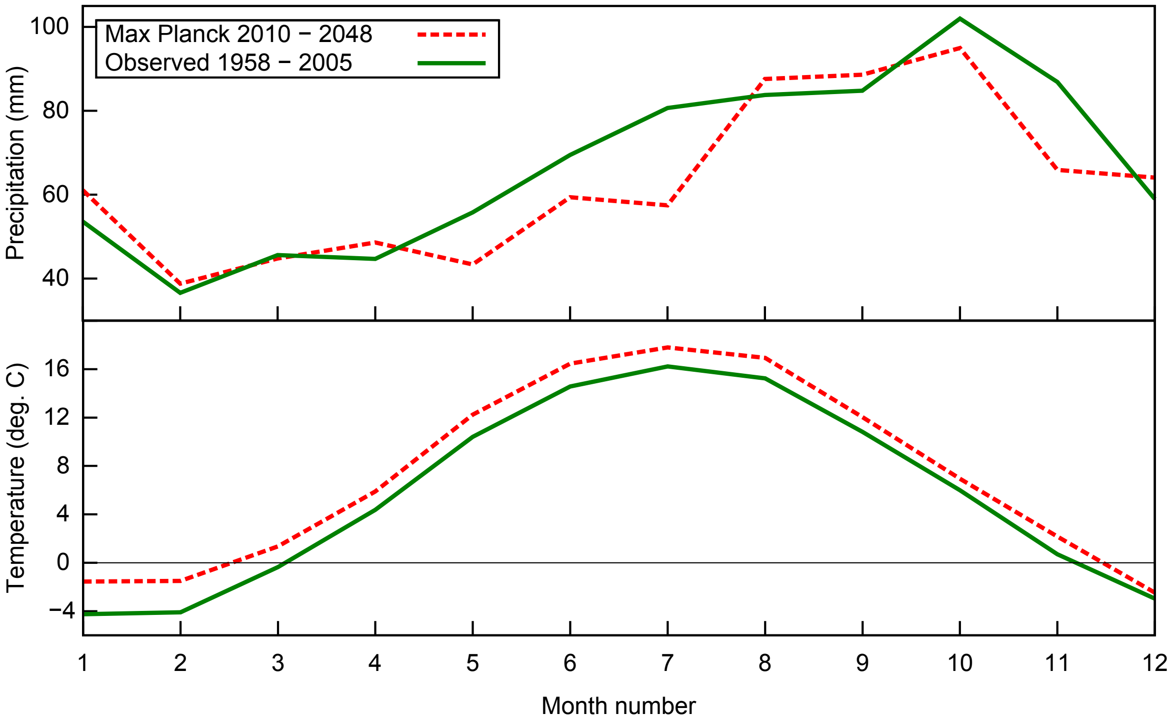

Figure 2. Mean monthly precipitation (upper part) and mean monthly temperature (lower part) in the two climate scenarios.

The yearly average temperature will increase by 1.6 °C and yearly average precipitation will decrease by 48 mm (about 6%) in the projected climate compared to the historical climate. The changes in the growth season are important for crop production: mean temperature in the period May through July will increase by 1.7 °C and mean monthly precipitation will drop by 15.2 mm. Increased temperature is normally viewed as positive for crop growth. However, phenological development in grains is mainly driven by temperature sums. Cet. par. this means that if the temperature increases the grains will ripen earlier and the period for grain filling will be shorter – resulting in lower yield levels. In order to mitigate the effect of increased temperature it is necessary to use a slower developing cultivar. In addition to a commonly used cultivar (*early barley*), we have also used a late cultivar (*late barley*), that under the present climate would not reach maturity. The latter is used under the projected climate in order to explore the mitigation possibilities.

Since SPN also includes the estimation of N_2O emissions, we have included these estimates in the results. Emission of N_2O is linked to the amount of soluble nitrogen in the soil, and thereby to the fertilization level. However, the processes are more complex and the variation from year to year larger than for nitrate leaching.

Since SPN simulate crop growth under close to ideal conditions, yields were adjusted to take into account factors like lodging, border effects, etc. The estimated yield levels are in line with the ones reported by Hoel (2007).

We have simulated five different situations regarding information and policy instruments (denoted fertilization scenarios in the tables below). For all of them, application of fertilizer, gross margin, nitrate leaching and N_2O emission are reported. In the fertilization scenario *Full info* it is assumed that the year specific yield functions are known with certainty and that farmers maximize Equation [1]. This is clearly not a feasible scenario, but it is included to show the value of information and how this influences the losses to the environment. In *Base* no information is available about the year, and farmers are assumed to maximize expected profit (Equation [2]). *Tax 100* is equal to *Base* except that a 100% tax is levied on nitrogen in fertilizers. A 100% tax does not result in a 10 kg N/ha fertilization reduction, which is the required fertilization reduction (q_t) in the split application scenario (see below). We have therefore included a tax scenario, *Opt. tax*, where the tax is set such that the required nitrogen fertilization reduction is reached. Finally, *Split* is the split application scenario where quotas are assumed to be allotted according to Equations [7] and [8]. The following values for the key parameters are used in the simulations:

$\overline{x}_t^1$ 60 kg N/ha,[7]

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[7] Hoel (2007) investigated split application in the period 2003 – 2005 for barley and oat. Two levels were used for the first application (50 and 80 kg N/ha) and two development stages for the timing of the second round. Only rather small differences were found between the different treatments.

$\hat{x}^*_{ijt}$ is calculated on the basis of Equation [1], and adjusted ± 10 kg N/ha using a uniform probability distribution around $\hat{x}^*_{ijt}$,[8]

q_t 10 kg N/ha,[8] and

$\overline{x}^2_{max}$ 140 kg N/ha.

The model is run 100 times in order to converge to the mean of the year specific optimal fertilization levels. The results reported in the tables are the mean and standard deviations of these 100 runs.

Based on the findings of Hoel (2007) we have assumed no yield loss from split application (i.e. $\alpha = 0$ in Equation [3]), but the costs of an extra application of fertilizer is included.

Since only one soil type is used, due to lack of data, the quotas are non-tradable. This means that the costs (changes in gross margin) are larger than would have been if we had modeled a quota market. The environmental effects of tradable versus non-tradable quotas are unknown a priori since the "correlation" between the willingness to pay for quotas and losses to the environment is unknown, e.g., quotas may be traded from less to more polluting farms (or vice versa).

5. Results and Discussion

In this section we will first present the main results from the simulations, followed by a short presentation of the effects of uncertainty about the year specific optimal fertilization level.

5.1. The historical climate scenario

As expected, full information about the yearly production functions yield the largest gross margin (Table 1). However, the gain compared to the base case, where fertilization is assumed to be constant across years, is mere 2%. This means that there are no (or at least only very small) economic incentives for farmers to resolve the uncertainty about the growth conditions during the growth season since this will be costly. Full information results in a substantial reduction in the losses to the environment compared to the base case: nitrate leaching is about 11% lower and N_2O emission are about 15% lower. There are (at least) two reasons for this. First, the mean fertilization level is lower when full information about the year is available. Second, as mentioned above, there is a positive (significant) correlation between the yearly growth conditions and optimal fertilization level. On average, this results

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[8] Simulations are also run for wider spreads and lager reduction. The main results will be presented only for a 10 kg N/ha reduction and an assumed error term of ± 10 kg N/ha. The effect of the uncertainty is discussed below.

in less residual nitrogen in the ground and thereby lower losses. However, the standard deviations for nitrate leaching indicate that the correlation is not “perfect”.

For the split quota fertilization scenario, the reduction in gross margin compared to Base is small (<1%). Compared to Full info, the reduction is about 2%, despite a rather large reduction in fertilization. The environmental effects compared to Base are rather large: leaching is reduced by 19% and N_2O emission is reduced by 21%. This means that Split achieves a rather large environmental improvement at low costs (for both farmers and society).

Table 1. Main results under historical climate (1958 – 2005), early barley.

Fertilization scenario	Mean fertilization (kg N/ha)[9]	Gross margin (NOK/ha)*)		Nitrate leaching (kg N/ha)		N_2O emission (kg N/ha)		Cost effectiveness (NOK/kg N)**)	
		Mean	Std.	Mean	Std	Mean	Std	Nitrate	N_2O
Full info.	154	8495	2218	64	26.5	2.8	1.16	.	.
Base	166	8328	2307	72	23.7	3.3	1.48	.	.
Tax 100	150	7380	2283	62	21.4	3.0	1.32	4.5	128.7
Split	144	8287	2197	58	25.1	2.6	1.09	3.0	58.4
Opt. tax	144	6942	2264	58	20.5	2.8	1.25	6.8	191.3

*) Fixed costs are assumed to be unaffected by the measures, and only variable costs that vary between the measures are included in the estimation of the gross margin.
**) Cost is difference in gross margin between the scenario and the base scenario plus tax revenue (if any), i.e. an estimate of the social costs excluding regulation costs. The two measures are calculated independently.

Both tax scenarios result in rather large reductions in gross margin compared to Base: about 11% for Tax 100 and 17% for the tax level that results in the same fertilization level as Split. The latter tax level is about 160%. Clearly, if the nitrogen price is more than doubled this will have a large economic impact. Opt. tax results (by coincidence) in the same leaching reduction as Split (19%), but yields lower N_2O emission reduction (15%). The standard deviation for leaching is larger for Split than Opt. tax. If the dose-response relationship, i.e. the effects in the recipient, is increasing and convex in nitrate supply, expected damage is larger for Split than for Opt. tax. Regarding N_2O emission the spread is of less importance since it is mainly the atmospheric concentration that matters and the decay rate is rather low (in the current perspective).

The low reduction in gross margin for Split means that the profit functions (and yield

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[9] It should be mentioned that the estimated fertilization levels are higher than the ones observed in practice. There is anecdotal evidence that farmers are not fertilizing at the point that maximizes expected profit. This is probably mainly due to fertilizer plans and advice that also take the environment into account. Also, N-supply form the soil used in the simulations is relatively low, resulting in higher optimal fertilization. However, this will only have a minor effect on the differences between the different fertilization scenarios.

functions) are rather flat round the optimal fertilization level. From a policy point of view this is important because it means that the loss from reducing (within a reasonable range) nitrogen application in terms of reduced yield is rather low. The challenge is to find an incentive mechanism that lead to reasonable costs, both for farmers and society. As we have seen above, a nitrogen tax will have a much larger negative effect on farm income than split application, mainly due to the tax revenue. For society the difference is much smaller, since the tax is a redistribution of income and not a cost.[10] As can be seen from Table 1, the cost per reduced unit of pollution is lowest for the split quota. In other words, if the costs of acquiring information about the year specific optimal fertilization rate is modest, split quota is the best instrument (from society's point of view). Given the results in the table, the upper bound for this cost is larger than NOK 100/ha (105 - 220). Since estimation of the year specific optimal fertilization level can be applied to a rather large area, the per ha cost are probably reasonably low.

Another way of viewing the results in the table above is that abatement costs are larger with respect to reduced leaching (or reduced N_2O emission) for a tax than for split application. However, these are only some points in the cost – reduced pollution space, and may not hold in general. The model was therefore run for different levels of required fertilization reduction (q_t). Since the yields are concave and increasing functions of applied nitrogen and the leaching functions are convex and increasing, abatement cost is convex and increasing in reduced leaching. The results are shown in Figure 3.

Up to a certain level, abatement costs are lower for the split quota, and above that point a tax results in lower costs. One advantage of split application is that it takes advantage of the differences between years. As the required reduction in nitrogen application increases (indicated by the markers in the figure) the difference in yield between years reduces. At some point the value of information becomes less than the extra cost of split application, hence abatement cost becomes larger for split application than for the tax. For the other climate scenario, abatement cost for the tax is larger than for split application for all levels of reduced leaching.

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[10] Indeed, tax collection is not free, and there are welfare effects from the tax. However, these are relatively small in our setting.

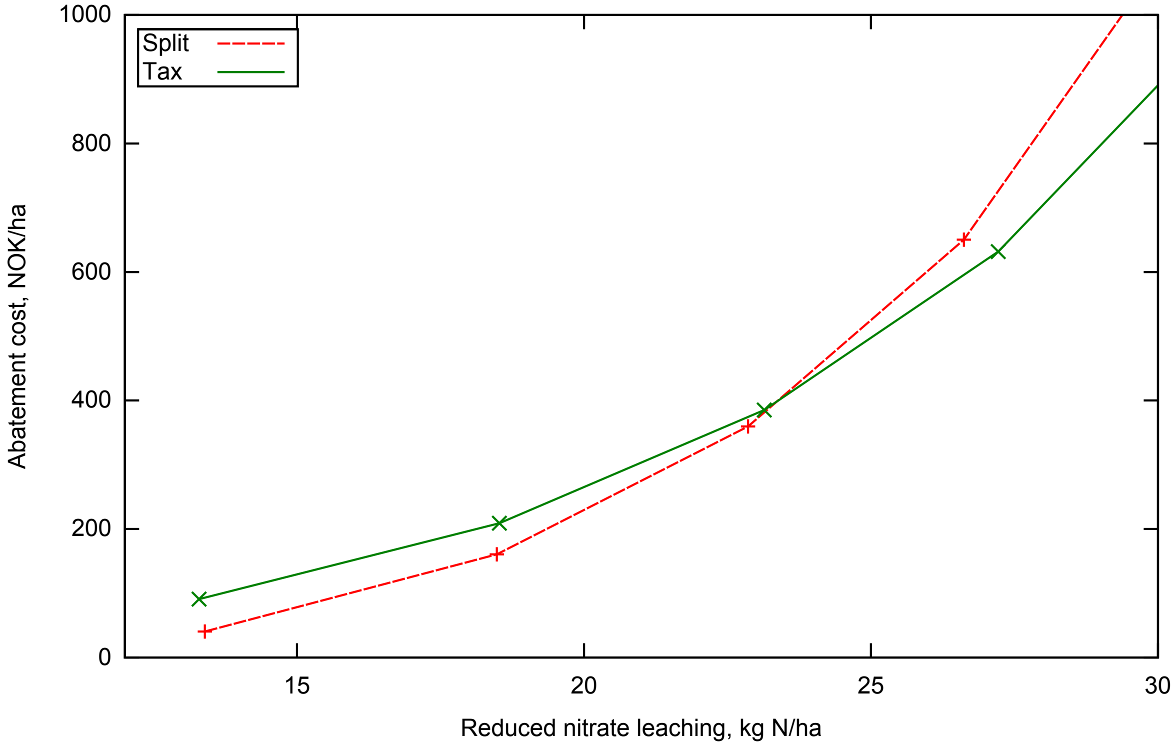

Figure 3. Abatement cost (reduced gross margin corrected for tax revenue and assuming no regulation costs) for a nitrogen tax and split application of fertilizer.

It should be noted that the tax level at the intersection of the two curves is about 370%. Hence, without a proper reimbursement scheme this is clearly not a feasible tax level.

5.2. The future climate scenario

Since temperature is projected to increase in the growth season yields are expected to drop if the current cultivar is used in the future (see above). This should then result in lower gross margins and lower optimal fertilizer levels. Table 2 confirms this hypothesis.

Table 2. Main results under the Max Plack climate scenario (2010 – 2048), early barley.

Fertilization scenario	Mean fertilization (kg N/ha)	Gross margin (NOK/ha)*)		Nitrate leaching (kg N/ha)		N_2O emission (kg N/ha)		Cost effectiveness (NOK/kg N)**)	
		Mean	Std.	Mean	Std	Mean	Std	Nitrate	N_2O
Full info.	139	6860	2856	59	21.7	3.2	0.88	.	.
Base	153	6685	2876	70	30.1	3.8	1.44	.	.
Tax 100	136	5823	2794	59	26.0	3.3	1.25	4.3	85.9
Split	129	6660	2806	53	20.1	2.8	0.84	1.5	26.0
Opt. tax	129	5378	2745	55	24.4	3.1	1.18	6.8	132.4

*) Fixed costs are assumed to be unaffected by the measures, and only variable costs that vary between the measures are included in the estimation of the gross margin.
**) Cost is difference in gross margin between the scenario and the base scenario plus tax revenue (if any), i.e. an estimate of the social costs. The two measures are calculated independently.

Using early barley in this climate would lead to large reductions in gross margin and optimal fertilization compared to under the current climate. Since both yields and fertilization are lower, losses to the environment are fairly the same as for the current climate.

One way to increase yields (and thereby income) is to use a cultivar with a longer growing period. Table 3 shows the results from the simulations using a hypothetical cultivar more adapted to the future climate then the current cultivar.

Table 3. Main results under the Max Plack climate scenario (2010 – 2048), late barley.

Fertilization scenario	Mean fertilization (kg N/ha)	Gross margin (NOK/ha)*)		Nitrate leaching (kg N/ha)		N_2O emission (kg N/ha)		Cost effectiveness (NOK/kg N)**)	
		Mean	Std.	Mean	Std	Mean	Std	Nitrate	N_2O
Full info.	137	8756	3048	39	17.3	4.7	2.21	.	.
Base	149	8617	3095	47	27.3	5.9	3.62	.	.
Tax 100	138	7757	3034	41	24.5	5.3	3.30	5.5	51.1
Split	127	8548	2995	34	15.7	4.2	1.98	5.4	38.9
Opt. tax	127	6794	2946	36	21.9	4.8	2.98	12.6	113.3

*) Fixed costs are assumed to be unaffected by the measures, and only variable costs that vary between the measures are included in the estimation of the gross margin.
**) Cost is difference in gross margin between the scenario and the base scenario plus tax revenue (if any), i.e. an estimate of the social costs. The two measures are calculated independently.

Using a late cultivar, the gross margins are larger than for the early cultivar, while the optimal fertilization levels are about the same and leaching is lower. This is so because when the yield level increases, a larger share of the applied nitrogen is taken up in the plants, leading to a large reduction in leaching.

Compared to the use of the current variety under the historical climate (see the previous section), gross margins are somewhat larger, except for Opt. tax. We also see that the standard deviations increase, indicating larger yield variability between years. Nitrate leaching are lower, again due to the combined effect of reduced fertilization and a slight increase in yields. For the Full info and Split scenarios the standard deviations of leaching are lower. This indicates a higher correlation between optimal fertilization level and growth conditions in the future.

The relative effects (compared to Base) regarding gross margin of the different policy options are about the same as under the historical climate except for Opt. tax which results in a larger reduction (both in relative and absolute terms). The reduction in leaching for Split and Opt. tax are larger in relative terms, but not in absolute terms. These two results lead to increased cost per unit of reduced leaching compared to under the current climate.

The simulations using the Max Planck climate scenario show that it is possible to mitigate the expected negative effects on yields from a warmer climate by using another cultivar. It should however be noted that the cultivar used in the simulations does not exist today. Further, the relative effects of the different policy instruments are similar for both the historical and future climate. Hence, split quota seems to be a good option also in the future.

5.3. Uncertainty

The results presented above were under the assumption that the error when estimating the year specific optimal nitrogen level was drawn form a ±10 kg N/ha uniform distribution. It is out of the scope of this paper to analyze how to estimate the optimal N level and the distribution of the error term of the estimate. However, the assumption may be crucial, and we have therefore preformed a sensitivity analysis of this assumption. This is done by running the model for the split quota under different assumptions about the spread (i.e. different widths of the uniform distribution). We have used spreads ranging from 0 to ±30 kg N/ha. The figure below shows the ratio between leaching under the assumption of perfect foresight and an error term of ±30 kg N/ha.

