CHAPTER 4

THE ROLE OF MEASUREMENT PROBLEMS AND MONITORING IN PES SCHEMES

GERDIEN MEIJERINK

Agricultural Economics Research Institute (LEI), Wageningen University and Research Centre, P.O. Box 29703, 2502 LS, The Hague, The Netherlands

Abstract. Payment for environmental services (PES) is seen as a mechanism that can achieve two goals, providing poor resource managers with an additional source of income and maintaining environmental services. Although some reservations have been made on the effectiveness of PES of reaching the poor, similar reservations can be made about achieving the second goal. Because many environmental services are intangible, developing simple and straightforward indicators to measure and monitor the environmental service provided and linking these to the efforts supplied by the resource managers is difficult and costly. But establishing this link is crucial to those who are paying and ultimately for the success of the PES concept. By reviewing the literature on this topic and analysing in a systematic way what types of measurement problems there are, we will show that the type of monitoring that is required within a PES has consequences for the institutional arrangement needed for a successful PES. We find that the institutional arrangements for monitoring vary according to (i) the type of environmental service and its underlying production process; (ii) the extent to which the environmental service can be freely observed or measured; (iii) the extent to which activities of the resource managers who provide the environmental service can be freely observed; and finally (iv) the deterministic or stochastic nature of production processes.
Keywords. PES; monitoring; measurement; institutional arrangement

INTRODUCTION

There is an increasing interest in Markets for Environmental Services (MES) as an approach to integrate economic growth, ecological integrity and poverty reduction goals (Hope et al. 2005; Landell-Mills 2002). Most come down to payments for environmental services (PES) where the ‘demand side’ is often the government (Kumar 2005). These environmental services have a public-good nature, governments have usually taken up the responsibility of maintaining them. Many PES schemes are funded by development agencies or rural-development programs, reflecting a combined goal of poverty alleviation and conservation of environmental services. However, recent research has shown that the poverty impact of PES is

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often mixed at best and may benefit the wealthier who have more natural assets (e.g., large landowners) (Landell-Mills 2002; Hope et al. 2005; Pagiola et al. 2005; Zbinden and Lee 2005; Grieg-Gran et al. 2005; Zilberman et al. 2006).

The idea of PES has an appealing simplicity, which may also account for its success in recent years. Proposals to apply PES for various goals abound. Successfully implemented PES schemes are far fewer though. Wunder (2005) identifies two key obstacles. The first obstacle is limited demand: too few service users are so confident about the mechanism that they are willing to pay – in some cases, because the link between land use and environmental services (ES) provision is insufficiently understood or ambiguous. The second obstacle is poor knowledge on the institutional requirements entailing incentive and livelihood mechanisms which so far have received comparatively little attention.

Wunder (2005, p. 3) defines a PES as: "a voluntary transaction where a well-defined ES (or a land use likely to secure that service) is being 'bought' by a (minimum one) ES buyer from a (minimum one) ES provider if and only if the ES provider secures ES provision (conditionality)". The last requirement on conditionality is the focus of our paper. It is an extremely important one because it ties in with the first obstacle mentioned by Wunder. As Pagiola and Platais (2005) state: "If services aren't delivered, people won't pay". Demonstrating that ES are in fact provided entails establishing a biophysical link between land uses and ES outcomes and developing suitable methods for measuring and monitoring provision of the service. The lack of information to link changes in practices to increased provision of environmental services remains the 'Achilles heel' for most PES programs (Pagiola et al. 2002).

It seems that poverty considerations may lead to disregarding this conditionality: "… most implementers seem to shy away from the business-like feature of only paying the providers if they actually deliver the agreed-upon service. In general, they are too concerned about disrupting their relationship with poor rural farmers to withhold payment" (Wunder 2006; see alsoScherr et al. 2006; Wunder et al. 2005; Hartmann 2004). Ironically, the concern of the implementers (mostly governments or donor agencies) with the livelihoods of poor rural farmers and ignoring the effectiveness of PES programs may compromise the long-term success of PES, jeopardizing the potential benefits of PES for these farmers.

Another important reason why many PES schemes have poor monitoring schemes is that it is often difficult to measure environmental services and to establish a cause–effect relationship between land use and the services (FAO 2004). Relationships among management practices on specific farmers, effects on environmental services, and benefits derived from these services are often complex and not completely understood (Claassen and Horan 2000; Kleijn 2006). Therefore, good science is important (Pagiola and Platais 2005), with models that can determine cause–effect relationships and predict and quantify environmental services. PES schemes intend to establish an information flow between service providers and users to facilitate the market exchange between both types of agents (FAO 2004). Ferraro (2005) also notes that hidden information (adverse selection) is a problem in all PES contract settings.