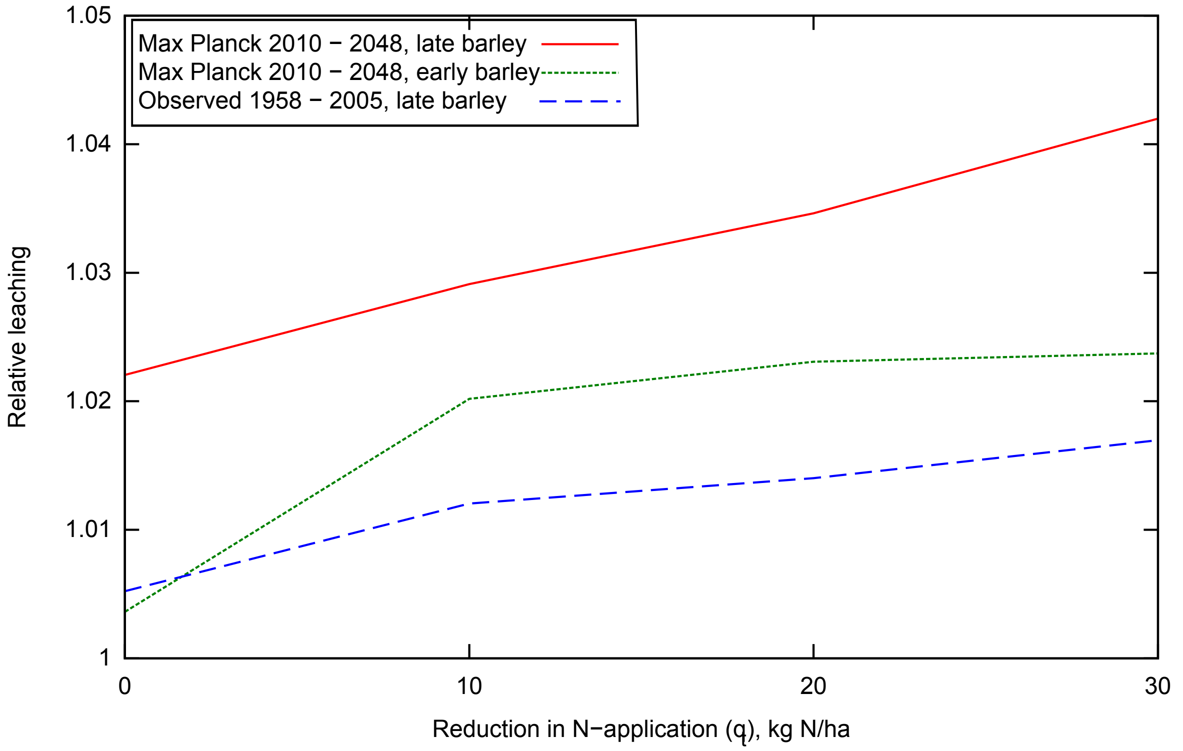

Figure 4. Ratio between leaching when the yearly optimal nitrogen level is known with certainty and when it is assumed to have a uniformly distributed (0, 300 kg N/ha) error term.

Sine leaching is concave in nitrogen application, a spread will lead to a higher expected value than leaching at the mean N level. However, the figure shows that the effect of uncertainty about the yearly optimal fertilization level on leaching is rather small. Similar results are found for also the other variables presented in the tables above. For example, the maximum reduction in gross margin is about 2% (for a 30 kg N/ha reduction in N application). For the same fertilization reduction used in the previous section (10 kg N/ha) the reduction is about 1%. This means that effects of the split quota are not very sensitive to the ability to correctly estimate the year specific optimal fertilization level.

6. Concluding Remarks

The convention wisdom regarding the control of nonpoint source pollution – control the use of the polluting inputs as it is technically difficult and costly to monitor leaching – is still valid. Our study indicates that more sophisticated ways of processing information may open up for other policy instruments than the traditional "let's tax the polluting input" option.

In this paper we have also demonstrated that using a two-tiered tax – a high tax in the first period and a lower tax in the second period – is only feasible if the difference between the two tax rates is below the costs associated with buying in the lower tax period and storing inputs for use in the subsequent year(s). The suggested policy to implement split fertilization does not suffer from this weakness, but will result in higher costs when it comes to gathering and processing information.

Past studies (like Simonsen, 1989) and results from ECECMOD (Vatn et al., 2006) suggest that the N-fertilizer tax rates needed to reduce nonpoint source pollution from agriculture are substantial. The need for looking at other policies that deliver comparable environmental performances and social abatement costs to input taxes, should therefore be obvious. The suggested approach – although in its infancy – is one attempt at developing such policies. As such, the preliminary results are encouraging.

The success of such approaches is clearly sensitive to their underlying informational assumptions. More research on the feasibility of these informational assumptions is needed.

More research is also needed to investigate the effects in other regions and for other crops than barley.

7. Acknowledgement

We would like to thank Lars Egil Haugen, Lars Bakken and Marina A. Bleken, all at the Department of Plant and Environmental Sciences, Norwegian University of Life Sciences, for providing data (model parameters and climatic/hydrological data) for the SPN simulations and commenting draft versions of this paper. We, the authors, are of course solely responsible for any errors in this paper.

8. Literature

Bakken, L. & E. Romstad (1992). Avlingskurver og variasjon – nye perspektiver, pp. 91-107 in Rørstad, P.K. & A. Vatn (eds): *Avlingskurver: Økonomiske og naturvitenskapelige perspektiver*. Report no. 1, Economics and Ecology, Resource Management and Pollution in Agriculture, Department of Economics and Social Sciences, Agricultural University of Norway, Ås, Norway.

Bleken M.A. (2001) *Konor: a Model for Simulation of Cereal Growth. Documentation*. Report 2/2001. Agricultural University of Norway, Ås.

Conrad, J.M. & C.W. Clark (1987). *Natural Resource Economics: Notes and Problems*, Cambridge University Press, Cambridge, MA.

Engen-Skaugen T. (2007). Refinement of dynamically downscaled precipitation and temperature scenarios. *Climatic Change*, **84**(3-4).

Hoel, B. (2007). Delt gjødsling til bygg og havre. *Bioforsk FOKUS*, **2**(8).

Hurwicz, L. (1959). Optimality and Informational Efficiency in Resource Allocation Processes, pp. 27-46 in K.J. Arrow, S. Karlin & P. Suppes (eds.) *Mathematical Methods in the Social Sciences*, Paolo Alto, CA, Stanford University Press.

Hurwicz, L. (1973). The Design of Mechanisms for Resource Allocation, *American Economic Review*, **63**(2):1-30.

Jansson P-E. & L. Karlberg (2001). *Coupled Heat and Mass Transfer Model for Soil–plant–atmosphere Systems*. Royal Institute of Technology, Dept of Civil and Environmental Engineering, Stockholm.

Parton W.J, E.A Holland, S.J Del Grosso, M.D Hartman, R.E. Martin, A.R. Mosier, D.S. Ojima & D.S. Schimmel (2001). Generalized modell for NOx and N2O emission from soils. *Journal of Geophysical Research – Atmospheres*, **106**(D15):17403-17419

Romstad, E. & O. Bergland (1994). *Manipulation of Emission Permit Markets*, Department of Economics and Social Sciences Discussion Paper #D-09/1994, Agricultural University of Norway, Ås, Norway.

Simonsen, J.W. (1989): *Miljøavgifter på kunstgjødsel-N og -*, a report commissioned by the Ministry of Agriculture to Department of Agricultural Economics, Agricultural University of Norway, Ås, Norway.

Uhlen, G. (1985). Plantenæringsstoffer fra landbruk som forurensing i vassdrag. *Vann*, **20**:2-6.

Vagstad, N.H. (1990). *Miljøoptimal gjødsling: Nitrogen som miljø- og produksjonsfaktor i jordbruket, spesielt i kornproduksjonen*. Report from the Centre of Soil and Environmental Research, Ås, Norway.

Vatn, A., L. Bakken, M.A. Bleken, O.H. Baadshaug, H. Fykse, L.E. Haugen, H. Lundekvam, J. Morken, E. Romstad, P.K. Rorstad, A.O. Skjelvag & T. Sogn (2006). A methodology for integrated economic and environmental analysis of pollution from agriculture. *Agricultural Systems*, **88**(2-3):270-293.

Vold A, Breland TA, Søreng JS (1999) Multiresponse estimation of parameter values in models of soil carbon and nitrogen dynamics. *Journal of Agricultural, Biological, and Environmental Statistics*, **4**(3):290-309.

PAPER 3

Multifunctional agriculture – the policy implications of jointness and positive transaction costs

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Abstract

Agriculture produces a multitude of outputs that contribute to several societal objectives at once, hence, the term multifunctional agriculture. At farm level, outputs of many goods (bads) are linked, through either a) economic factors like fixed resources or b) biological and physical processes. This link between outputs is termed jointness, and this paper concerns the latter type of jointness.

In a transaction cost free economy, jointness is of little interest since providing the incentives to farmers for producing all goods at the optimal levels is costless. However, regulation is not costless, and it will be shown that transaction costs are much lower for polices targeting commodities than polices targeting other goods. Also, the analysis shows that transaction costs can be reduced dramatically by reducing the number of support schemes.

If a non-market good is linked to a commodity in a way that cannot be altered by the farmer, what we term fixed proportions, targeting the commodity is the optimal policy, since this results in lowest transaction costs.

One property of (physical) joint production is that it exhibits economies of scope. This means that separate production of non-market goods and imports of commodities is optimal only if the difference between domestic costs and the world market price is large.

In the case of flexible proportions, i.e. it is possible to alter the relationship between outputs, it is not possible to draw universal conclusions regarding what type of output to target. The recommendation will depend on the trade-off between reducing transaction costs and securing precise delivery of the public good.

For a small country that is not competitive at world market prices, like Norway, we suggest, to use commodity support up to a certain point and to combine this with specific support schemes more directly targeted at the non-market goods to increase precision.

Key words: multifunctional agriculture, agricultural policy, transaction costs, joint production

1. Introduction

In addition to commodities – i.e., food and fiber products – agriculture also produces a large range of other goods and services, e.g. landscape, food security, food safety, biodiversity, etc. This multitude of outputs is often referred to as the multiple functions of agriculture. Multifunctionality is of course nothing new, but has been an issue in the debate over policy reforms for the last decennium, especially within the OECD and in the WTO-negotiations.

However, multifunctionality means more than just multiple outputs. OECD (2001:11) gives the following description of the concept:

> "Multifunctionality refers to the fact that an economic activity may have multiple outputs and, by virtue of this, may contribute to several societal objectives at once. Multifunctionality is thus an activity oriented concept that refers to specific properties of the production process and its multiple outputs."

When treating the issue of multiple outputs, the concepts used in the WTO-negotiations have been trade and non-trade concerns – with the latter covering outputs that are not commodities. At first glace this difference in conceptualization may seem just to be about wording. Both the OECD and the WTO definitions cover the wide span of agricultural outputs. However, while the multifunctionality concept recognizes that there might be links between the different outputs potentially implying that they must or should be handled simultaneously, the notions of trade and non-trade concerns seem to be built on the assumption that there are no links between the commodity and non-commodity outputs of agriculture.

The main aim in the WTO-negotiations is to reduce the barrier to trade, i.e. reduce (and ultimately remove) trade distorting policies. This means reducing e.g. border protection measures (e.g. tariffs), export subsidies and commodity price support. Given standard presumptions, this would increase global welfare. If there are public goods involved, like landscape effects, food security etc., these should be paid for separately.

This conclusion depends on several assumptions. This paper concerns three of these. First is the idea that the commodities and non-commodities can be produced independently. Second, we have the assumption that the costs of making them separately are not significantly different from producing them jointly with commodity production. Finally, that the costs of setting up and running separate policies – policy related transaction costs – are insignificant.

The existence of physical jointness, the existence of economies of scope and the fact that transaction costs often are significant, may all have the power to change the policy conclusions from analyses where these factors are not included. The aim of this paper is to make an enquiry into these relationships. The goal is to clarify when the standard type policy advice of separate payments for commodities and public goods holds and when other policies are warranted

The structure of the paper is as follows: In section 2 we will present our view of jointness and the types of jointness that are important for our analysis. We will then (section 3) look at optimal production of joint outputs for different types of goods and types of jointness under the assumption of no transaction costs. In section 4 the effects of transaction costs will be analyzed. Even though some policy conclusions can be drawn from sections 3 and 4, the main aim of the paper is to develop a consistent framework including all the various elements above. This is done in section 5, followed by our final section where we evaluate our findings and conclude.

2. Joint production

2.1. All production is joint production

Jointness in production implies that there is a connection between two or more outputs. The more precise definition of the concept varies, however. We may distinguish two main traditions. First, we have those who emphasizes that jointness implies some kind of physical linkage where two or more outputs follow from a given production process. A typical definition is given by Gravelle and Rees (1981) when they state that

> "In some cases where one firm produces more than one output it may be possible to relate the output to a specific part of the bundle of inputs, so that the firm has a production function for each output….If a firm is producing several outputs, and inputs cannot be assigned to outputs in this way the firm is said to be producing joint products" (Gravelle and Rees, 1981:177).

In practical terms, producing electricity in a power plant also implies the production of hot water. Producing grain implies also the simultaneous production of straw, and so on.

A quite different tradition defines jointness in terms of interrelations via prices. Shumway et al. (1984) defines, as an example, jointness by the fact that changes in prices for one product influences the supply of another:

$$\frac{\partial y_i}{\partial p_j} \neq 0, \; j \neq i \qquad [1]$$

where y_i is the output supply function for good i and p_j is the price of another output. In terms of cost functions, jointness may be defined as (Havlík et al., 2005):

$$\frac{\partial^2 C(y)}{\partial y_j \partial y_i} \neq 0,\ j \neq i \qquad [2]$$

where $C(\bullet)$ is the multiproduct cost function and y_i and y_j are two different outputs.

In this report we will base our understanding of jointness on the perspective implicit in the definition of Gravelle and Rees (1981), that is, we see it as a physical interlinkage. Given the laws of thermodynamics a) conservation of mass and energy (the first law), and b) non-decreasing entropy (second law), one realizes that all production must in reality be joint production. Given these laws, it is simply impossible to produce only one output. The latter would demand that all energy and material input could be incorporated in one product. This is impossible. Hence, Faber et al. (1998:131) conclude that "…every process of production is necessarily joint production. This means that every process of production yields at least two outputs and requires at least two inputs." The inputs and outputs can be material (e.g. fertilizer) or immaterial (e.g. heat), and the value may be negative (e.g. pollution), zero (e.g. nitrogen gas) or positive (e.g. grain).

Hence, there will always be byproducts. Whether these products are valuable or waste depends on their characteristics. A change in preferences and technology may also turn a waste byproduct into a valuable product or *vise versa*. As an example, waste heat from power plants has been turned into a valuable product in district heating.

2.2. Jointness in agriculture

While all production is joint, there are few areas where this is demonstrated so overtly as in agriculture. We know it from the production of private goods where meat and hides are jointly produced. The same goes for mutton and wool, grain and straw etc. Lately, the combination of the production of private goods, public goods and public bads is much emphasized. The list of public goods normally referred to covers environmental goods (landscape, biodiversity increase, and cultural heritage), food security, food safety and rural concerns. Public bads mainly take the form of pollution (to air and water) and biodiversity reduction.

It is important to acknowledge that the various goods and bads are components of an integrated production system. They often appear as linked sets of functions. While some of the public goods may also be produced independently of agriculture, we cannot envision an agriculture that does not affect the landscape, the level of food security, food safety and rural settlement/activity. In this sense, all the listed public goods/bads are dependent on primary production. They are characteristics of the system as a whole. This works through the combined use of inputs as illustrated in Figure 1.

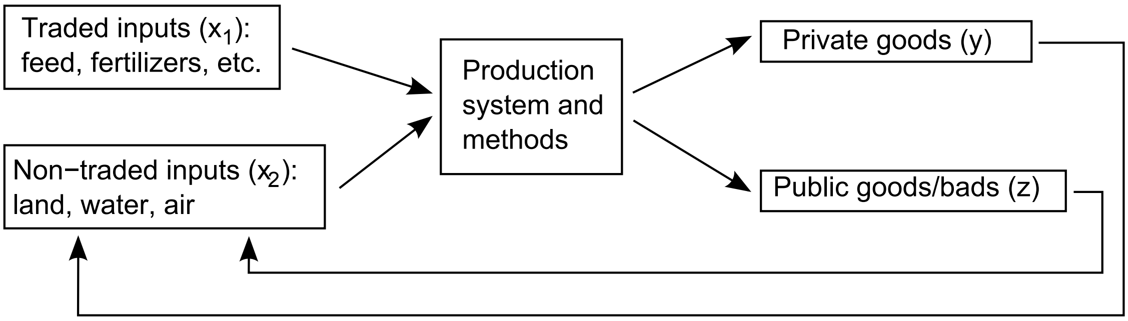

Figure 1. The linked set of inputs and outputs in the agricultural production system. Source: Vatn (2002).

On the input side, the figure distinguishes between inputs that are (easily) traded (x_1) and those that are not (x_2). The latter resources are typically local, and they are often public goods/common pool resources (like water and air). Inputs are combined in different production processes. Out of these come sets of outputs in the form of tradable goods (y), and public goods and bads (z). As already emphasized, all resources that are put into the production process must in the end appear as outputs of one form or the other – i.e. either as private goods (commodities), public goods or public bads.

As already emphasized in the introduction, the joint production of private and public goods in agriculture has become an important issue in international policy evaluations. The reason for this is that given such jointness, the standard solution to pay for each good/tax each bad may not be efficient. Not least the OECD has been very active in this field with the ambition to clarify both how to understand jointness and what it implies for policy formulation (OECD, 2001; OECD, 2003).

The OECD defines jointness in a way that may seem quite similar to Gravelle and Rees: "Joint production refers to situations where a firm produces two or more outputs that are interlinked so that an increase or decrease of the supply of one output affects the levels of the others" (OECD, 2001:16). When listing the main sources for jointness in production, we still see that there are differences pertaining to the understanding of jointness:

- Technical interdependencies,
- Non-allocable inputs, and
- Fixed allocable inputs.

The two first are primarily physical and/or biological and describes the kind of interrelationships implicit in the formulation of Gravelle and Rees (1981). They also reflect jointness as understood from a thermodynamic perspective as they are physical necessities. The third includes also other dynamics – i.e. institutional and economic mechanisms.

At farm level, land, capital and labor are often considered fixed, at least in the short run. These fixed inputs may be used in different productions. Due to their fixity, using more of one input in one production leads to reduced input use in other productions. Normally, this means that increasing one output will reduce at least one of the other outputs. Thus, this situation fits the third type of jointness as defined by OECD (2001). Even though the fixity of the inputs is physical, the source of the jointness is economic. The use of an input in one production versus another is mainly driven by the relative prices, but the productions are still (normally) separable. In this case the main challenge for the policy maker is to set the relative prices at the right level. This may not be an easy task, but it is not different from the "normal" situation without jointness. We will hence not discuss this type of relation further.

2.3. Different forms of jointness

When there are technical interdependencies, the linkages between different outputs may take on different forms. Baumgärtner (2000) divides the interdependencies into four types (Figure 2). For the first type the linkage is fixed and constant (upper left graph). Fixed means that it is not possible to alter the proportions of the two outputs produced, given the level of production. Constant means that the proportions are the same for all levels of output. If we have non-constant proportions, the relationship between the two goods in question is non-linear. In the upper right graph of Figure 2 proportions are fixed for a given level of production, but vary with the level of production.

The lower part of Figure 2 shows the two last types. Here the proportions are said to be flexible. This means that technology is such that it is possible to alter the proportions of the outputs. For a given level of production of the good on the y_1-axis the output of the other good will lie somewhere between the two lines. However, once the "parameters" of the technology and the input mix are chosen, we are back to fixed proportions.

One example of the flexible proportions is the classical example of production of mutton and wool. Different sheep breeds yield different proportions of the two goods. The proportions may also to some extent depend on feed, the shed, the length of the grazing season, etc. Once these factors are chosen, an increase in the amount of mutton (more sheep) will lead to a (fixed) proportional increase in wool.

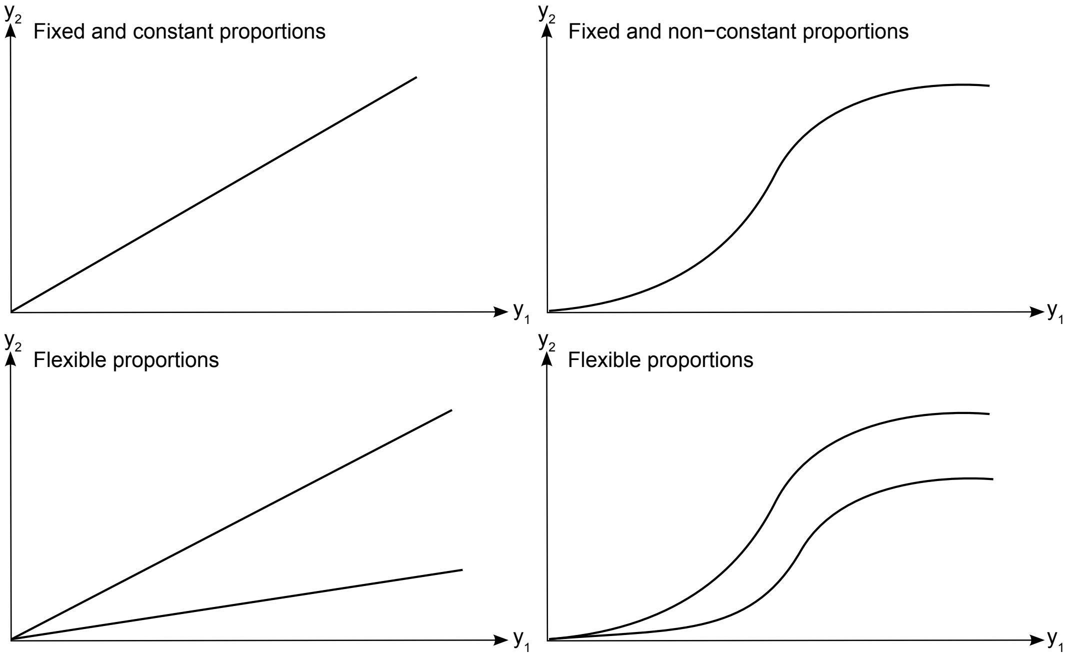

Figure 2. Different types of jointness between different outputs (y_1 and y_2 axis). Source: Baumgärtner (2000).

In order to utilize the jointness concept presented above, we need to define jointness in mathematical terms. In the case of fixed proportions the relationship between two outputs (y_1 and y_2) may be described by:

$$y_2 = f(y_1) \qquad [3]$$

while in the case of flexible proportion the corresponding formulation is

$$y_2 = f(y_1, x, \alpha) \qquad [4]$$

where x is inputs and α is a vector of technological parameters.

The two equations above can clearly be termed technological interdependencies, but also the case of non-allocable inputs may be viewed as one type of technological interdependency. The simplest example of production of two outputs from a non-allocable input (x_{na}) may be described by the following two equations:

$$y_1 = f_1(x_{na}) \qquad [5]$$

$$y_2 = f_2(x_{na}) \qquad [6]$$

If one of the two functions is monotonic in the relevant range of x_{na}, it is possible to invert it and get an expression for the non-allocable input:

$$x_{na} = f_1^{-1}(y_1) = x_{na}(y_1) \qquad [7]$$

If we now use this in equation [6], we get the relationship between the two outputs:

$$y_2 = f_2(x_{na}(y_1)) = g(y_1) \qquad [8]$$

Hence, we are back to a formulation similar to [3]. This means that we can treat the case of non-allocable inputs in the same way as other technical and/or biological interdependencies. As we see it, there are two sources of jointness: technical interdependencies and fixed allocable inputs.

2.4. Measuring jointness

While jointness is a necessity, establishing what the relationships look like, is demanding. We close this section by looking into this issue. Let us start by looking at the relationship between production of barley and the joint loss of nitrate to water bodies. We will base the illustration on data from model simulations using the crop growth model KONOR (Bleken, 2001) and the nitrogen transformation model SOILN-NO (Vold et al., 1999). These models were used to generate data for barley in South-eastern Norway. The model was run for 30 years and for different N-fertilization levels. The relevant results are shown in Figure 3.

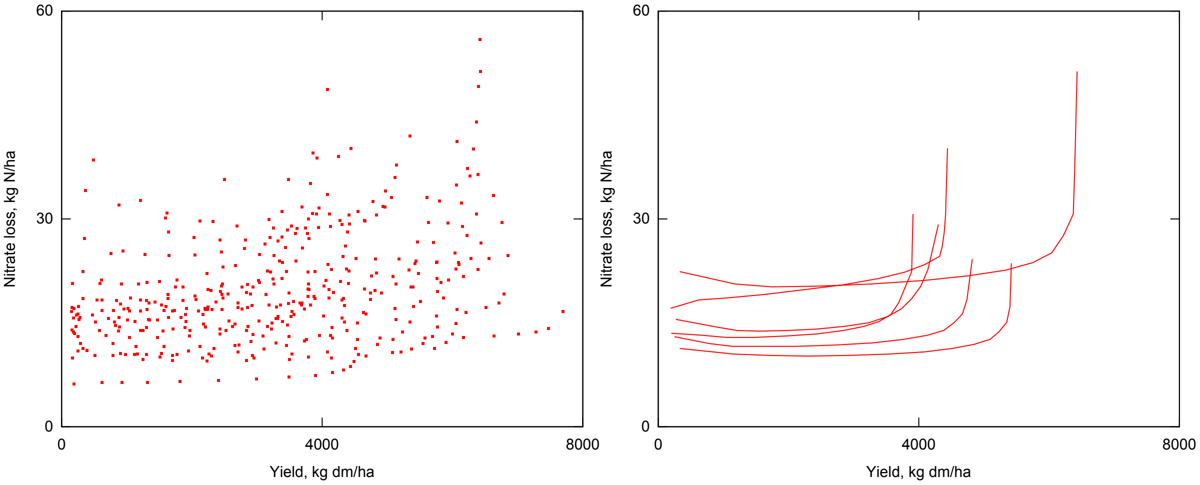

Figure 3. Results of model simulations for barley in Southeastern Norway. Left panel: Scatter plot of all observations. Right panel: Yearly relationships – randomly selected years.

The left part of Figure 3 shows a scatter plot of the results. The plot shows a large variation and a rather weak correlation between yields and nitrate losses. The right part of the figure shows the results for some randomly selected years. Each line represents a certain year of the data in the left panel (markers are mitted to ease the presentation). Here we see that there is a clear link between the two outputs for each year. The biology behind this is rather straight-forward. At low fertilizer levels, plant growth is low and increased growth increases the marginal N-absorption. Thus, at low yield levels/N-levels marginal nitrate loss may even be negative. At higher N-levels marginal N-absorption decreases and nitrate losses increases. At

some point yield reaches the maximum level, and marginal N-absorption reduces to almost zero. Additional fertilizer is mostly lost to the environment, hence the almost vertical part of the curves. It is however important to note that the years differs both regarding level and form of interlinkage. This is due to the variation in weather between years.
Real world data contains much more noise than the data from a simulation model. This means that it would be even harder to reveal the relationship between the two outputs. The main point here is that spatial and temporal variation may complicate the observation of jointness.

3. Optimality, jointness and economies of scope

After having clarified the jointness concept we use, we will now turn to an analysis of what jointness may imply for the optimal production of the different goods in agriculture and policies to induce optimal production.

As we have seen in the previous sections, some of the goods produced in agriculture (e.g. cultural landscape) cannot normally be traded in a market. Even though these non-market goods are produced jointly with marketable goods, the market prices may not bring about the optimal level of the jointly produced goods. This means that policies are needed to ensure optimal production of all goods. How these policies should be formulated depends on, among other things, the involved economies of scope, the type of jointness and the transactions costs related to various policies. In the present section we will focus on the implications of the two first, while transaction costs will be treated in later sections.

We will look at three different situations. First we will look at the case where a jointly produced good may also be produced separately from agriculture. Next we will analyze the case of multiple joint outputs under the assumption that proportions are fixed. Finally we will look at the case of flexible proportions.

3.1. Joint versus separate production

Some of the goods and services produced by agriculture are not unique to agriculture in the sense that they may also be produced by other sectors, maybe in different forms, though. If these goods and services are jointly produced with food, agriculture will provide a certain level of these as long as there is food production. If these non-market goods are not produced at optimal levels, this raises some questions. Should the deficit be produced separately, should the production of the market good be increased and thereby increase the production of the non-market good or should one do both?

The question of separate vs. joint production is clearly linked to the concept of economies of scope (Baumol et al., 1988:71; OECD, 2003:17). In the case of two products (y_1 and y_2), there are economies of scope if

$$C(y_1, y_2) \le C(y_1, 0) + C(0, y_2) \qquad [9]$$

where $C(\bullet)$ is the multiproduct minimum cost function. "There are economies of scope where it is less costly to combine two or more product lines in one firm than to produce them separately" (Panzar and Willing, 1981:268).

One important proposition regarding economics of scope is: "The multiproduct minimum cost function $C(y)$ that is dual to a set of multiproduct production techniques employing a public input of nontrivial value exhibits economics of scope" (Baumol et al., 1988:77).

A public input here means an input that once it is acquired for use in producing one good, it is available costlessly for use in the production of others. This is clearly the case of joint production in agriculture. In the case of food and landscape, land is a public input of nontrivial value. The (almost trivial) conclusion from this is that if one wants to produce both food and landscape, joint production is the cheapest way to do this.

For a society's point of view, the analysis above is valid only if production (of food and landscape) happens within the specific society. It is of course possible to consume agricultural products produced without any landscape production in the society, i.e. imports. This means that landscape production may be lower than optimal, and this opens up for separate production of landscape. In order to analyze this, let us assume we are in a situation where the (agricultural) economy is small and open[1]. Open means that import and export are allowed. Small means that whatever is produced in the economy, it does not influence the world market (i.e. imports and exports have no effect on world market prices). Two goods are produced in the agricultural sector of this economy: food (y_n) and landscape (z). Since this is an open economy, it is possible to import food, y_i. Landscape is produced jointly with food production ($f(y_n)$), and may in addition be produced separately by using an input, x. Separate production is given by $g(x)$. The objective of society is to maximize welfare ($W(\bullet)$).

Since resources are not unlimited in the society, we need to impose a resource constraint on the optimization problem. Since the central theme in this paper is agricultural policies, it is

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[1] Others have analyzed multifunctional agriculture in large economies. One example, using a different framework, is Peterson et al. (2002).

natural to use a budget constraint. We therefore assume that the sum of the cost of importing food, the cost of producing food domestically and the cost of producing landscape separately should equal some given amount. The optimization problem and the first order conditions are shown in Textbox 1.

Textbox 1. Optimality conditions: joint and separate production.

The objective of society is to maximize welfare:

$$W(y_i, y_n, z) \tag{10}$$

The welfare function, *W*(•), is assumed to meet the requirements for maximization, e.g., concave and strictly increasing in all elements.

The production of landscape is:

$$z = f(y_n) + g(x) \tag{11}$$

Welfare is maximized subject to the following budget constraint:

$$p_i y_i + C_n(y_n) + C_x(x) = M \tag{12}$$

where p_i is the price on imported food, $C_n(y_n)$ is the cost of domestic food production, $C_x(x)$ is the cost of separate landscape production and *M* is the budget.

The Lagrangian for this problem is:

$$L = W(y_i, y_n, z) + \mu\left[f(y_n) + g(x) - z\right] + \lambda\left[M - p_i y_i - C_n(y_n) - C_x(x)\right] \tag{13}$$

with the following first order conditions:

$$\frac{\partial L}{\partial y_i} = \frac{\partial W}{\partial y_i} - \lambda p_i = 0 \tag{14}$$

$$\frac{\partial L}{\partial y_n} = \frac{\partial W}{\partial y_n} + \mu\frac{\partial f}{\partial y_n} - \lambda\frac{\partial C_y}{\partial y_n} = 0 \tag{15}$$

$$\frac{\partial L}{\partial z} = \frac{\partial W}{\partial z} - \mu = 0 \tag{16}$$

$$\frac{\partial L}{\partial x} = \mu\frac{\partial g}{\partial x} - \lambda\frac{\partial C_x}{\partial x} = 0 \tag{17}$$

If we assume that the marginal welfare of imported and domestically produced food is the same the first order conditions may be written as:

$$\frac{\partial C_y}{\partial y_n} = p_i + \frac{\mu}{\lambda}\frac{\partial f}{\partial y_n} \tag{18}$$

$$\frac{\partial C_x}{\partial x} = \frac{\mu}{\lambda}\frac{\partial g}{\partial x} \Leftrightarrow \frac{\mu}{\lambda} = \frac{\frac{\partial C_x}{\partial x}}{\frac{\partial g}{\partial x}} \tag{19}$$

$$\frac{\mu}{\lambda} = p_i\frac{\frac{\partial W}{\partial z}}{\frac{\partial W}{\partial y_n}} \tag{20}$$

Equations [18] and [19] yield the standard economic result; marginal costs should equal marginal benefits. The first term on the right hand side of [18] is the marginal welfare of food consumption in monetary terms, i.e. the alternative cost of domestic food production (imports). The last term is the marginal value product, where μ divided by λ is the marginal welfare of landscape in monetary terms.

One interesting point from [18] is that if there is a positive relationship between the production of food and landscape, i.e. the last term is positive, the marginal cost of food production cannot be smaller than the price on imported food. This means that the world market price would not bring about the optimal production of food and landscape. *Cet. par.*, combining [18] and [19] we see that the difference between the world market price and domestic marginal costs increases as the marginal costs of x increases and/or the marginal production of separate production decreases. Put another way: marginal cost of separate production should equal marginal cost of joint production, adjusted for the marginal cost of the commodity output.

The optimality conditions above implicitly assume that an interior solution exists. That needs not be the case. If no interior solution exists, the optimal solutions is then one of the corner solutions, i.e., producing food and landscape jointly or producing landscape separately and import all the food. The first corner solution may also include the import of some of the food. In addition, the marginal conditions do not take into account fixed costs. If the fixed cost for one of the production is large (relatively), one of the corner solutions may be the optimal one.

Regarding policy recommendations, this is to some extent an empirical question. Up to the point where domestic marginal cost equals the world market price, no separate production should be used. This since joint production exhibits economies of scope. If this does not bring about the optimal level of landscape production, joint production, separate production or both should be used, depending on (both fixed and marginal) costs. In general it is clear that joint production is optimal if the cost of joint production is lower than the cost of separate production plus the cost of importing the commodities.

We have here only looked at food and landscape. If we include other jointly produced goods, e.g., biodiversity, food safety and food security, it is clear that economies of scope become even more important. Loosely put, if more outputs are produced jointly, the less likely is it that separate production will lead to lower total costs. Let us now turn to a situation with multiple join outputs.

3.2. Multiple joint outputs

In the example above we looked at a situation where only one good where jointly produced with food. In the real world more outputs are produced jointly and some of these are linked to the level of production. Let us therefore expand the analysis by looking at a situation where agriculture produces one market good ("meat") and two non-market goods: food safety (z_{fs}) and landscape (z_l). These two goods are produced jointly with the domestic production of "meat". In this section we will moreover assume that separate production of the landscape is not possible. In addition to domestic meat production, y_n, it is possible to import "meat", y_i. The import will have a negative effect on the domestic food safety. This does not mean that domestic production has to be "cleaner", but that the imported "meat" may contain illnesses that are not common domestically, and that these would result in societal costs. By controlling imports, the negative impact on domestic food safety may be reduced (or eliminated).

The society wants to maximize welfare from the production and consumption of the four goods (y_i, y_n, z_{fs} and z_l). The problem formulation and optimality conditions are shown in Textbox 2.

Textbox 2. Optimality conditions: multiple joint outputs

The problem may be formulated as:

$$Max W(y_i, y_n, z_{fs}, z_l) \qquad [21]$$

Welfare is maximized subject to the following budget constraint:

$$C_y(y_n) + p_i y_i + C_{fs}(q, y_i) = M \qquad [22]$$

The first term on the right hand side is the strictly increasing domestic cost function, the second term is the cost of imports with p_i being the world market price, and the last term is the cost of controlling imports where q is controlling intensity. The cost of controlling imports is assumed to be increasing in both arguments.

The level of food safety is assumed to be governed by the following equation:

$$z_{fs} = f(y_n) + g(q, y_i) \qquad [23]$$

The first function on the right hand side is the effect of domestic "meat" production, i.e., the jointly produced food safety. $f(y_n)$ is assumed to be strictly increasing in y_n. The last part is the negative impact of imported "meat". $g(\bullet)$ is therefore negative, and is assumed to increase in q and decrease (i.e. become more negative) in y_i.

Landscape is produced jointly with domestic "meat":

$$z_l = h(y_n) \qquad [24]$$

We may now set up the Lagrangian for this problem:

$$\begin{aligned} L = {} & W(y_i, y_n, z_{fs}, z_{bd}) + \mu\left[f(y_n) + g(q, y_i) - z_{fs} \right] + \\ & \eta\left[h(y_n) - z_l \right] + \lambda\left[M - C_y(y_n) - p_i y_i - C_{fs}(q, y_i) \right] \end{aligned} \tag*{[25]}$$

The first order conditions:

$$\frac{\partial L}{\partial y_i} = \frac{\partial W}{\partial y_i} + \mu \frac{\partial g}{\partial y_i} - \lambda \left[p_i + \frac{\partial C_{fs}}{\partial y_i} \right] = 0 \tag*{[26]}$$

$$\frac{\partial L}{\partial y_n} = \frac{\partial W}{\partial y_n} + \mu \frac{\partial f}{\partial y_n} + \eta \frac{\partial h}{\partial y_n} - \lambda \frac{\partial C_y}{\partial y_n} = 0 \tag*{[27]}$$

$$\frac{\partial L}{\partial z_{fs}} = \frac{\partial W}{\partial z_{fs}} - \mu = 0 \tag*{[28]}$$

$$\frac{\partial L}{\partial z_l} = \frac{\partial W}{\partial z_l} - \eta = 0 \tag*{[29]}$$

$$\frac{\partial L}{\partial q} = \mu \frac{\partial g}{\partial q} - \lambda \frac{\partial C_{fs}}{\partial q} = 0 \tag*{[30]}$$

If we assume that marginal welfare for domestic and imported "meat" are the same, the first order conditions for the four goods (y_i, y_n, z_{fs} and z_l) may be written as:

$$\frac{\partial C_y}{\partial y_n} = p_i + \frac{\partial C_{fs}}{\partial y_i} + \frac{1}{\lambda} \left(\frac{\partial W}{\partial z_{fs}} \left(\frac{\partial f}{\partial y_n} - \frac{\partial g}{\partial y_i} \right) + \frac{\partial W}{\partial z_l} \frac{\partial h}{\partial y_n} \right) \tag*{[31]}$$

The interpretation of the optimality condition [31] is rather straightforward: the marginal cost of domestic production should equal the sum of the world market price, the marginal cost of controlling imports, the marginal welfare of food safety and the marginal welfare of landscape.

The standard policy recommendation is to tax the import, due to the negative impact on food safety, and to use direct payments for food safety and landscape production. The tax on import consists of two elements: the (marginal) cost of control[2] and the marginal welfare loss from imports:

$$\tau_i = \frac{\partial C_{fs}}{\partial y_i} - \frac{1}{\lambda} \frac{\partial W}{\partial z_{fs}} \frac{\partial g}{\partial y_i} \tag*{[32]}$$

The functions should be evaluated at the optimal level of y_i and q. The payments for jointly

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[2] It may be argued that border control measures are transaction costs, which we have left for later discussions. On the other hand, we may also view these costs as resulting from lack of quality control in the producing firm.

produced food safety and landscape should be set according to the following:

$$\rho_{fs} = \frac{1}{\lambda}\frac{\partial W}{\partial z_{fs}} \text{ and } \rho_l = \frac{1}{\lambda}\frac{\partial W}{\partial z_l} \qquad [33]$$

again evaluated at the optimal levels of production. We may now rewrite equation [31]:

$$\frac{\partial C_y}{\partial y_n} = p_i + \tau_i + \rho_{fs}\frac{\partial f}{\partial y_n} + \rho_l \frac{\partial h}{\partial y_n} \qquad [34]$$

If producers (farmers) are maximizing income, i.e.:

$$\max \pi = p_y y_n + p_{fs} f(y_n) + p_l h(y_n) - C(y_n) - FC \qquad [35]$$

it is easy to show that by setting $p_y = p_i + \tau_i$, $p_{fs} = \rho_{fs}$ and $p_l = \rho_l$, the first order condition of [35] will equal [34]. If $f(y_n)$ and $h(y_n)$ are invertible, there are, however, many combinations of the prices that will yield the same level of marginal cost, hence result in efficient allocations. This means for example that, set at the right level, paying for only landscape production or only food production and setting all other prices to zero are efficient policies in this setting[3]. Paying for only food production is efficient also in the case when production functions for landscape and food safety are not monotonic.

One important conclusion from the analysis in this section is that when proportions are fixed (both constant and non-constant) there is no need to target each and every good. Set at the right levels, different combinations of price/subsidy levels will be efficient polices.

If proportions are fixed, relative prices do not matter since it is not possible for the farmer to control the composition of the outputs. If proportions are not fixed, i.e. they are flexible, the conclusions above do may hold. We will therefore turn to the case of flexible proportions.