The economic literature on moral hazard and monitoring in agri-environmental schemes (Hart 2005; Fraser 2002; 2004; Ozanne et al. 2001) bases monitoring and payment on the *activities* of farmers as specified in the contract. Clear and measurable indicators for the environmental services are often lacking as well as a clear link between the agricultural practices and their effect: “most of Europe’s agri-environment schemes have very vague goals, such as to ‘prevent damage to the environment’ or ‘provide wildlife habitats’. Specific targets are not set; progress is rarely monitored; the baselines from which they start are not defined. The good that they do is thus hard to measure, which in some eyes makes the schemes hard to justify” (Whitfield 2006, p. 908). When a study evaluated these agri-environmental schemes and found them to be less effective than assumed (Kleijn et al. 2001), this led to a storm of discussion and possibly to reduced funding for such schemes (Whitfield 2006). In a follow-up project on evaluation of agri-environmental schemes, one of the conclusions was that “insights into cause and effect are important for the design/re-design process, for which monitoring and clarity of objectives are key” (‘EASY’-project 2006).

We will analyse the issues of measuring environmental services and monitoring the activities of resource managers. By reviewing the literature on this topic and analysing in a systematic way what types of measurement problems there are, we will show that the type of monitoring that is required within a PES has consequences for the institutional arrangement needed for a successful PES[1]. Monitoring is only one aspect of the institutional design of PES, and so far, it has received comparatively little attention. We shall not focus on other important aspects of institutional design of PES, such as property rights, the necessary legal framework, contract type and length, and hidden information. There is a growing amount of economic literature devoted to this, often making use of principal-agent theory (Rojahn and Engel 2005; Engel and Palmer 2005; Ferraro 2005; Rojahn 2006 and other articles in press which are not yet for citation). More literature is available on agri-environmental schemes (Moxey et al. 1999; Ducos and Dupraz 2006; Ozanne et al. 2001; Fraser 2002; 2004; Hart 2005 to mention some recent literature). Other literature focuses on predicting the supply of environmental services, which can incorporate heterogeneity of opportunity costs and can thus be used to address the hidden information problem (Antle and Valdivia 2006; Antle and Stoorvogel 2006).

THE ROLE OF MONITORING IN PES

In general, a PES scheme includes certain economic agents (resource managers or farmers) who manage resources that provide a positive environmental externality or environmental service. This environmental service benefits another group of people, which can be a specific group of people or society as a whole. These beneficiaries can be labelled as the ‘service demand side’ or buyers. For simplicity and following principal-agent theory, we will hereafter call the service providers ‘agents’ and the service demand side the ‘principal’, except in cases where we want to describe the type of agent or principal. In many cases the government, representing the interests of the beneficiaries, acts as the principal. We therefore assume there is only one principal and refrain from cases where there are multiple principals entering into contract with one or more agents. We also assume that agents face the same opportunity costs and are symmetric in their influence over the production of the environmental service, although we will relax that restriction at the end[2]. The agents and principal agree on a contract which specifies the actions that the agents should undertake and the payments terms. The principal expects the actions of the agent to lead to certain environmental services, for which she is prepared to pay. The payments cover at least the opportunity costs of the actions implemented by the agent, satisfying the participation constraint.

Transaction costs play an important role in PES schemes. Transaction costs are often underestimated and may undermine the viability of a PES scheme (Landell-Mills and Porras 2002). Therefore the setup of any PES scheme must aim to reduce transaction costs. This can be achieved by choosing the most appropriate institutional setup (Eggertsson 2005). Within institutional economics three sources of transaction costs can be distinguished, viz., contact, contract and control (North 1990, p. 28-33):

1. Contact entails the cost of measuring the valuable attributes of what is being exchanged. Individuals engaged in a transaction need to know what they are buying. In case of simple products, such as oranges, the cost of getting information about the product is low. In the case of PES, the cost of getting this information can be high, as was outlined in the introduction.
2. Contract entails the costs of protecting rights. Property rights of individuals over assets consist of the rights, or the powers to consume, obtain income from and separate from these assets. Exchange involves the mutual ceding of rights. The rights people have over assets are not constant; they are a function of their own direct efforts at protection, of other people's capture attempts, and of government protection (Barzel 1989). PES schemes require the allocation of titles *de jure* or *de facto* on environmental externalities benefiting third parties (environmental service). Protecting rights over environmental services can involve high costs because of their transient nature.
3. Control entails the costs of policing and enforcing agreements. Enforcement poses no problems when it is in the interest of the other party to live up to agreements. But without institutional constraints, self-interested behaviour will exclude complex exchange because of the uncertainty that the other party will find it in his or her interest to live up to the agreement. This conflict of interest coupled with asymmetric information gives rise to contract theory. There are two sources of asymmetric information: when the agent can take an action unobserved by the principal there is moral hazard or hidden action, and when the agent has some information about his cost or valuation that is ignored by the principal there is adverse selection or hidden knowledge (Laffont and Martimort 2001).