3.3. Flexible proportions

As discussed above, flexible proportions means that it is possible to control/alter the production process, within certain limits, such that the proportion of the two (or more) goods in question is changed. The two goods are still jointly produced, but we are able to vary the character of jointness. The simplest example of flexible proportions is where the proportions are constant, given the choice of technology or parameters of the technology. Different technologies or parameters may lead to different proportions, hence the term flexible

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[3] This only holds if proportions are fixed, i.e. that the jointly produced landscape and food security are linked only to domestic food production. If proportions are flexible, paying for e.g. only food production may cause inefficiencies. Flexible proportions will be analyzed in the next section.

proportions. In a situation with one private good (*y*), one non-market good (*z*) and one technology variable (*α*) this may be modeled by the following equation:

$$z = \alpha y \tag{36}$$

where α (the technological parameter) is limited to vary within a certain range:

$$\alpha_{low} \le \alpha \le \alpha_{high} \tag{37}$$

This corresponds to the lower left graph in Figure 2. In this situation we have three choice variables: *y*, *z* and *α*. The derivation of the optimality conditions is shown in Textbox 3.

Textbox 3. Optimality conditions when proportions are flexible.

The problem at hand is to maximize welfare:

$$W(y, z) \tag{38}$$

subject to the production of the environmental good ([36]and [37]) and a budget constraint:

$$C(\alpha, y) = M \tag{39}$$

The cost function is assumed to be strictly increasing and convex in both arguments.

The Lagrangian for this problem is.

$$L = W(y, z) + \mu\left[\alpha y - z\right] + \rho_l\left[\alpha - \alpha_{low}\right] + \rho_h\left[\alpha_{high} - \alpha\right] + \lambda\left[M - C(\alpha, y)\right] \tag{40}$$

The first order conditions are

$$\frac{\partial L}{\partial y} = \frac{\partial W}{\partial y} + \mu\alpha - \lambda\frac{\partial C}{\partial y} = 0 \tag{41}$$

$$\frac{\partial L}{\partial z} = \frac{\partial W}{\partial z} - \mu = 0 \tag{42}$$

$$\frac{\partial L}{\partial \alpha} = \mu y + \rho_l - \rho_h + \lambda\frac{\partial C}{\partial \alpha} = 0, \rho_l\left[\alpha - \alpha_{low}\right] = 0, \rho_h\left[\alpha_{high} - \alpha\right] = 0 \tag{43}$$

If we assume an interior solution, i.e., $\rho_l = 0$ and $\rho_h = 0$, the first order conditions may be written as

$$\frac{\frac{\partial W}{\partial y}}{\frac{\partial W}{\partial z}} = \frac{\frac{\partial C}{\partial y}}{\frac{\partial C}{\partial \alpha}\frac{1}{y}} - \alpha \tag{44}$$

The left hand side of the last equation is the slope of an indifference curve (iso-welfare curve) and the right hand side is the slope of the iso-costs curve (budget constraint) in y-z space. Hence, this is a traditional optimality condition.

Possible optimal solutions are shown in the figure below. The output of the two goods must lie between the two lines marked α_{low} and α_{high}. The arch between A and C represents the budget constraint, i.e. it is an iso-cost curve. This means that the optimal production lies somewhere on this curve (A-C). The location of the optimal point is determined by the welfare function. Three different indifference (iso-welfare) curves are drawn in the figure, W_A, W_B and W_C. In the second case (W_B), an interior solution would be the optimal one, i.e. the slope of the iso-welfare curve equals the slope of the iso-cost curve. The first and last case would result in a corner solution. The relevant policy options here are price support for commodity production, direct payment for the production of the non-market good and a technology subsidy (price support for α). The farmer's problem with its first order conditions are shown in Textbox 4.

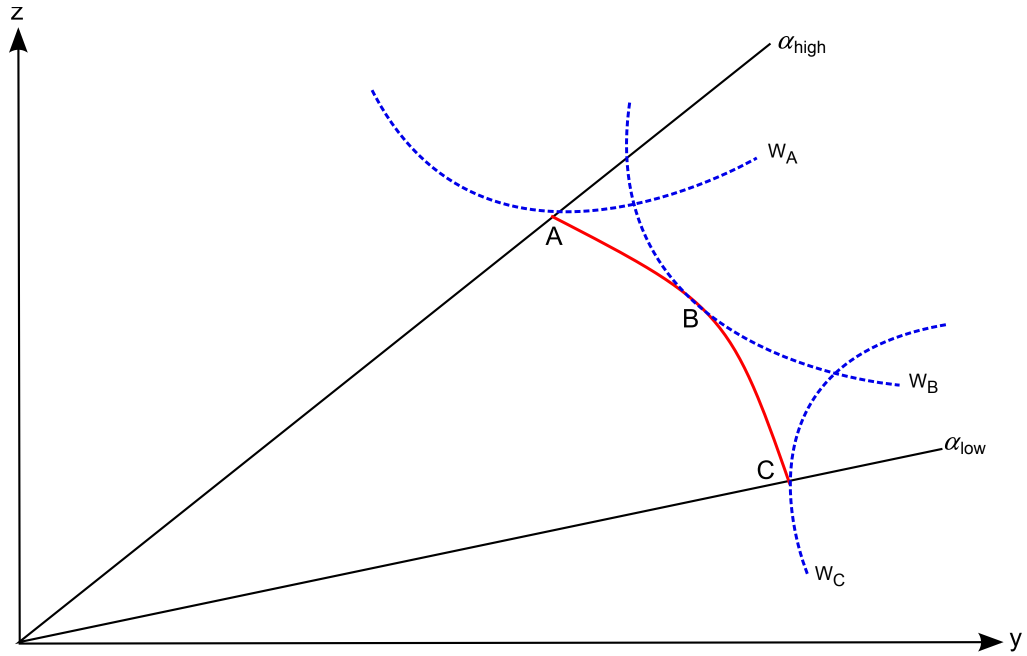

Figure 4. Flexible proportions and optimal production under a budget constraint.

In the absence of policies targeted at the environmental good, production will happen along lower line in Figure 4. If the social optimal production is on this line (e.g. point C) then the optimal policy is to set the commodity price at the right level. If this is a small open economy and the world market price is lower than the price that results in optimal production, direct price support may be used. If production given world market price is too high, a tax on the commodity will lead to optimal production. From the comparative statics below we see that using one or both of the two other policy options (i.e. setting $p_z > 0$ and/or $s_\alpha > 0$) will lead to production above α_{low}-line (partial derivatives of α wrt. p_z and s_α are positive).

Textbox 4. Optimality condition for a profit maximizing farmer.

If we assume that farmers are maximizing income and we substitute equation [36] for z, their problem is to

$$\max \pi = p_y y + p_z \alpha y + s_\alpha \alpha - C(\alpha, y) \quad [45]$$

where p_y is commodity output price, p_z is the price on the environmental good and s_α is the subsidy for technology.

In addition we impose the double constraint on α (equation [37]). The first order conditions are (the private counterparts to [41] and [43]):

$$\frac{\partial \pi}{\partial y} = p_y + p_z \alpha - \frac{\partial C}{\partial y} = 0 \qquad [46]$$

$$\frac{\partial \pi}{\partial \alpha} = p_z y + s_\alpha - \frac{\partial C}{\partial \alpha} + \rho_l - \rho_h = 0 \qquad [47]$$

Given that the cost function is strictly increasing and only the commodity price is positive (p_z and s_α are both zero), it follows from [47] that $\rho_l > 0$, hence $\alpha = \alpha_{low}$. This means that if there is no payment for the non-market good or technology subsidy, we have a corner solution. Hence, the farmer will produce somewhere along the line marked α_{low}.

Assuming an interior solution and using the first order conditions, we may derive the following comparative statics:

$$\begin{aligned}
&\frac{\partial y}{\partial p_y} = \frac{\frac{\partial^2 C}{\partial \alpha^2}}{H} > 0 && \frac{\partial \alpha}{\partial p_y} = \frac{p_z}{H} \geq 0 \\
&\frac{\partial y}{\partial p_z} = \frac{\alpha \frac{\partial^2 C}{\partial \alpha^2} + y p_z}{H} > 0 && \frac{\partial \alpha}{\partial p_z} = \frac{y \frac{\partial^2 C}{\partial y^2} + \alpha p_z}{H} > 0 \qquad [48] \\
&\frac{\partial y}{\partial s_\alpha} = \frac{p_z}{H} \geq 0 && \frac{\partial \alpha}{\partial s_\alpha} = \frac{\frac{\partial^2 C}{\partial y^2}}{H} > 0
\end{aligned}$$

If social optimal production is above the lower line, for example point B in Figure 4, a combination of the three policy instruments may be used. If world market prices result in a commodity production to the left of point B, a technology subsidy alone will not lead to optimal production. From the comparative statics above we see that if $p_z = 0$, an increase in s_α will only lead to an increase in z and have no effect on commodity production (y). Direct payment for z is the only single instrument that will lead to an increase in production of both y and z. This is of little importance if transaction costs are zero because then any combination of the three policy instruments may be used without any loss of precision.

4. Transaction costs

Transaction costs have so far been assumed away to keep the exposition as simple as possible. As mentioned above, they may play an important role when choosing policy instruments. Arrow (1969) has defined transaction costs as the “costs of running the economic system”. Dahlman (1979) operationalized the concept by splitting transaction costs into three elements: the cost of information gathering, the cost of contracting and finally the cost of control. Both these are rather wide, and there seems to be no consensus in the literature over how to measure them and what elements to include (McCann et al., 2005).

OECD (2007) use the term policy-related transaction costs (PRTC), and divide them into a) initial and final costs, and b) implementation and participation costs. The first group consists of all costs occurring before the policy is implemented (e.g. research and design of the measure) and costs occurring after the policy is ended (e.g. evaluation). The other group is the costs of running the policy.

If transaction costs vary between different policies, the conclusions drawn in section 3 may have to be altered. The aim of the present section is to discuss to what extent transaction differ across policies and to see if these variations in any way relate to the characteristics of the goods involved. For this we will utilize data from Rørstad et al. (2007). The study covers transaction costs of 12 different policy measures in Norwegian agriculture. They were chosen to cover the most important policies and a wide range of different policy characteristics. It is, as far as we know, the only transaction costs study covering both payments to commodities and non-commodities. As in most other studies in this field, only running costs (implementation and participation costs) are included.

Transaction costs were quantified through interviews with representatives from different public administrations, market participants and involved farmers. The costs cover labor costs, general overhead, computer cost, costs related to information material and postage.

The results indicate that, in general, transaction costs (measured in % of the transfer) increase as the complexity of the policy measure increases. Policies targeted at easily observable objects (e.g. milk, fertilizer and acreage) have fairly low transaction costs, while targeting more idiosyncratic goods (e.g. old cattle breeds and special landscape ventures) is more costly per monetary unit transferred.

The policy measures in the study were classified along three dimensions:

- Point of policy application, i.e., whether the policy measure is applied to a commodity or not,
- The degree of asset specificity involved, and
- Frequency: how often the transaction is undertaken and how many transactors or agents can be treated similarly.

The analyses showed that all three dimensions are significant in determining transaction costs.

The classification of the policies revealed a correlation between the degree of asset specificity and frequency. If asset specificity is high, frequency is generally low, and vice versa. None of the studied policies had high asset specificity and high frequency or low asset specificity and low frequency. For a plausible explanation of this, see Rørstad et al. (2007). Since frequency in addition is closely linked to the total amount transferred to or from farmers, we may use the transfer as a proxy for asset specificity and frequency. As the total amount transferred increases, frequency increases and asset specificity decreases. With this we will have a new look at the data in Rørstad et al. (2007) comparing the level of transaction costs when policy measures are oriented at commodities and non-commodities respectively.

Since the range of total transfer is large, a log-log transformation of the data will be used. By using dummy variables to capture the effects of point of policy application, two different regression equations may be specified[4]:

$$Log_{10}(TC) = \alpha_0 + \alpha_{0d} d + \alpha_1 Log_{10}(TR) \quad [49]$$

$$Log_{10}(TC) = \beta_0 + (\beta_1 + \beta_{1d} d) Log_{10}(TR) \quad [50]$$

where *TC* is transaction costs (in NOK), *TR* is transfer (tax revenue or payment in NOK) from/to farmers and *d* is a dummy variable for point of policy application (*d*=1 for policies applied to commodities). Parameter estimates and statistics can be found in Table 1, and data and estimated regression lines for [50] are shown in Figure 6.

Observed transaction costs increase as the transfer increases, and transaction costs in percentage terms are falling. This means that the transaction costs functions are concave in transfer (in non-log terms).

Table 1. Parameter estimates and statistics.

Parameter	Parameter Estimate	Standard Error	Pr > |t|
α_0	3.38	0.622	<.01
α_{0d}	-1.30	0.201	<.01
α_1	0.45	0.077	<.01
β_0	3.11	0.590	<.01
β_1	0.48	0.074	<.01
β_{1d}	-0.17	0.025	<.01

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[4] It is also possible to use dummy variables for both the intercept and slope. Under this specification none of the dummy variables have significant parameters. This is not a surprise since we have only four observations for polices applied to commodities.

The estimated equations indicate that policies targeted at non-commodities are more than 15 times more expensive in terms of transaction costs than commodity based policies. Using regression equation [49] the ratio between transaction costs for polices targeting non-commodities and polices targeting commodities is constant at $10^{1.3} \approx 20$. For specification [50] the ratio equals $TR^{0.17}$, hence is increasing in TR. For $TR = 10^6$, which is the lowest transfer in Figure 6, the ratio is about 15.5 and for $TR = 10^{8.7}$ (the highest transfer for commodity schemes) the ratio is about 29.5.

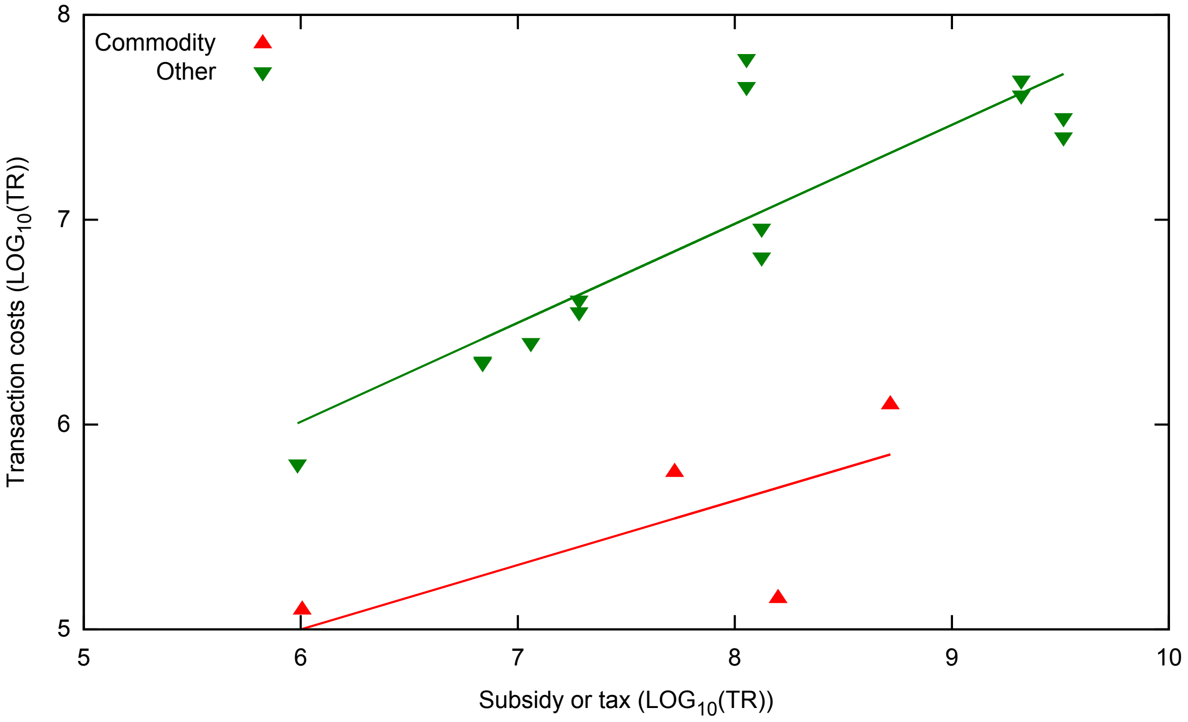

Figure 6. Observed transaction costs and estimated regression lines as a function of total transfer under the different schemes (both in NOK).

Since the transaction costs function is concave, transaction costs are increasing if a certain transfer is split into two (or more) different policy schemes (transfers), or the other way round: total transaction costs are lower if two or more schemes are merged. This is easily seen by using the fact that transaction costs in percentage terms are decreasing in the transfer. In order to explore the room for possible cost savings, we will use the functional form and parameter estimates above. In normal terms, the general form of the two transaction costs equations ([49] and [50]) is

$$TC(TR) = 10^{\eta} TR^{\varepsilon} \qquad [51]$$

where η and ε are parameters that can be calculated from Table 1 (see Table 2).

Table 2. Parameter values for the generalized transaction costs function. Values are calculated from Table 1.

	Specification eq. [49]		Specification eq. [50]	
	Commodity	Non-commodity	Commodity	Non-commodity
η	2.08	3.38	3.11	3.11
ε	0.45	0.45	0.31	0.48

Suppose we want to divide an amount of TR into n (>1) different policy schemes targeting the same type of good (i.e., either commodities or non-commodities) and that the share of the total transfer for each scheme is denoted Θ_i. The total transaction costs will then be:

$$TC_n = \sum_{i=1}^{n} 10^{\eta} (\Theta_i TR)^{\varepsilon} = 10^{\eta} TR^{\varepsilon} \sum_{i=1}^{n} \Theta_i^{\varepsilon} \qquad [52]$$

From this we see that the last term is the ratio between transaction costs when splitting the transfer into n different schemes and transaction costs when using only one scheme. Since ε<1 and Θ_i <1, Θ_i^{ε} is larger than Θ_i and the sum of the former must be larger than one, i.e. as expected transaction costs are larger when split into more schemes.

The ratio has its maximum when all the n transfers are equal (Θ_i = 1/n). It is intuitive that using one large scheme and many small ones will result in a lower ratio. However, there is no (theoretical) limit to how small a transfer can be and still be positive. In order to illustrate the effect of the "spread", Figure 7 shows the ratio under four different assumptions: transfers under all schemes are equal, transfers for the n-1 schemes are 1%, 1‰ and 0.1‰ of total transfer, respectively. The estimations are done using the largest ε in Table 2. The ratios will therefore be the lowest possible for our data.

The figure shows that the ratio between transaction costs using many schemes and only one increases as the number of schemes increases. The ratio is rather large if the schemes have the same size. It is also interesting to notice that the ratio is about 2 when there are 10 different schemes and about 90% is used in one scheme and the rest equally in the nine other.

Looking at the data in Figure 6 it is obvious that we do not find an "extreme" bimodal distribution of the size of the transfer under the different schemes. Using the data from the eight non-commodity schemes in the figure as an example, the ratio is about 1.9. It is important to underline that we do not think it would be wise to merge these eight schemes into one, the example is meant as an illustration of the size of the ratio.

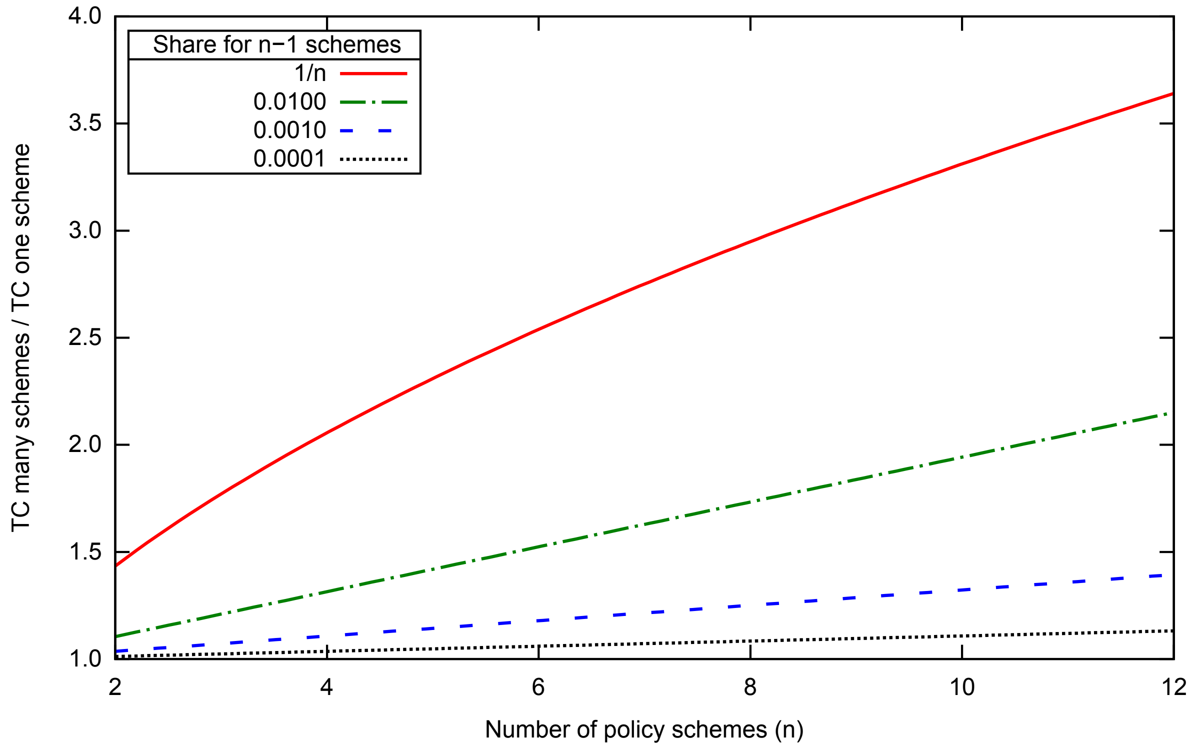

Figure 7. Ratio between transaction costs when a given amount is transferred using a single measure and when using more measures.

Even in the case only two schemes are merged, there may be rather large relative cost savings. If these schemes are of equal size, the reduction in transaction costs is about 30%, while if the size of one is nine times the size of the other, the saving is 20%.

We have so far looked at the effect of merging schemes under the assumption that the single instrument targets the same type of good, e.g. Figure 7 is for non-commodity goods. Above we showed that transaction costs are lower when the point of policy application is a commodity than when applied to non-commodities. The general expression for the ratio between transaction costs for multiple measures and a single measure, assuming that the total transfer is the same in both cases, is:

$$\frac{TC_n}{TC_1} = \frac{\sum_{i=1}^{n} 10^{\eta_1} (\Theta_i TR)^{\varepsilon_1}}{10^{\eta_2} TR^{\varepsilon_2}} = 10^{\eta_1 - \eta_2} TR^{\varepsilon_1 - \varepsilon_2} \sum_{i=1}^{n} \Theta_i^{\varepsilon_1} \qquad [53]$$

The last term on the right hand side is the ratio discussed above (ref. Figure 7), while the product of the first two terms is the ratio presented earlier (15.5 to 29.5). Thus, merging a set of non-commodity policy schemes into one commodity scheme may reduce transaction costs dramatically.

It may seem limiting that the analysis of transaction costs above were performed in terms of the transfer and not the extent of the different targeted goods. The main property driving the conclusions is that transaction costs are concave in transfer. This also holds for transaction costs as a function of the targeted good if the transfer is a concave function in the good targeted (see Berck and Sydsæter, 1993:60). Normally, subsidies or taxes are constant, or at least non-increasing, per unit, so this condition seems to hold. We therefore conclude that transaction costs are concave also in the extent of the targeted goods.

The large transaction costs ratios between policy instrument targeted at commodities and instruments targeting other goods and services does not mean that the former type of instruments should always be used. Clearly, if there is no jointness between the production of a commodity and a non-market good, commodity price support will not have any effect on the production of the non-market good. One or more policy instruments targeting the non-market goods directly must therefore be used to change the provision of these goods. Second, in some cases the jointness is such that commodity support will be imprecise with respect to the non-market good. This is typically the case if jointness is not fixed. If the (marginal) value of the non-market good is large, the value of increased precision when using environmental payments may outweigh the difference in transaction costs.

5. Optimal policy

We have now analyzed the various elements jointness, economies of scope and transaction costs separately. The aim of the present section is to bring these elements together. We will again start with the situation where a good that is produced jointly with food production also can be produced separately.

5.1. Joint versus separate production

Recall that in this situation two goods are produced in the agricultural sector of this economy: food (y_n) and landscape (z). Since this is an open economy, it is possible to import food, y_i. The objective of society is to maximize welfare ($W(\bullet)$). Landscape may be produced jointly with food or separately. Since landscape is a non-market good that enhances welfare, a payment from society is needed in order to secure production at the appropriate level.

The standard solution would be to pay the producers directly for their production of the public good (z), e.g. payment per hectare of landscape or payments for different landscape elements. On the other hand, we have assumed that proportions are fixed, i.e., the level of jointly produced landscape is determined by the level of food output (only). This means that the commodity output may be used as a proxy for landscape production. As shown above, transaction costs are much lower for policies targeted at commodity outputs.

Before we look at the implications of this, we will reformulate the model in section 3.1 to include transaction costs. Transaction costs for both joint and separate production will be assumed to be an increasing function of the commodity output and landscape production, respectively, as justified above.

Textbox 5. Optimality conditions: joint versus separate production.

The objective of society is to maximize wefare:

$$W(y_i, y_n, z) \tag{54}$$

The welfare function, *W*(•), is assumed to meet the requirements for maximization, e.g., concave and strictly increasing in all elements.

The production of landscape is:

$$z = f(y_n) + z_s \tag{55}$$

where $f(y_n)$ is the joint production of the public good (landscape) and z_s is the separate production of landscape.

Welfare is maximized subject to the following budget constraint:

$$p_i y_i + C_n(y_n) + TC_n(y_n) + C_{zs}(z_s) + TC_{zs}(z_s) = M \tag{56}$$

where p_i is the price on imported food, $C_n(y_n)$ is the cost of domestic food production, $C_{zz}(z_s)$ is the cost of separate landscape production, $TC_n(y_n)$ is transaction costs for policy measures for joint production, $TC_{zs}(z_s)$ is transaction costs for policies aimed at separate production and M is the budget.

The Lagrangian for this problem is:

$$L = W(y_i, y_n, z) + \mu\left[f(y_n) + z_s - z\right] + \lambda\left[M - p_i y_i - C_n(y_n) - TC_n(y_n) - C_{zs}(z_s) - TC_{zs}(z_s)\right] \tag{57}$$

with the following first order conditions:

$$\frac{\partial L}{\partial y_i} = \frac{\partial W}{\partial y_i} - \lambda p_i = 0 \tag{58}$$

$$\frac{\partial L}{\partial y_n} = \frac{\partial W}{\partial y_n} + \mu\frac{\partial f}{\partial y_n} - \lambda\left[\frac{\partial C_y}{\partial y_n} + \frac{\partial TC_y}{\partial y_n}\right] = 0 \tag{59}$$

$$\frac{\partial L}{\partial z} = \frac{\partial W}{\partial z} - \mu = 0 \tag{60}$$

$$\frac{\partial L}{\partial z_s} = \mu - \lambda\left[\frac{\partial C_{zs}}{\partial z_s} + \frac{\partial TC_{zs}}{\partial z_s}\right] = 0 \tag{61}$$

If we assume that the marginal welfare of imported and domestically produced food is the same, and by dividing through by λ, the first order conditions may be written as:

$$\frac{\mu}{\lambda} = p_i \frac{\frac{\partial W}{\partial z}}{\frac{\partial W}{\partial y_n}} \tag{62}$$

$$\frac{\partial C_y}{\partial y_n} = p_i + \frac{\mu}{\lambda}\frac{\partial f}{\partial y_n} - \frac{\partial TC_y}{\partial y_n} \tag{63}$$

$$\frac{\partial C_{zs}}{\partial z_s} = \frac{\mu}{\lambda} - \frac{\partial TC_{zs}}{\partial z_s} \qquad [64]$$

The latter two equations correspond to equations [18] and [19] adjusted for transaction costs. Again they are the marginal gains in monetary terms less the costs. If we combine [60] and [61] equations we get:

$$\frac{\partial C_y}{\partial y_n} = p_i + \left[\frac{\partial C_{zs}}{\partial z_s} + \frac{\partial TC_{zs}}{\partial z_s}\right]\frac{\partial f}{\partial y_n} - \frac{\partial TC_y}{\partial y_n} \qquad [65]$$

Both [63] and [64] show that positive (non-zero) marginal transaction costs will reduce the optimal production levels. Some of the direct effect may be offset by changes in the value of [62] and the second term in [63]. Intuitively, if there is a binding budget constraint, the existence of positive transaction costs means that there will be less left for (direct) production costs. Hence, optimal production must be lower.

From [65] we see that in optimum the domestic marginal costs of food production may deviate from the world market price. If the country is competitive given world market prices, it is likely that landscape production is high. This means that both the value of [62] and marginal landscape production (the derivative of f with respect to y_n) are relatively low. The second term of the right hand side of [65] may therefore in this case be low. Since it is costly to regulate, it is likely that the absence of any regulation will yield the highest level of welfare in this case. However, in a country where agriculture is not internationally competitive, the situation is quite different. In the absence of any support, i.e. at world market prices, the production levels in Norway will be very low compared to the current levels (Flaten, 2003).

Domestic food production is not an issue in itself in this example since food may be imported. Landscape, on the other hand, cannot be imported, and without any or little food production there will be little landscape production. As shown above, the transaction costs related to price support are rather low. This indicates that the last term in [65] is close to zero. This means that the middle term is the key to determine the division between joint and separate production of landscape. The obvious conclusion is that the more expensive (in marginal terms) separate production is (both production costs and transaction costs), the less should be produced separately. This also means that the optimal deviation from the world market price increases as marginal costs of separate production increases (every thing else held constant).

5.2. Multiple joint outputs

In section 3.2 (Textbox 2) we used an example with multiple joint outputs where food safety and biodiversity where jointly produced with the primary agricultural output (“meat”). We also assumed that imported “meat” had a negative effect on food safety, which could be reduced by controlling imports. In order to make our points in this section clear we will drop the effect of imports on domestic food safety.

We will still assume we have fixed proportions and that there are multiple joint outputs (z_j) linked to an agricultural output (y_n). The relationship between commodity output and the non-commodity goods may be described by:

$$z_j = f_j(y_n),\ j = 1,2,\ldots,J \qquad [66]$$

Regarding the policy measures, these may target the commodity output and the J jointly produced outputs. For simplicity we assume that there is a policy instrument for all outputs. The maximization problem and the optimality condition are shown in Textbox 6.

Textbox 6. Optimality conditions with multiple joint outputs

The problem may be formulated as:

$$Max W(y_i, y_n, z_1, .., z_J) \qquad [67]$$

Welfare is maximized subject to the following budget constraint:

$$C_y(y_n) + TC_y(y_n) + p_i y_i + \sum_{j=1}^{J} TC_j(z_j) = M \qquad [68]$$

$TC_y(\bullet)$ is transaction costs for the policy targeting commodity output, while $TC_j(\bullet)$ is the transaction cost function for the environmental good j. The rest of the terms are as previously defined.

The production of the joint outputs are:

$$z_j = f_j(y_j)\ j = 1, \ldots, J \qquad [69]$$

We may now set up the Lagrangian for this problem:

$$L = W(y_i, y_n, z_1,,, z_J) + \sum_{j=1}^{J} \mu_j\left[f_j(y_n) - z_j\right] + \lambda\left[M - C_y(y_n) - TC_y(y_n) - p_i y_i - \sum_{j=1}^{J} TC_j(z_j)\right] \qquad [70]$$

The first order conditions:

$$\frac{\partial L}{\partial y_i} = \frac{\partial W}{\partial y_i} - \lambda p_i = 0 \qquad [71]$$

$$\frac{\partial L}{\partial y_n} = \frac{\partial W}{\partial y_n} + \sum_{j=1}^{J} \mu_j \frac{\partial f_j}{\partial y_n} - \lambda\left[\frac{\partial C_y}{\partial y_n} + \frac{\partial TC_y}{\partial y_n}\right] = 0 \qquad [72]$$

$$\frac{\partial L}{\partial z_j} = \frac{\partial W}{\partial z_j} - \mu_j - \lambda \frac{\partial TC_j}{\partial z_j} = 0 \; \forall j \qquad [73]$$

If we again assume that the marginal welfare of imported and domestically produced food is the same, solve [73] for μ_j, and use this in [72] we get:

$$\frac{\partial L}{\partial y_n} = \lambda p_i + \sum_{j=1}^{J} \left[\frac{\partial W}{\partial z_j} - \lambda \frac{\partial TC_j}{\partial z_j} \right] \frac{\partial f_j}{\partial y_n} - \lambda \left[\frac{\partial C_y}{\partial y_n} + \frac{\partial TC_y}{\partial y_n} \right] = 0 \qquad [74]$$

or

$$\frac{\partial C_y}{\partial y_n} = p_i + \sum_{j=1}^{J} \frac{1}{\lambda} \frac{\partial W}{\partial z_j} \frac{\partial f_j}{\partial y_n} - \sum_{j=1}^{J} \frac{\partial TC_j}{\partial z_j} \frac{\partial f_j}{\partial y_n} - \frac{\partial TC_y}{\partial y_n} \qquad [75]$$

The interpretation of [75] is that in optimum the marginal cost of production should equal the marginal welfare of the food output (evaluated at the alternative price, i.e. world market price) plus the sum of the marginal welfare from the jointly produced goods minus the sum of marginal transaction costs in terms of y_n. This implies that if all z_j's are goods (positive marginal welfare) and the production of them are positively related to y_n (positive marginal production), the production of y_n would be lower than without any polices targeted at the jointly produced goods despite the fact that production results in only positive valued outputs. Intuitively this result makes sense. When the budget is fixed, positive transaction costs means that less can be used on output production. Hence, if proportions are fixed the optimal policy is the one with lowest transaction costs.

In section 4 we analyzed the potential cost savings by merging policy schemes and/or changing the point of policy application. Clearly, this may reduce the precision of the policies. As mentioned above, a commodity scheme is as precise as a non-commodity scheme if the jointness is known (equation [69]). In this respect there are some issues that need to be discussed. If there is spatial variation in the relationship between the commodity and non-commodity output, an undifferentiated commodity policy will not lead to an optimal outcome (in the absence of transaction costs). For some goods this is a small or non-existing problem. It can, for example, be argued that a kg of grain in southern Norway contribute the same to food safety and food security as a kg in northern Norway. Other goods, especially environmental goods, are often site specific, and the relationship to the commodity production is affected by factors like farm structure and climate. Hence, it is likely that there is a spatial variation in this relationship. A uniform commodity price support will then lead to losses compared to a direct payment for environmental goods in the case of no transaction costs. Since the difference in transaction costs for these two situations is large, we need to evaluate the losses due to the imprecise policy against the gains due to reduced transaction costs. If the spatial variation is mainly due to climatic conditions, i.e. the relationship is fairly constant within a region, it is possible use regionalized commodity price support without increasing transaction costs substantially. This has been done in Norway for milk prices.

A related problem is that the relationship may be non-monotonic. One example is the relationship between grazing intensity (meat production) and biodiversity. Data indicate that biodiversity increases up to a certain point and reduces thereafter (e.g. Hadjigeorgiou et al., 2005). If all farms are currently at the same side of the stocking rate that maximizes biodiversity production, support in the form of commodity price support (or commodity price reduction/tax if the stocking rate is higher than optimal) may yield the right incentive. However, if some farms are above and some below this point, we need farm specific incentives, e.g. biodiversity production support, in order to be precise. Again we need to compare the gains due to increased precision against the increase in transaction costs.

Finally, there will certainly be costs involved in estimating the relationships between commodity outputs and non-commodity outputs that are needed in order to evaluate the feasibility of using commodity support in stead of direct non-commodity support. This is clearly an empirical question. However, it must be noted that there are additional costs involved when using the so-called “first best” solution, i.e. non-commodity support, that are not included in the analysis above. None of the non-commodity schemes presented in section 4 target environmental goods directly, and are thus also imprecise.

We have in this section argued for using commodity support (e.g. commodity price support) in stead of a set of non-commodity support when proportions are fixed. The main arguments have been that a) there is a large difference in transaction costs between schemes targeting commodities and schemes targeting non-commodities and b) merging schemes will reduce transaction costs.

In some cases the jointness is not as “perfect” as assumed in the analysis above. Using only commodity support will then lead to losses in precision, but we believe that the value of reduced precision is lower than the reduction in transaction costs. However, we certainly see that there is a limit to how far it is wise to go in this direction. Some outputs are only vaguely linked to commodity production, and for some the variation in linkage is so large that the value of the losses in precision will be larger than the reduction in transaction costs.

While proportions may be assumed fixed in the short run, they may be more flexible in the long run, at least for some of the outputs. The reason for this is that technology in the short run is fixed, but technological development and innovations may over time change the proportions. However, using only commodity support will not give incentives for technological development toward goods with zero prices. Romstad (2008) argues that changing the relative prices will lead to a new production possibility set and lead to an increase in the output of the relatively more valuable output. This change will happen gradually, as new technology replaces old. If such changes are desirable, non-commodity support (or technology subsidy) is needed. This is clearly an argument that should be taken into account by policy makers, but still, the gains form this change should be compared to the costs, including transaction costs. Even though cast in a static perspective, the following section may give some insights regarding the dynamic perspective.

5.3. Flexible proportions

Let us finally return to the example of flexible proportions (see section 3.3). The policy may be directed toward the private good (*y*), the environmental good (*z*) or the production technology (*α*). It is of course also possible to use a combination of these three.

Textbox 7. Optimality conditions when proportions are flexible.

Let us start by restating the problem at hand:

$$\max W(y,z) \tag{76}$$

subject to

$$z = \alpha y \tag{77}$$

$$\alpha_{low} \le \alpha \le \alpha_{high} \tag{78}$$

Again we will assume that transaction costs are a function of the level of input or output. Since the choice of using a certain policy measure is a discrete choice, we need to introduce some shift variables in our maximization problem. These variables (d_y for a commodity policy, d_z for a non-commodity policy and d_α technology support) have the value 1 if the policy option is used and 0 if it is not. The budget constraint may now be written as:

$$C(\alpha, y) + d_z TC_z(z) + d_y TC_y(y) + d_\alpha TC_\alpha(\alpha) = M \tag{79}$$

The Lagrangian for this problem is then:

$$\begin{aligned} L = {} & W(y,z) + \mu\left[\alpha y - z\right] + \rho_l\left[\alpha - \alpha_{low}\right] + \rho_h\left[\alpha_{high} - \alpha\right] \\ & + \lambda\left[M - C(\alpha, y) - d_z TC_z(z) - d_y TC_y(y) - d_\alpha TC_\alpha(\alpha)\right] \end{aligned} \tag{80}$$

Differentiating with respect to the choice variables yields the following first order conditions:

$$\frac{\partial L}{\partial y} = \frac{\partial W}{\partial y} + \mu\alpha - \lambda\left[\frac{\partial C}{\partial y} + d_y \frac{\partial TC_y}{\partial y}\right] = 0 \qquad [81]$$

$$\frac{\partial L}{\partial z} = \frac{\partial W}{\partial z} - \mu - \lambda d_z \frac{\partial TC_z}{\partial z} = 0 \qquad [81]$$

$$\frac{\partial L}{\partial \alpha} = \mu y + \rho_l - \rho_h - \lambda\left[\frac{\partial C}{\partial \alpha} + d_\alpha \frac{\partial TC_\alpha}{\partial \alpha}\right] = 0, \rho_l\left[\alpha - \alpha_{low}\right] = 0, \rho_h\left[\alpha_{high} - \alpha\right] = 0 \qquad [82]$$

Again it is possible to show that the first order condition for an interior solution implies equality between the slopes of the indifference curve and the iso-cost curve (budget constraint).

In addition to the question about the preferences, i.e. the shape of the indifference curves, the central question regarding policy choice is the effect of the different policy measures on the budget set (i.e. production possibility set). Intuitively, as the transaction costs increase, less resources may be used for production, hence the budget set shrinks, i.e. the front shifts towards the origin. This neither mean that the policy with the lowest transaction costs always is the optimal one, nor does it mean that it is always optimal to use only one policy measure.