This paper focuses mainly on the last source of transaction costs. In contract theory, the solution to moral hazard is the internalizing of incentives, via the contract terms while the solution to an adverse selection situation involves offering several alternative contracts, and the agent's choice between these alternatives reveals his private information (Macho-Stadler and Pérez-Castrillo 2001). Many of these models assume that the final outcome can be measured and can be attributed to effort. Monitoring in these models is often costless. Incorporating the right incentives into the contract is therefore key while monitoring usually plays a minor role, although some models do not assume costless monitoring and the use of (external) auditors play a role. When monitoring is not costless, Demougin and Fluet (2001) show that monitoring and incentives can be either substitutes or complements in a moral-hazard situation, depending on the circumstances. Monitoring includes the direct supervision of the agent (i.e., the agent's actions) as well as the use of output-related performance indicators when this is relevant. Demougin and Fluet (ibid.) suggest that the principal will presumably need to combine signals from various sources, taking into account the cost and informativeness of the signals.

Although there is a wide range of economic literature on enforcement (see Polinsky and Shavell 2000 for an overview), monitoring and enforcement have often been ignored by both academics and policy-makers when discussing environmental-policy alternatives (Cohen 1999). In the economic literature on enforcement, the principal's problem is to choose enforcement expenditures (or equivalently, probability of detection through monitoring), the level of fine, the standard for imposing liability and, if relevant, the imprisonment term. Because there is a trade-off between the level of fine and enforcement expenditures, the principal can reduce monitoring costs by imposing high fines (Becker 1968). In PES schemes, the voluntary nature limits the range of punishment mechanisms. Either they do not exist at all (see Wunder et al. 2005) or they are limited either to decreasing payments or to ending the contract completely. In some PES schemes, payments are made to communities in the form of community social support, such as building a road, giving access rights or any other royalties, or building a new school or health centre (Rosa et al. 2003; Van Noordwijk et al. 2004). However, this undermines the conditionality of payments as these cannot be taken away when environmental services are not supplied. We will therefore assume that payments are made contingent and that non-compliance leads to reduction or discontinuance of payments. Finally, information gathered from monitoring serves as the basis for enforcement.

In agri-environmental schemes in Europe and the USA, the possibility of a fine is often included (Ozanne et al. 2001), but because many PES schemes in developing countries aim to enhance rural development and reduce poverty, imposing a fine on poor resource managers in addition to withholding payments might be considered inappropriate. Thus, in most PES schemes there is no additional fine and the 'punishment' consists of reducing payments, which is of a limited range. This can be modelled as limited liability. Given that there is a trade-off between the level of fine and level of enforcement or required monitoring, this implies that monitoring and enforcement expenditures cannot be decreased much.

Three main environmental services can be distinguished (Landell-Mills and Porras 2002)[3]; these categories are also used by Rohjan and Engel (2005):

- Biodiversity conservation
- Carbon offset
- Watershed protection.

Rohjan and Engel (ibid.) categorize these according to production technology. We will do the same but in a slightly different manner. Our criteria are twofold and linked to monitoring of input (activities implemented by the agents) and outcome (the environmental service). The first criterion is thus at the level of the activities where we make a distinction between those services whereby the individual activities can be measured independently and those whereby the activities influence each other, i.e., the activities of one agent affects the activities or outcome of another agent. The second criterion is at the level of the outcome, where a distinction is made between those services that can be attributed to an individual agent and can thus be monitored per agent, and those services that are pooled or joined. This classification is illustrated in Figure 1. Following Rohjan and Engel (2005), we characterize environmental services that can be supplied through an independent, a joint additive or a joint multiplicative production function. One square (bottom left) is left empty because it is technically not possible that a production function is characterized by interdependence but its outcome is not.

		Outcome: environmental service	
		Individual	**Joint**
Input	**Individual**	Production function: *Independent* Example: Carbon offset through tree planting	Production function: *Joint additive* Example: Groundwater management, watershed protection, decrease of run-off
	Group		Production function: *Joint multiplicative* Example: biodiversity conservation through joint forest management or through agri-environmental management practices

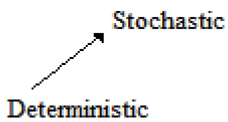

Figure 1*. Classification of environmental services according to measurement of input or outcome*

A third dimension is added in the figure and that is whether the link between input and outcome is deterministic, which means that the outcome is completely determined by the activities implemented by the agent, or whether it is stochastic, and that the outcome is influenced by natural processes such as climate. Most environmental services are more or less influenced by natural processes, and thus the agent has no complete control over the outcome. Generally, in a market, buyers of a good or service pay for the good or service itself, and do not care how much effort was put into the production[4]. When you buy bread from the baker you are not interested in how much effort the baker put into it, you care about the bread you buy.