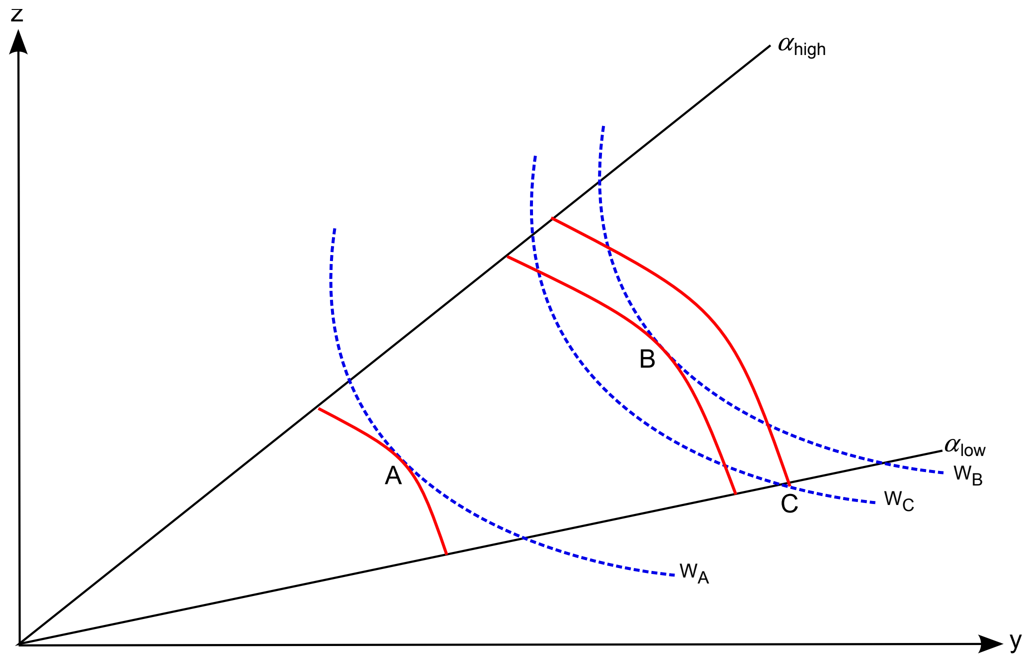

Figure 8. Optimal policy under flexible proportions and three different policies.

In Figure 8 the rightmost iso-cost curve represents the policy with lowest transaction costs, i.e. commodity price support. Given this policy, the actual production is in point C along the line marked α_{low}. The reason that this policy yields a corner solution is as shown above (see section 3.3): as long as we only support the commodity output, there are no incentives for the producers to use an environment enhancing technology (i.e. increase α) if this is costly. The welfare level in C is W_C. In order to find the optimal policy, we need to compare the welfare level implied by the point C (W_C) with the welfare level of the alternative policy measures.

The points A and B are the optimal solutions under two other policies. The differences in budget sets in the figure reflect the differences in transaction costs, i.e. the amounts available for the production of the two goods. In other words, transaction costs are larger for the policy with optimal production in point A than the policy with B as the optimal production. One of the policies may be a direct support for environment enhancing technologies and the other direct environmental payment. The first one induces the farmers to produce by using a certain level of α. If environmental payments are used, the price on z needs to be set such that the negative of the ratio between the commodity price and environmental price equals the slope of the budget constrain (and indifference curve) in the optimal point.

In the example above, point B is preferred to C, and point C is preferred to A. From the figure above it is clear that transaction costs are the key determining factor for the optimal policy when the budget is given. If the distance between the two rightmost cost curves increases, at some point C will become the optimal solution, i.e. the welfare level for W_C will be larger than the welfare level for W_B. In other words, the larger the difference is, the larger is the likelihood that commodity support is the optimal policy.

A complete analysis of this issue is hard to perform, since this demands that we know the transaction costs of the different policy options, the actual cost function and the welfare function. In general, the distance between iso-cost curves will depend on the size of the budget (M in [79]) via two separate effects. Figure 6 indicates that the difference in transaction costs is increasing in the transfer to farmers (and thereby also in the size of the budget). The isolated effect of this is that the difference between the iso-cost curves is increasing as the budget expands. However, there is another effect that works in the opposite direction. If we hold the transaction costs of the two different alternative polices fixed (i.e. the difference in transaction costs is constant) and expand the budget, the distance between the iso-cost curves will decrease[5]. To establish which of these effects is largest is an empirical question outside the scope of this paper.

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[5] Heuristically, we may use a balloon as a metaphor. The effect on the diameter from blowing air into the balloon is lager when the balloon is small compare to when the balloon is large.

6. Discussion and conclusions

The standard policy recommendation is to use as many policy instruments as there are policy objectives. This is known as the Tinbergen's rule. However, this rule only applies to independent policy objectives (Mundell, 1968:201) and situations with zero transaction costs. If there is jointness in the physical sense, there is no need to target all the jointly produced outputs. If transaction costs are added to this, it is clear that it is not optimal to target all goods and services produced jointly. First, setting up more policy schemes will be more expensive than setting up only one. Second, running more schemes will be more expensive than running only one. Finally, we have shown that transaction costs are much lower for policies applied to commodities than for polices applied to non-commodities. If there is physical or biological jointness, proportions are fixed and one or more commodity is involved, it is optimal to target a commodity.

If proportions are flexible, i.e. when it is possible to control/alter the proportions within certain limits, it is not possible to draw a universal conclusion. The reason for this is that it depends on whether the optimal solution is a corner or an interior solution. If one of the goods in question is a commodity, and a corner solution is the optimal, then the optimal policy is a policy applied to the commodity. If the optimal solution is an interior solution, using other policy measures is warranted. Using only a technology subsidy will lead only to an increase in the non-commodity output. This means that if the commodity output is less than optimal given the world market price, one need to combine measures. A commodity price support or support targeting the non-commodity output directly may then in addition be used, with the former yielding lowest transaction costs.

Since the costs of regulating differ between the different policy instruments, the different policy options will in general lead to different optimal production mix and thereby optimal welfare levels. Since the choice of policy instrument is a discrete choice, we have to compare the welfare level for the different policy options. We have in our analysis assumed that the budget available for production of all the goods and regulation is fixed (at an arbitrary level). To put our reasoning simple: if transaction costs increase there is less left for the production in the agricultural sector. This is not a problem in the case of fixed proportions, rather the opposite: it simplifies drawing the conclusions! In the case of flexible proportions, the difference in transaction costs between the different policy options, together with the size of the transfer to farmers, will determine whether the optimal solution is an interior or corner solution (assuming that one of the goods is a commodity). Clearly, the larger the difference between transaction costs is, the more likely is it that a corner solution is the optimal one and that commodity support is the optimal policy.

It must be emphasized that we only have information about a subset of Norwegian policy schemes and that magnitude of the differences may be different in other cases and may change over time. Modern information technology opens up for more automatic monitoring of measures made by farmers. Using remote sensing it is, in principle, possible to monitor for example tillage practice. If this is combined with digital cadastre information, it is possible to subsidize farmer for reduced tillage without the need to apply for the subsidy and with virtually no need for control. With steadily reducing information technology prices one could envision that this will be a low cost solution in the future.

For some goods and services in agriculture, the jointness is not due to physical and/or biological factors, but farm level constraints (e.g. land and capital). This means that the goods may be produced separately, but since the productions of the different outputs are competing over the same (limited) resources (in the short run), the level of output of one good will affect the output of the others. This may be described by a functional relationship between the goods, but still, it is not a physical/biological relationship. In this case the main challenge is to set the relative prices at the right level. However, some goods and services may be hard or costly to target directly. In the latter case different proxies may be used, with losses in precision as a result. Again transaction costs may be important when choosing the policy instruments to use. Policy-makers have to balance precision and transaction costs.

A general policy recommendation that may be made from the analysis of transaction costs in this paper is that one should use as few policy instruments as possible. This is almost self-evident, but we are somewhat surprised over how fast the total policy costs increase when a given total amount is split into an increasing number of policy schemes. The analysis also showed that the spread in size of the schemes affects the total transaction costs to a large degree. If all schemes are of the same size this will maximize total transaction costs for a given number of schemes and total transfer. In order to reduce transaction costs one should use one large and many small in stead.

For a small country like Norway that is not competitive given current world market prices, the analysis indicate that the optimal policy mix is to use commodity price support up to a certain point in order to secure a certain level of non-commodity outputs and to use smaller non-commodity schemes to increase the precision with regard to the production of non-commodity outputs. The latter may also yield incentives for technological development toward the non-commodity outputs.

7. References

Arrow, K. J. (1969). *The organization of economic activity. Issues pertinent to the choice of market versus nonmarket allocation*. The Analysis and Evaluation of Public Expenditure: The PPB System. Vol. 1. U.S. Joint Economic Committee, 91st Congress, 1st Session. Washington D.C.: U.S. Government Printing Office, 59-73.

Baumol, W.J, J.C. Panzar and R.D. Willing (1988). *Contestable Markets and the Theory of Industry Structure*. Harcourt Brace Jovanovich, Inc.

Baumgärtner, S. (2000). *Ambivalent Joint Production and the Natural Environment. An Economic and Thermodynamic Analysis*. Physica-Verlag, Heidelberg and New York.

Berck and Sydsæter (1993). *Economists' Mathematical Manual*. Springer-Verlag.

Bleken, M.A. (2001). *KONOR – a Model for Simulation of Cereal Growth. Documentations*. Report no. 2/2001, Reports from AUN. Department of Horticulture and Crop Sciences, Agricultural University of Norway.

Dahlman, C. J. (1979). Problem of Externality, *Journal of Law & Economics* **22**(1):141-162.

Flaten, O. (2003). Norsk mjølkeproduksjons konkurranseevne i forhold til andre land. *Landbruksøkonomisk forum*, **20**(2): 5-15.

Faber, M., J.L.R. Proops and S. Baumgärtner (1998). All Production is Joint Production - A Thermodynamic Analysis in S. Faucheux, J. Gowdy and I. Nicolaï (eds), *Sustainability and Firms: Technological Change and the Changing Regulatory Environment*, Edward Elgar, Cheltenham, pp. 131-158.

Gravelle, H. and R. Rees (1982): *Microeconomics*. Longman., London,

Havlík, P., P. Veysset, J.-M. Boisson, M. Lherm and F. Jacquet (2005). Joint production and multifunctionality of agriculture: policy considerations and applied analysis. *European Review of Agricultural Economics* **32**(4):489-515.

Hadjigeorgiou, I., K. Osoro, J.P. Fragoso de Almeida and G. Molle (2005). Southern European grazing lands: Production, environmental and landscape management aspects. *Livestock Production Science* **96**:51–59.

McCann, L., Colby B., Easter, K.W., Kasterine, A and Kuperan, K.V. (2005). Transaction cost measurement for evaluating environmental policies, *Ecological Economics* **52**:527-542.

Mundell, R.A. (1968). *International economics*. Macmillan, New York.

OECD (2001). *Multifunctionality: Towards an analytical framework*. OECD, Paris.

OECD (2003). *Multifunctionality: The policy implications.* AGR/CA/APM(2002)10/FINAL, OECD, Paris.

OECD (2007). *The implementation costs of agricultural policies*. OECD, Paris.

Panzar, J.C and R.D. Willig (1981). Economices of scope. *The American Economic Review* **71**(2):268-272.

Peterson, J.M., R.N. Boisvert and H. de Gorter (2002). Environmental polices for a multifunctional agricultural sector in open economies. *European Review of Agricultural Economics* **29**(4):423-443.

Romstad, E. (2008). The informational role of prices. *European Review of Agricultural Economics*. Forthcoming.

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

Shumway, C.R., R.D. Pope and E.K. Nash (1984). Allocatable fixed inputs and jointness in agricultural production: implications for economic modeling. *American Journal of Agricultural Economics* **66**(1):72-78.

Vatn, A. (2002). Multifunctional Agriculture – some Consequences for International Trade Regimes. *European Review of Agricultural Economics* **29**(3):309-327.

Vold A; Breland TA, and Søreng JS. 1999. Multiresponse estimation of parameter values in models of soil carbon and nitrogen dynamics. *Journal of Agricultural, Biological, and Environmental Statistics*. 4(**3**):290-309.

PAPER 4

AGRICULTURAL
ECONOMICS

Agricultural Economics 36 (2007) 1–11

Why do transaction costs of agricultural policies vary?

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Received 10 June 2005; received in revised form 15 January 2006; accepted 24 April 2006

Abstract

Policy related transaction costs (TCs) is an important issue when evaluating different policy options. However, TCs are often not taken into account in policy evaluations, but may be as important for efficiency as the direct production costs. Different policies may result in different TCs, and the main aim of this article is to explore possible reasons for these differences. We compare the level of TCs for 12 different agricultural policy measures in Norway, and we analyze the causes of the differences along three different dimensions: asset specificity, frequency, and point of policy application. At the national level we find that all three dimensions are of importance when explaining the differences, while variation in TCs incurred by farmers are mainly due to differences in point of policy application and asset specificity. Data show that direct price support has the lowest TCs, while more direct payments for environmental amenities has the highest.

JEL classification: H230, Q180

Keywords: Transaction costs; Agricultural policy

1. Introduction

In the ongoing discussions over reforms in agricultural policy, the costs of its management—i.e., the policy related transaction costs (TCs)—have become an increasingly focused issue (Falconer and Whitby, 1999; OECD, 2001; Vatn, 2002). The main point is that the cost of managing a policy may be as important for efficiency as the cost of producing the goods and services.

Ceteris paribus, lowering the costs of administering a policy is a good thing. While standard economic analyses assume zero transaction costs, we observe a growing interest of including TCs in the analysis, not least when studying the choice of contractual arrangements, the development of firms and market structures, and finally the role of the state in the economy (e.g., Furubotn and Richter, 1998; North, 1990; Williamson, 1985). Whereas most of this literature focuses on transactions within the market/firm nexus, there is an increasing interest also in understanding what determines the costs of administering various public policies.

On the basis of economic reasoning it has been argued that if the reason for supporting agriculture is delivery of public goods, decoupled and targeted measures are far more efficient than traditional price support. It has, however, also been argued that this reasoning may not hold if TCs are positive and private and public goods are joint products or complements in production (Vatn, 2002). First of all, if jointness and/or complementarity exist between private and public goods (such as, landscape values or food safety), it may be cheaper to combine these goods in production than to produce them separately. Second, if TCs are positive, it may be cheaper in transaction cost terms to pay for the public good via the (joint) private one, than to set up a separate policy paying directly for the public good.

Certainly, if the public and private goods are not strictly joint, we face demanding trade-off problems. If policy related TCs are low or differences in TCs are small across policies, there is less reason to believe that they will matter. If this is not the case, greater care is warranted.

The aim of this article is hence to study the level of and variation in TCs for a set of agricultural policy measures. The analysis is based on an inquiry of 12 different agricultural policy schemes in Norway. A summary of some of the data is previously published in Vatn (2002). The present article includes extended material. More measures are studied, and we have conducted replications of previous studies to improve the reliability of the results. Still, the main contribution of the present article is the analysis of the variation in the data and how this variation is linked to variables or dimensions that are of great importance for policy choices. The analyses are done at both

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the national level, i.e., analyzing the TCs for the total schemes, and at the farm level, i.e., analyzing farmers' TCs.

2. The theoretical basis

Arrow (1969) has defined transaction costs as the "costs of running the economic system."[1] Dahlman (1979) operationalized the concept by splitting TCs into three elements: the cost of information gathering, the cost of contracting, and finally the cost of control.

Williamson (1985) is a substantial effort into analyzing why TCs may vary across different goods. He identifies three main factors, namely asset specificity, frequency, and uncertainty. Asset specificity is considered the most important, and Williamson distinguishes between what he calls nonspecific and idiosyncratic goods. The latter concerns at the limit goods that are specific to each transaction. Williamson also operates with a middle category which he calls "mixed." TCs are assumed to increase the more idiosyncratic the good is.

Frequency is regarded as the second most important factor. It concerns the relationship between specific sellers and buyers/contracting partners—i.e., whether they are engaged in one-time, occasional, or recurrent transactions. Concerning uncertainty, Williamson focuses foremost on "behavioral uncertainty" where opportunism is a core factor. Frequency and behavioral uncertainty are linked in the sense that frequent transactions create trust and thus reduce this form of uncertainty.

Williamson's analysis focuses on explaining various fundamental institutional arrangements in modern capitalism, such as ordinary market transaction, different contractual forms, the establishment of firms, of vertical integration, etc. Our interest is in agricultural policy. We are hence studying quite different types of transactions. Therefore, Williamson's conceptual frame needs to be restructured to some extent.

As emphasized in the introduction, due to the jointness in production of private and public goods, one has the choice between policy instruments applied to commodities, e.g., price support, deficiency payment, or more direct payments when intending to support the production of public goods, such as landscape features, etc. While the former will be less precise, it may also generate less TCs. First, necessary information for making the payment such as quantity, time, place, etc. are already available as a consequence of the trade of the private good. Hence, information cost should be expected to be very low. Second, there is no need to formulate separate contracts for the payment in this case. Finally, the need for independent control should also be expected to be substantially lower in situations in which policies can be applied to existing commodity transactions. This is because there are control mechanisms already in place as part of the private contract. Certainly, the importance of the above arguments depends on the type of market transactions. Hence, TCs are expected to be lower if agricultural commodities are mainly marketed through large cooperatives compared with delivery through local merchants or several wholesale dealers.[2]

On the basis of this, we will assume that transaction costs in implementing agricultural policy will vary according to:

1. *Point of policy application*, i.e., whether the policy measure is *applied* to a commodity or not;
2. The degree of *asset specificity* involved; and
3. *Frequency*: how often the transaction is undertaken and how many transactors or agents can be treated similarly.

In the Norwegian setting, several existing policy instruments are *applied* directly to a marketed good, e.g., price subsidies on milk or taxes on pesticides. In this case necessary information about volumes, etc. exists as a function of the market transaction itself. As indicated above, TCs may vary according to the marketing systems involved. Some goods such as milk are marketed mainly through a national cooperative. There are only two other distributors involved. In the case of pesticides, the number of wholesale dealers is, however, larger.

In our case, *asset specificity* concerns mainly variation in the quality of the good—i.e., what Williamson calls physical asset specificity.[3] Following Williamson, the hypothesis is that increased asset specificity enlarges TCs. If the public good is jointly produced with the private, asset specificity may be of some importance if the value of the joint public good varies let for example between areas, types of production, etc. Transaction costs will increase somewhat if payments must vary, e.g., between areas and productions. Still, increased asset specificity becomes far more important in cases in which payments are aimed at the public good directly. If the good is very specific, e.g., a local landscape or a certain stone fence that one wants maintained or developed, information gathering and contracting can be undertaken only for each concrete case. There are often few or no options for establishing standardized routines, and the solution must be sought on the basis of locally specified information.

If an easily observable factor—a proxy—for the public good exists, information gathering and control is expected to be much less demanding. A typical example here will be the area of agricultural land of different kinds as a surrogate measure for some landscape features. While such proxies may give rather imprecise information, this lack of precision may again be offset by the lower transaction costs.

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[1] Cited in Williamson (1985).

[2] One might actually understand the above as an expansion of the use of the asset specificity concept. Instead of paying for e.g., an idiosyncratic good one attaches the payment to a nonspecific one—the commodity. Our argument goes one step further, though, since we also emphasize that important information about the nonspecific good will already exist.

[3] Williamson (1985) distinguishes between four types or causes of asset specificity, namely "site specificity," "physical asset specificity," "human asset specificity," and finally "dedicated assets."

Frequency affects mainly transaction costs through how often the transaction is undertaken and how many operations or agents that can be treated equally. If market information already exists—e.g., information about volumes and relevant quality aspects, etc.—transaction costs will normally be low, but still dependent on the number of agents involved and the size of each agent's operation. Some fixed transaction costs will always be involved. If market information does not exist or is incomplete, frequency will normally be low and the hypothesis is that transaction costs will increase. This is particularly the case if information gathering and contracting becomes specific for each single transaction.

From the above we observe that some interrelations between the three factors are likely to appear. Policies applied to a commodity will tend to imply lower asset specificity and higher frequency than policy instruments focused at public goods directly. In the "middle case," in which policies are applied to proxies for public goods, e.g., area payments, the situation is less clear. Specific systems for information gathering must be set up. Still, asset specificity may not be very high and frequency can be rather substantial. Both asset specificity and frequency are of continuous nature, but policies where both are high or both are low will rarely exist. High asset specificity normally implies that the object is rare, and rarity implies low frequency. Low asset specificity implies that the good is a widespread good, and frequency is therefore normally not low. It is therefore unlikely that both are low at the same time.

3. Previous studies

Extensive literature exists on measuring transaction costs (Wang, 2003). Studies related to agriculture are more limited: Eklund (1999); Falconer (2000); Falconer and Whitby (1999); Falconer and Saunders (2002); Falconer et al. (2001); McCann and Easter (1999); McCann and Easter (2000). One problem when comparing results from different studies is that there is no consensus on what transaction costs are. The result of this is that the different studies include slightly different elements when estimating transaction costs. This means that the estimated transaction costs are not directly comparable between the different studies. Still, some conclusions can be drawn from the literature.

There is a rather wide range in TCs. Falconer and Whitby (1999) report administration costs less than 1% of the payment to farmers for arable area payments in U.K. in 1996. At the other end of the scale we find wildlife enhancement scheme (WES) with TCs of more than 110% of the payment to farmers (Falconer and Saunders, 2002). Generally, the results in the literature seem to suggest that TCs are less than 10% of payments to farmers for schemes that are applied to more or less easily observable indicators, e.g., acreage or livestock. For more complex schemes (agri-environmental schemes (AES), WES, preservation of cultural heritage, etc), TCs tend to be larger than 10%.

None of the cited studies have measured transaction costs for policies applied to commodities. McCann and Easter (1999) has estimated transaction costs of policies to reduce agricultural phosphorous pollution to the Minnesota River by 40%. Their assessments are based on interviews of staff from governmental agencies. They found that a tax on phosphate fertilizers had the lowest transaction costs. The estimated TCs for this tax was about one third of the second least expensive alternative (educational programs) and one tenth of the most expensive alternative (expansion of a permanent conservation easement program).

All the cited articles discuss different causes for TCs, but only Falconer et al. (2001) use a formal model to explain TCs. They estimate empirical administration cost functions, using panel data for 22 English environmental sensitive areas. Their results suggest that administration cost decreases as the number of agreements increase. This supports our hypothesis that TCs fall as frequency increases. We have found no tests of the hypotheses concerning asset specificity and point of policy application.

4. Policy schemes and data collection

4.1. *Classification of the policy schemes included in the study*[4]

Norwegian agricultural policy is characterized by a large number of different support schemes. These schemes cover a wide range of objectives, from general support for which almost all farmers are eligible (e.g., acreage payments) to more specific forms of support (e.g., support for summer mountain farming). It is not the intention of this study to cover the whole span of measures, but to include the most important and to cover a range of policy measure characteristics (as outlined above: point of policy application, asset specificity, and frequency). A short description of the different policy measures is given below. A more complete description (except for investment support for environmental measures) is given in Vatn et al. (2002).

Based on an evaluation of the different policy schemes we have classified them along the three dimensions; point of policy application, asset specificity, and frequency (Table 1). We have chosen to use categorical scales for asset specificity and frequency. Certainly, defining what is low, medium and high is a difficult task, and this seems to be a problem common to all studies in this field (see, e.g., Falconer and Whitby, 1999).

Farmers who produce milk receive *price support per liter of milk* they deliver (Ministry of Agriculture, 1999e). The number of farmers who receive this support is large (see Table 2). Part of this subsidy varies with geographical location.

From 1988 till 2000 there was an environmental *tax on mineral fertilizers* in Norway. Information about volumes and types of fertilizers existed as an effect of involved market transactions.

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[4] Due to a regionalization of the agri-environmental policies, some of the studied schemes were removed or changed after our study.

Table 1
Classification of the policy schemes

Policy scheme	Group*	Policy application	Asset specificity	Frequency
Price support milk	A1	Commodity	Low	High
Tax on fertilizers	A1	Commodity	Low	High
Tax on pesticides	A2	Commodity	Low	Medium
Price support home refined dairy products	A3	Commodity	Medium	Low
Acreage payments	B1	Other	Low	High
Livestock payments	B1	Other	Low	High
Subsidy for reduced tillage	B2	Other	Medium	Medium
Acreage support to organic farming	B3	Other	Medium	Low
Conversion support organic farming	B3	Other	Medium	Low
Support for preserving cattle breeds	B4	Other	High	Low
Support for special landscape ventures	B4	Other	High	Low
Investment support for environmental measures	B4	Other	High	Low

*The policy schemes in a group have the same characteristics. The group names are used later to ease the presentation of the results.

The producers and importers were required to give information on the content of nitrogen and phosphorus in their fertilizers irrespective of the tax system (Ministry of Agriculture, 1998). There is some variation in the quality of mineral fertilizer products, but the only relevant quality elements were the nitrogen and phosphorus contents.

Table 2
Size (total payments, number of applications, and units subsidized/taxed) of the different policy schemes

Policy scheme	Subsidy/tax, mill NOK	Applications, 1,000	Number of units
Price support milk	520	.	1580.3 mill liter
Tax on fertilizers	158	.	1191.1 100 tons
Tax on pesticides	53	.	3.8 100 tons
Price support home refined dairy products	1	.	1.7 mill liter
Acreage payments	3,267	63.2	1.0 mill ha
Livestock payments*	2,088	77.9	62.7 mill animals
Subsidy for reduced tillage	133	12.3	1.4 mill decares
Acreage support to organic farming	19	1.9	17.1 1,000 ha
Conversion support organic farming	7	0.4	1.6 1,000 ha
Support for preserving cattle breeds	1	0.4	1,597 animals
Support for special landscape ventures	113	2.8	.
Investment support for environmental measures	11	0.2	.

Source: Norwegian Agricultural Authority (2005).

*Farmers apply for support under this scheme two times a year. The number of applications does therefore not represent the number of livestock farms in Norway nor does the number of animals represent the size of the livestock herd.

The *tax on pesticides* in Norway is levied according to the environmental and health risks of the different pesticides. Again we are in a situation in which information about the good exists as an effect of market transactions. There are about 30 importers of pesticides (Norwegian Agricultural Inspection Service, 2004)—a fairly low number. The authorities have to acquire information on health and environmental risks of pesticides in addition to information on imported and volumes sold (Ministry of Agriculture, 2004). The number of products is rather high. This implies that asset specificity is higher and frequency is lower than for the fertilizer tax.

Price support for home-refined dairy products—mainly cheese—is a special type of price support for milk with the same purposes as ordinary price support for milk (Ministry of Agriculture, 1999e). Products are either sold from the farmer to the national dairy cooperative, or through other channels—mainly directly to consumers. The support is given per liter of milk used in the production, and this amount is calculated from the sales of the final product. If the products are not sold to the dairy cooperative, a monthly sales report has to be filed. Additional administration is thus required compared with ordinary price support on milk. We have classified this as a support scheme applied to a commodity, but it should be emphasized that this scheme is quite different from the other schemes in this group. It is included to give an indication of the effects of a situation in which information has to be separately gathered and volumes are very small for policies applied to commodities. Hence, one should not expect that TCs here are in the same range as in the other cases where policy application is on commodities.

Acreage payment is a general support scheme for which almost all farmers in Norway are eligible (Ministry of Agriculture, 1999c). The payments are made per decare of cultivated land, and depend on the crop grown, the geographical location and the acreage of the different crops.

Livestock payment is also a general support scheme and the number of farms receiving this support is thus also large. The payment is based on the number of animals (Ministry of Agriculture, 1999b). Payments are differentiated according to type of animal, the number of animals on each farm, and geographical location.

The *subsidy for reduced tillage* is based on decares of agricultural land under certain soil management practices (Ministry of Agriculture, 1999d). It is differentiated according to erosion risk. The local agricultural authority determines the erosion risk of each field.

Acreage support to organic farming is based on acreage of organic farmland, and differentiated according to the crops grown (Ministry of Agriculture, 2000b). Due to a rather low number of applications, frequency is low for this policy measure.

Farmers who want to convert from conventional to organic agriculture have to follow certain procedures for a period of time before they can be certified as organic farmers. These farmers receive a one-time payment (*conversion support to organic farming*). The payment is made per decare of converted land (Ministry of Agriculture, 2000b). Most farmers that convert, convert only part of their land each year.

The purpose of *support for preserving cattle breeds* is to contribute to the preservation of old cattle breeds (Ministry of Agriculture, 1999f). Information must be specifically acquired. Payments are per animal and are equal for all old cattle breeds. Standardized routines are therefore utilized. The number of animals of old cattle breeds is rather limited.

Payments under the *support for special landscape ventures* scheme are given to five different ventures types: (1) preservation and promotion of biodiversity, (2) preservation of old cultivated land, (3) promotion of availability and experience of qualities in or in connection with agricultural land, (4) preservation of cultural sites, and (5) restoration of protected buildings or buildings that are worthy of preservation (Ministry of Agriculture, 1999a). The payments are given per venture. The payments are directed towards a public good. Each venture has a unique quality, and must therefore be treated individually.

Investment support for environmental measures can be granted for technical installations, planting of vegetation that is beneficial for the cultural landscape and ecological cleanup measures (e.g., catchment ponds) (Ministry of Agriculture, 2000a). The complexity is lower than for the previous scheme, but each application has still to be evaluated individually. The number of projects receiving support under this scheme is low.

One particular problem when categorizing policy schemes is related to policies applied to commodities. The commodities we have studied have low asset specificity and relatively high frequencies. This means that all policies applied to traded goods in principle should be categorized into the same group. Still, there are large differences between these schemes. For example, the liters of milk under *price support milk* are more than 900 times the liters under *price support for home-refined dairy products*—i.e., a large difference in frequency. Using a finer scale for asset specificity and frequency could have solved this problem. However, the number of observations is low, and a further reduction of the number of observations in each group would have reduced the possibility for testing our hypotheses. The categorization was therefore made relative to the point of policy application. This has two implications: the levels of asset specificity and frequency are not directly comparable between the two groups of policy application, and analysis must be done separately for the two groups.

4.2. Data collection

As mentioned in Section 2, Dahlman (1979) splits TCs into three elements: the cost of information gathering, the cost of contracting and the cost of control.[5] However, there seems to be no consensus over how to measure them and what elements to include (McCann et al., 2005). There are different sources and methodologies for elicitation of TCs. McCann et al. (2005) list four for *ex-post* analysis: (1) surveys or interviews of government personnel and stakeholders, (2) government reports, (3) financial reports, and (4) proposed budgets. In the current article, we have used the first option.

Transaction costs were quantified through interviews with representatives from different public administrations, market participants, and farmers involved. The costs cover labor costs, general overhead, computer cost, costs related to information material and postage. For nine of the twelve policy measures, transaction costs are incurred at the farm level. A number of farmers—from 4 up to 22 (see Table 8)—were interviewed to get the necessary input about farmers' costs. For the other participants, one to three representatives from the relevant agencies/market participants were interviewed for each policy measure.

We would have liked to quantify both set up and running costs. It has, however, been very difficult to find data on the costs of establishing the various policy instruments since most of them were established many years ago. We therefore had to reduce our ambitions and focus only on running costs.

The data were collected in 2001 and 2003. The number of years since a policy measure was established could influence the annual running transaction costs. Cost savings from fine-tuning and learning processes are likely to occur over time (see, e.g., Falconer et al., 2001). We have not considered this aspect. However, most of the measures in this study had been in place for several years, and we believe that, for the policy measures in our study, there are only small differences in TCs between years.

There exist no internal procedures in the involved administrations for attributing the transaction costs/administrative costs to the various policy measures that these administrations are responsible for, and some costs are joint for two or more policy measures. Thus, we had to make assessments together with the involved representatives about how to split these. In some cases the degree of jointness was such that it was impossible to attribute the costs to the individual instruments. In these cases we have split the costs between policy measures on the basis of the number of applications. Certainly, a lot of judgment will always be involved in calculations like these. One should be aware of the uncertainties implied.

In cases in which policy measures are applied to existing commodities, the administration of the instrument overlaps the administration of the market transaction. There are no *a priori* rules existing concerning how such joint transaction costs should be divided. In cases in which policy measures are applied to existing commodities, the system for operating the market must already be in place. Thus, the transaction costs for the market players are the additional costs of running a system on top of an already existing market system.

5. Analysis

When presenting the data, we have mostly chosen to use TCs in percent of the subsidy or the tax revenue. The main reason for this is that our aim is to compare TCs for different

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[5] Other typologies of transaction costs exist, e.g., McCann et al. (2005), which can be viewed as an expansion of Dahlman (1979).

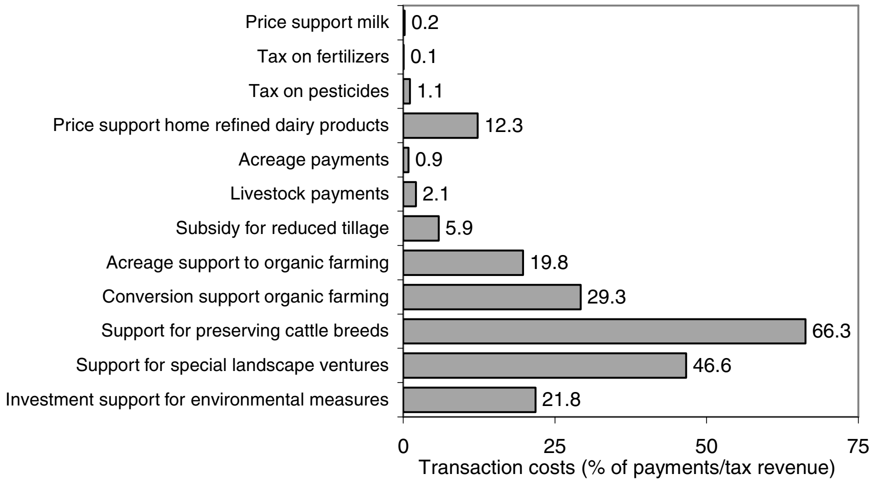

Fig. 1. Transaction costs (as percent of payments to farmers/tax revenue) at the national level.

policy schemes. Such a comparison has no meaning if TCs are not “normalized” in some way. The only available common denominator is the subsidy or tax. Since taxes and the subsidies may not reflect the benefits involved, the solution is not ideal. Still, it is the solution normally used by other authors.

TCs may be fixed (i.e., invariant to the subsidy, liter of milks, decares, number applicants, etc.) and/or variable. Different schemes will differ as to the relative size of the two cost elements. For example, there are reasons to believe that the major part of TCs for a tax on fertilizers is fixed, while for support for special landscape ventures the major part is variable. Ideally, we would have liked to make a distinction between fixed and variable TCs in our analysis, but due to limited data availability, this is not possible at the aggregate level.[6] Due to this, one should be careful when extrapolating our results.

The presentation of the analyses, both at the national level and for farmers, is organized in the following way. First we present the overall picture of the policy schemes. Next, we present tests for differences between the different groups of policies (as described in Table 1). Finally, we present the results from tests of the effects of the three explanatory dimensions point of application, asset specificity and frequency.

5.1. Analysis at the national level

5.1.1. Differences between the groups of policy schemes.

The estimated transaction costs in percent of payments to farmers/tax revenue for the different policy measures are shown in Fig. 1.

In Fig. 1 we see that TCs are (almost) negligible for policies that are applied to commodities with low asset specificities and with high frequencies. Price support for home-refined dairy products has higher TCs than the other applied to commodities. As mentioned above, this scheme involves more administration than the others. TCs are low for policies applied to easily observable proxies (e.g., acreage or animals). It should be mentioned that in these cases the volume of the support is large. At the other end of the scale we find policies that have low frequency and high asset specificity. This tendency becomes even clearer if we look at the mean TCs for the different groups (Table 3).

Table 3
Mean transaction costs and standard deviations for the different policy groups

Group	Policy application	Asset specificity	Frequency	Mean	Standard deviation	No. obs.
A1	Commodity	Low	High	0.2	0.1	2
A2	Commodity	Low	Medium	1.1	.	1
A3	Commodity	Medium	Low	12.3	.	1
B1	Other	Low	High	1.5	0.7	4
B2	Other	Medium	Medium	5.9	1.3	2
B3	Other	Medium	Low	24.5	5.6	4
B4	Other	High	Low	45.3	19.2	4

Note: See Table 1 for the classification of the policy schemes.

With the rather large differences we see in Table 3, we would expect that differences between the groups would be statistically significant, but the variance for some of the groups is also large. It is therefore not obvious that all of the differences are significantly different from zero.

We have performed both parametric and nonparametric tests of differences between the different groups (Table 4).[7] Except for the two groups with only one observation (A2 and A3), all tests are significant at 10% level or better.

Some of the *t*-tests for the two groups with only one observation are significant, but these tests are done under the assumption that the variances of the tested groups are the same. Given the

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[6] We also doubt that it is possible to collect enough data at the national level to do so.

[7] The SAS System for Windows v8 (SAS Institute Inc., 1999) is used for all statistical tests.

Table 4
Statistical test for difference between groups

	A1	A2	A3	B1	B2	B3	B4	Mean	Standard deviation	No. obs.
A1		– – *	– – ***	* * *	– – **	* * ***	* * **	0.2	0.1	2
A2	– – *		n.a.	– – –	– – –	– – **	– – –	1.1	.	1
A3	– – ***	n.a.		– – ***	– – –	– – –	– – –	12.3	.	1
B1	* * *	– – –	– – ***		* * ***	** ** ***	** ** **	1.5	0.7	4
B2	– – **	– – –	– – –	* * ***		* * **	* * *	5.9	1.3	2
B3	* * ***	– – **	– – –	** ** ***	* * **		* * *	24.5	5.6	4
B4	* * **	– – –	– – –	** ** **	* * *	* * *		45.3	19.2	4

Significance level: *** = 1%; ** = 5%; * = 10%; – = not significant; n.a. = not applicable.

Tests: upper = Wilcoxon (one-sided); middle = Kruskal–Wallis; bottom = t.

Table 5
One-sided t-tests of the groups with only one observation (A2 and A3) against the other groups

	A1	B1	B2	B3	B4
A2	**	–	*	***	***
A3	***	***	**	**	**

Note: See the main text for details.

Significance level: *** = 1%; ** = 5%; * = 10%; – = not significant.

data in Table 3, this assumption is doubtful. We have therefore performed one-sample t-tests, where the null hypothesis is that the mean of the different groups is equal to the mean (as a parameter) of group A2 or A3.[8]

As can be seen from Table 5, all these tests are significant at 10% level or better, except for the test between A2 and B1 (where the difference is small). A2 consists of one scheme, (tax on pesticides), while B1 is comprised of schemes applied to easily observable objects (acreage and livestock).

5.1.2. The effects of point of policy application, asset specificity, and frequency.

We have so far looked at the differences between groups of policy schemes, and in most cases the differences are significant. This seems to support the conclusion that the TCs increase as frequency reduces and asset specificity increases. The next step is to conduct explicit tests of these dimensions.

Table 6
Mean TCs for the different groups

		Asset specificity		
		Low	Medium	High
Frequency	High	0.2^{*} 1.5^{**}		
	Medium	1.1^{*}	5.9^{**}	
	Low		12.3^{*} 24.5^{**}	45.3^{**}

*Policy is applied to commodity.
**Policy applied to noncommodity.

As pointed out above, the classification along the two dimensions asset specificity and frequency is relative to point of policy application. This means that model estimations must be done separately for the two groups of policy application.

Fig. 1 and Table 3 indicate that policies applied to traded goods generally have lower TCs. The mean TCs for this group of policies is 3.4 and the standard deviation is 5.9. For the other group of policies, the corresponding numbers are 21.2 and 20.7. This means that the mean TCs for the latter group is more than six times the mean TCs for policies applied to commodities. The difference in means is significantly different from 0 at 5% level or better (P-values: Kruskal–Wallis = 0.03, Wilcoxon (one sided) = 0.02, t (Satterthwaite) = 0.01). Thus, point of policy application influences the level of TCs.

Before we analyze the effects of frequency and asset specificity, we will have a look at the data along these two dimensions. Three levels of frequency and asset specificity imply a 3 by 3 factorial setup, while we have only three combinations for policy measures applied to commodities and four schemes for the other group. Also, the policy schemes are mainly located along the diagonal of the 3 by 3 matrix (Table 6).

The unbalanced data set is neither due to our classification nor the selection of the policy measures. Indeed, we believe that policy measures always will lie more or less along the diagonal of such a matrix. As previously emphasized, is it hard to envisage the implementation of policy schemes where both asset specificity and frequency are high or where both are low.

We have used linear regression to analyze the effects of frequency and asset specificity. Since the independent variables are categorical, we have used dummy variables in this analysis. Four dummy variables (two for each dimension) may theoretically be used in the regressions. However, the matrixes for the independent variables (including the constant term) are not of full rank. This makes it impossible to test all hypotheses outlined above simultaneously. Two dummy variables (in addition to a constant term) can be included in the analysis of policy measures applied to commodities and three for the other group. Models were estimated for all possible combinations of these dummy variables. Table 7 shows examples of parameter estimates.[9]

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[8] More precisely the hypotheses tested are the following: If $\bar{x}_i > \bar{x}_j$, where i = A1, B1, B2, B3 or B4 and j = A2 or A3, then the alternative hypothesis is $\mu_i > \bar{x}_j$, and if $\bar{x}_i < \bar{x}_j$ then $\mu_i < \bar{x}_j$ is the alternative hypothesis. The null hypothesis is the same in both cases $\mu_i = \bar{x}_j$.

[9] The complete set of estimates is available upon request.

Table 7
Examples of parameter estimates

	Policy application	
	Commodity	Other
Intercept	1.1*	24.5***
Asset specificity: high		20.8*
Asset specificity: medium	11.2***	
Frequency: high	−0.9*	−23.0***
Frequency: medium		−18.6**

Significance level: *** = 1%; ** = 5%; * = 10%.

Since variance increases as TCs increase (Table 3), we would expect increasing variance of the residuals in a fitted model, i.e., heteroscedastic residuals. In such a case, OLS parameter estimates are still unbiased, but the estimator is not efficient. Tests based on OLS residuals indicated heteroscedasticity for policies applied to commodities (White's test: $P = 0.07$). The regression models were estimated using weighted least squares combined with the method proposed by Cohen et al. (2003) for estimation of the weights. In addition, the models were also estimated using heteroscedasticity-consistent (HC) standard error estimators (Long and Ervin, 2000). Both methods resulted in similar significance levels for the estimated parameters and identical parameter values (as expected).

For all models, all parameters have expected signs, and except for a few cases, parameters are significant at 10% level or better. R^2 (and thereby the P-value of the joint test of the slope parameters in the models) are identical for all estimated models within each policy application group. Also the "ranking" of the parameter values are as expected, e.g., low asset specificity yields a lower parameter estimate than medium asset specificity, etc.

5.1.3. The effects of the "size" of the policy schemes

One important question is how robust our results are to variations in the levels of the subsidy/tax, since TCs are measured as percent of total subsidy/tax revenue. The observant reader has seen, by combining Fig. 1 and Table 2, that the general trend in our material is that TCs are falling in the size of the scheme. Fig. 2 confirms this. Since two of the schemes are much larger than the others, we have chosen to plot the data in log form. The falling trends indicate that TCs (in normal terms) are falling and convex in the size of the schemes.

The relevant question here is whether the size of the subsidy/tax in any way has influenced the conclusions drawn so far. Is it simply the level of support (the denominator) that has made TCs low, e.g., in measures applied to commodities?

As can be seen from the figure, there is a clear difference in TCs with respect to point of policy application. For all levels of the subsidy of tax, TCs are lower for schemes that are applied to commodities.

The size of the schemes may affect TCs (in percentage terms), but this does not explain the variation between schemes in our data. We have run regressions with subsidy/tax as an independent variable, but they turn out to be not significant.

The conclusions from the analysis at the national level are that point of policy application, asset specificity and frequency are significant factors for the determination of TCs. Policies applied to traded goods have lower TCs compared to other policies. TCs increase as asset specificity increases and frequency decreases.

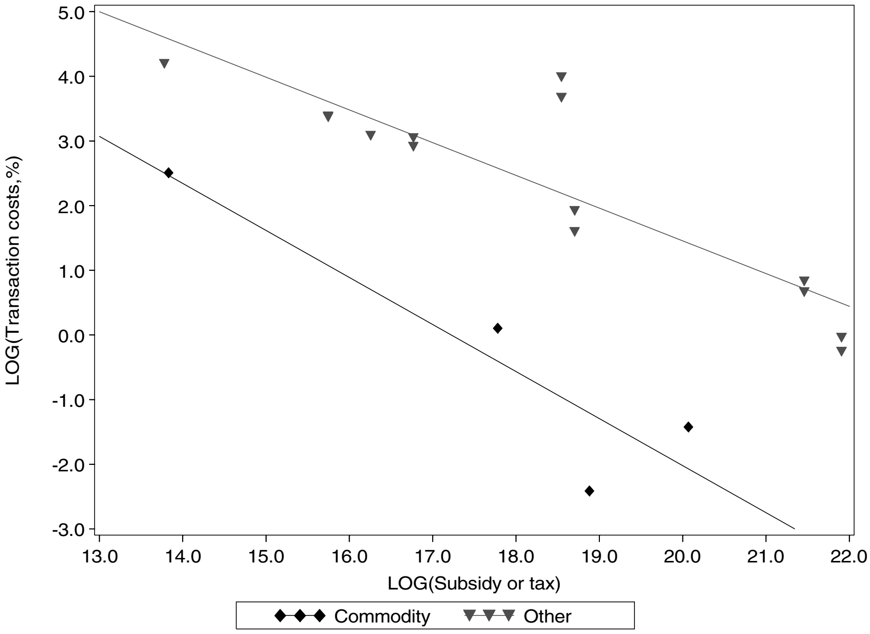

Fig. 2. The natural logarithm of TCs plotted against the natural logarithm of the total subsidy or tax revenue. Lines are fitted linear regression lines.

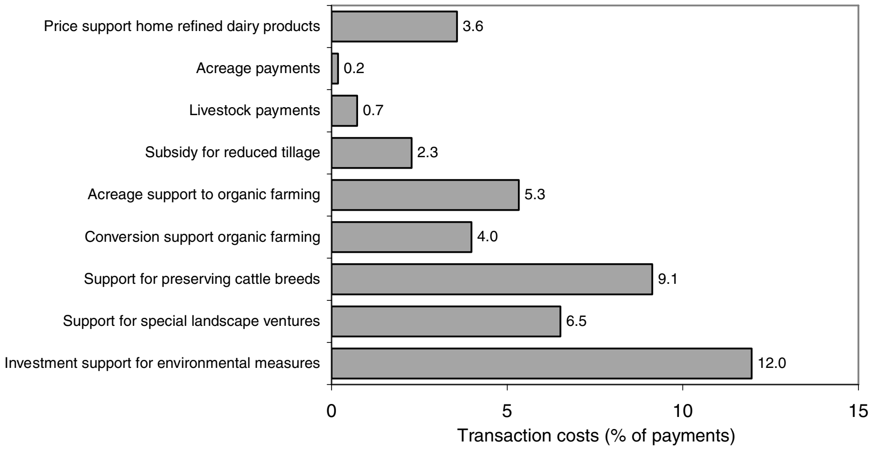

Fig. 3. Mean TCs for farmers. (The three schemes with no farmer participation are excluded.)

5.2. *Analysis at the farmer level*

For policy schemes that involve farmers, the farmers' mean share of total TCs is about 13%. The share varies from about 7% (conversion support organic farming) to about 37% (subsidy for reduced tillage). There is no clear systematic pattern in these shares, but it seems to be higher for the schemes acreage payments, livestock payments, and subsidy for reduced tillage, than for the other schemes. The total TCs for these schemes are generally rather low, but still require some input from the farmers.

Fig. 3 shows the mean TCs for farmers, and we see a pattern similar to the one for total TCs (Fig. 1). The correlation between the farmers' TCs and TCs at the national level is moderate ($\rho^2 = 0.46$), but still significantly different from zero at the 5% level. The investment support for environmental measures scheme is a clear outlier, and if excluded the squared correlation coefficient increases to almost 0.9.

Acreage and livestock payments have TCs that are considerably lower than for the other schemes. The reason for this is probably that the farmers apply for these types of support each year, and that the schemes are applied to objects that are easily observable—the farmers know their livestock and acreage. This information is also easy to process for the authorities, so the total TCs are therefore also rather low.

At the other end of the scale we find investment support for environmental measures. The farmer normally applies for this type of support only once, and the application demands rather detailed information about the project.

Farmers' knowledge about the different schemes and competence in applying for support differ. The information requirement and complexity also differ between the different schemes. Therefore, we expect differences in the variance of TCs between different schemes, and lowest variance for the schemes with the lowest information requirement. Since most of the TCs for farmers are information costs, and there is a strong correlation ($\rho^2 = 0.99$) between the means and standard deviations in Table 8, there seems to be a link between variation and information complexity. On the other hand, in percentage terms, the standard deviation does not vary much.

Since we have more observations for each policy scheme at this level, it is possible to test for differences between schemes. The rather large standard deviations, at least for some of the schemes, result in relatively few significant differences. The two schemes with the lowest TCs (B11 and B12) are significantly different from all other schemes. The most "expensive" scheme with respect to TCs for farmers (B43) is significantly different from all other schemes except one (B41). Also, B21 (subsidy for reduced tillage) is significant different from most of the other.

Also at the farm level we have classified the policy schemes according to our three explanatory dimensions. There is one difference. For frequency we have chosen to use only two levels: high and low. For the policy schemes evaluated in this study, farmers normally apply for support either one time or each year. Policy scheme for which farmers apply each year are classified as having high frequency (A31, B11, B12, B21, and B31), while others are low. The mean TCs for the different groups are shown in Table 9.

The groups with medium asset specificity are not significantly different from each other. This may indicate that the point of policy application is not important at farm level if we look at only policy schemes where farmers incur TCs. Price support for home-refined dairy products differs from subsidy for reduced tillage and acreage support to organic farming only by point of policy application, and the difference in mean TCs is not significantly different from zero. It should again be noted that the price support for home-refined dairy products differs rather much from the other schemes applied to commodities. For three of the 12 policy measures we have analyzed, the TCs at the farm level are zero. All these three schemes are applied to commodities, and if these are included, it is obvious that farmers' TCs are lower if policies are applied to commodities.

For the three groups of policies with medium asset specificity, frequency is not a factor affecting TCs. The groups in the upper left and lower right cell of Table 9 are significantly different from each other and the other groups. This means that asset

Table 8
Simple statistics of the transaction costs for the different schemes

Scheme	Code*	Mean	Standard deviation	Min.**	Max.	No. obs.
Price support home refined dairy products	A31	3.6	3.01	0.6	9.8	9
Acreage payments	B11	0.2	0.14	0.0	0.4	16
Livestock payments	B12	0.7	0.51	0.1	1.6	20
Subsidy for reduced tillage	B21	2.3	1.97	0.5	8.2	20
Acreage support to organic farming	B31	5.3	6.07	0.0	22.8	22
Conversion support organic farming	B32	4.0	2.94	0.5	10.5	11
Support for preserving cattle breeds	B41	9.1	9.32	2.3	22.7	4
Support for special landscape ventures	B42	6.5	6.14	1.3	17.8	16
Investment support for environmental measures	B43	12.0	11.87	3.3	44.4	10

*The letter and first digit of the code is the same as used at the national level.

**All farmers have reported positive TCs. Due to rounding, some minimum values are reported as 0.0.

Table 9
Mean TCs for the different groups

	Asset specificity		
Frequency	Low	Medium	High
High		3.6*	
	0.5**	3.9**	
Low		4.0**	8.7**

*Policy is applied to commodity.

**Policy is applied to noncommodity.

specificity is the only significant dimension at farm level. This conclusion is confirmed by regression analyses, in which only dummy variables for asset specificity are significant.

6. Discussion and conclusions

The data presented in this article clearly show that there are differences in transaction costs between different policy schemes, both at the national level (total costs) and for farmers. The analyses also support the hypothesis that these differences at the national level are due to differences in point of policy application, asset specificity and frequency. TCs are lower for policies that are applied to commodities than other points of application, and they increase as asset specificity increases and/or frequency decreases. For policies, which also generate TCs at the farm level, differences in farm level TCs are mainly due to differences in asset specificity. TCs increase as asset specificity increases. For many policies applied to commodities there are no TCs at the farm level. This, of course, means that the point of policy application also affects the farm level TCs.

We have used data from Norway, but the hypotheses tested were posed in rather general terms. We believe that our conclusions may apply to agricultural policies in general, at least in situations with the same type of administrative and market systems.

Our findings have implications for policy design. However, they cannot be used alone to find the optimal policy mix. The reason for this is that transaction costs are only one element that needs to be included in a complete analysis. Different schemes will differ with respect to how targeted they are, and they will give different incentives for entry and exit. Our results indicate that TCs increase as the schemes become more targeted or precise (higher asset specificity). For example, support for preserving cattle breeds is well targeted, but have high TCs, while acreage support is rather imprecise with respect to what the target is, but TCs are low. The main point here is that there is a trade-off between transaction costs and precision of the scheme. This means, for example, that if we want to secure the production of a (public) good of high value, we may have to accept high TCs. Likewise, if the degree of jointness is sufficiently large, a scheme with low TCs may still offer the best solution.

References

Arrow, K. J., 1969. The organization of economic activity. Issues pertinent to the choice of market versus nonmarket allocation. In: The Analysis and Evaluation of Public Expenditure: The PPB System. Vol. 1. U.S. Joint Economic Committee, 91st Congress, 1st Session. U.S. Government Printing Office, Washington DC, pp. 59–73.

Cohen, J., Cohen, P., West, S. G., Aiken, L. S., 2003. Applied Multiple Regression/Correlation Analysis for the Behavioral Sciences. Lawrence Erlbaum, Mahwah, NJ.

Dahlman, C. J., 1979. Problem of externality. J. Law Econ. 22(1), 141–162.

Eklund, A., 1999. Transaction costs of the Swedish agri-environmental program. Report. 128, Swedish University of Agricultural Sciences, Uppsala, Sweden.

Falconer, K., 2000. Farm-level constraints on agri-environmental scheme participation: a transactional perspective. J. Rural Stud. 16(3), 379–394.

Falconer, K., Saunders, C., 2002. Transaction costs for SSSIs and policy design. Land Use Pol. 19(2), 157–166.

Falconer, K., Dupraz, P., Whitby, M., 2001. An investigation of policy administrative costs using panel data for the English environmentally sensitive areas. J. Agric. Econ. 52(1), 83–103.

Falconer, K., Whitby, M., 1999. The invisible costs of scheme implementation and administration. In: Van Huylenbroeck, G., Whitby, M. (Eds.), Countryside Stewardship: Farmers, Policies and Markets. Elsevier Science Ltd, pp. 67–88.

Furubotn, E. G., Richter, R., 1998. Institutions and Economic Theory : The Contribution of the New Institutional Economics. The University of Michigan Press, Ann Arbor.

Long, J. S., Ervin, L. H., 2000. Using heteroscedasticity consistent standard errors in the linear regression model. Am. Stat. 54(3), 217–224.

McCann, L., Colby, B., Easter, K. W., Kasterine, A., Kuperan, K. V., 2005. Transaction cost measurement for evaluating environmental policies. Ecol. Econ. 52, 527–542.

McCann, L., Easter, K. W., 1999. Transaction costs of policies to reduce agricultural phosphorous pollution in the Minnesota River. Land Econ. 75(3), 402–414.

McCann, L., Easter, K. W., 2000. Estimates of public sector transaction costs in NRCS programs. J. Agric. Appl. Econ. 32(3), 555–563.

Ministry of Agriculture, 1998. FOR 1998-05-28 nr 562 Forskrift om handel med gjødsel og jordforbedringsmidler m.v. Oslo, Norway.

Ministry of Agriculture, 1999a. FOR 1999-02-26 nr 273: Forskrift om tilskudd til spesielle tiltak i landbrukets kulturlandskap med freda og verneverdige bygninger. Oslo, Norway.

Ministry of Agriculture, 1999b. FOR 1999-07-01 nr 784 Forskrift om tilskudd til husdyr. Oslo, Norway.

Ministry of Agriculture, 1999c. FOR 1999-07-01 nr 785 Forskrift om areal- og kulturlandskapstilskudd. Oslo, Norway.

Ministry of Agriculture, 1999d. FOR 1999-07-02 nr 793 Forskrift om tilskudd til endret jordarbeiding m.m. Oslo, Norway.

Ministry of Agriculture, 1999e. FOR 1999-08-26 nr 965: Forskrift om tilskott til mjølkeproduksjon. Oslo, Norway.

Ministry of Agriculture, 1999f. FOR 1999-11-15 nr 1173 Forskrift om tilskudd til bevaringsverdige storferaser. Oslo, Norway.

Ministry of Agriculture, 2000a. FOR 2000-01-01 nr 1531: Forskrift om investeringsstøtte til miljøtiltak. Oslo, Norway.

Ministry of Agriculture, 2000b. FOR 2000-11-27 nr 1682 Forskrift om tilskudd til økologisk landbruk. Oslo, Norway.

Ministry of Agriculture, 2004. FOR 2004-07-26 nr 1138: Forskrift om plantevernmidler. Oslo, Norway.

North, D. C., 1990. Institutions, Institutional Change and Economic Performance. Cambridge University Press, Cambridge.

Norwegian Agricultural Authority, 2005. Statistikk fra søknader om produksjonstilskudd i jordbruket. Oslo, Norway. Available at http://32.247.61.17/skf/prodrapp.htm.

Norwegian Agricultural Inspection Service, 2004. Godkjente importører og norske tilvirkere av plantevernmidler. Oslo, Norway. Available at http://landbrukstilsynet.mattilsynet.no/plantevernmidler/plvm_importorer.cfm.

Organisation for Economic Co-operation and Development (OECD), 2001. Multifunctionality: Towards an Analytical Framework. OECD, Paris.

SAS Institute Inc., 1999. SAS/STAT User's Guide, Version 8. SAS Institute Inc, Cary, NC.

Vatn, A., 2002. Multifunctional agriculture: some consequences for international trade regimes. Euro. Rev. Agric. Econ. 29(3), 309–327.

Vatn, A., Kvakkestad, V., Rørstad, P. K., 2002. Policies for multifunctional agriculture—the trade-off between transaction costs and precision. Report 23, Agricultural University of Norway, Department of Economics and Social Sciences, Ås, Norway.

Wang, N., 2003. Measuring transaction costs: an incomplete survey. Working Paper Number 2. Ronald Coase Institute.

Williamson, O. E., 1985. The Economic Institutions of Capitalism: Firms, Markets, Relational Contracting. Free Press, New York.

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ISSN: 0802-3220
ISBN: 978-82-575-0822-7

Per Kristian K. L. Rørstad was born in Eidsvoll, Norway, in 1965. He holds a Cand. Agric. degree in Forestry Economics and Planning from the Agricultural University of Norway (1990).

Agriculture produces more than just commodities that can be and are traded in markets. These multiple outputs may contribute to different societal objectives at once, which is the essence of the concept of multifunctional agriculture. The quantities of the non-market goods, bads and services may not be socially optimal since the producers do not receive the right signals through the markets. Since there are interlinkages, jointness, between the outputs, different combinations of taxes/subsidies on inputs, outputs and practices may be used to induce the socially desirable output levels.

Two of the papers in this thesis discuss policy measures to reduce nitrogen pollution from agriculture. The first paper analyzes the effect of private transaction costs in a market for fertilizer quotas. It is shown that transaction costs do not influence trade much, and that tradable fertilizer quotas have the expected environmental effects. In the second paper a two-round quota system is analyzed. The results indicate that abatement costs (both private and social) are lower for the proposed instrument than for a nitrogen tax.

The two other papers concern transaction costs and optimal policies under jointness. Transaction costs are much lower for polices targeting commodities than for polices targeting other objects. If jointness is such that it is not possible for the farmer to influence the proportions of the different outputs, it is clearly optimal to target the commodity. For more flexible forms of jointness, it is not possible to draw a general conclusion.

The analysis also shows that transaction costs can be reduced substantially by reducing the number of schemes. It is not surprising that merging schemes would result in lower administrative costs, but it is surprising how fast the total transaction costs increase as the number of schemes increases.

For a country that is not competitive on the world market, like Norway, the analysis suggests that the optimal policy is to use commodity based support to induce production up to a certain level and to supplement this with other measures like direct payment for the production of public goods.

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