Similarly, buyers of environmental services presumably therefore care only about the outcome of the production process, and not about the activities the resource managers have put into this. Thus, buyers on the environmental-services markets would pay a certain price for each tonne of carbon offset, cubic metre of water supplied downstream, tonne of sedimentation reduced and number of rare species protected. This would suggest that monitoring would only need to be done at the outcome level. But this is only possible when the production process of environmental services is almost completely deterministic and the cause–effect relation between input and outcome is clear. Since it is not, monitoring is necessary of the activities implemented by the agents.

The stochastic nature of the provision of environmental services thus includes a certain amount of risk. It is possible that certain activities have been implemented (at a certain cost), but that natural processes reduce the outcome. For instance, resource owners are paid to conserve a forest, but this forest is destroyed by natural forest fires. In some cases, climatic conditions render the activities implemented by the agents ineffective. To illustrate this case, farmers are paid to implement soil and water conservation to reduce soil erosion, but in a year with little rainfall there is little erosion anyway and the effectiveness of these structures is negligible. These effects are to some extent measurable – it is easy to verify whether there has been a fire, or the amount of rainfall. But in other cases the exact link between activities implemented by the agents and the environmental service is not clear because the natural processes are not well understood.

The stochastic nature of the production of environmental services means that there is a production risk. Who should bear this risk, the agents or the principal, depends on the contract. Especially when the agents are poor and are vulnerable to financial insecurity the balance should be carefully considered. Rojahn and Engel (2005) discuss the role of risk through environmental processes in optimal incentive contracts (see also Ozanne et al. 2001; Fraser 2002). They observe that the general structure of PES contracts should be a two-part linear payment. The two parts of the payment scheme are a fixed compensation and a variable payment based on the produced amount of the environmental service. They serve to balance risk and reward. In general, risk and risk aversion on the part of the agent increase the risk premium of the agent and in that way their cost of supplying the environmental service. We will not discuss the role of risk further, although we acknowledge that risk and risk aversion are important aspects in designing PES contracts.

INDEPENDENT PRODUCTION FUNCTION

An example of an independent production function is tree planting to provide the service carbon offsetting. The activities of the resource manager planting the trees can be easily observed. The outcome, reduced carbon in the air, cannot be observed easily. Nevertheless the link between the number of trees and the amount of carbon offset is clear and can be measured easily, thus we can safely interpret this as the outcome being easy to measure.

In the simplest case, three criteria are satisfied: (i) the production function is independent; (ii) the link between input and outcome is clear; and (iii) both input and outcome are measurable, and a simple institutional arrangement will probably do. A contract or agreement will specify certain (measurable) targets that need to be met, which can then be verified by the principal with negligible transaction costs. PES schemes are often portrayed in these terms, but this simple case is rare in reality. Even in situations with an independent production function shown in Figure 1, such as tree planting, the principal must make some costs to verify input or outcome. Especially in a PES scheme in which many agents participate, the sum of all monitoring costs can be substantial, let alone the enforcement costs. Monitoring costs can be reduced by using techniques such as remote sensing, which will cover many agents. The number of trees planted and amount of carbon sequestration can be monitored by, e.g., remote-sensing techniques (Vincent and Saatchi 1999), which will reduce monitoring costs per tree planted. Another approach can be to work with groups of agents, where the agents monitor each other and the principal monitors the group and holds the group accountable for the input and outcome. Ghate and Nagendra (2005) for instance examine the impact of the institutional structure on monitoring and on the effectiveness of forest management in India. They find that local enforcement (i.e., by the agents themselves) has been most effective in the case where forest management was initiated by the communities. However, this approach brings about potential problems of free-riding within a group, and specific solutions must be found for this problem. We will discuss group monitoring below under joint additive production function.

When outcome can be observed easily but input cannot, there is a moral-hazard situation. In general, in principal-agent models with moral hazard, if the principal observes the outcome but not the action, she can design a payment rule for the agent, based on the outcome, that provides the latter with appropriate incentives to act (Singh 1985). Monitoring is therefore often excluded from principal-agent models. However, Grossman and Hart (1983) in their seminal paper on moral hazard, acknowledge that the assumption that the principal cannot monitor the agent’s actions at all, may in some cases be rather extreme. In such cases, imperfect monitoring of the activities or effort of agents plays a role. Choe and Fraser (1998) and Ozanne et al. (2001) for instance include the option of imperfect monitoring in agri-environmental schemes[5]. They find that risk aversion of farmers plays a role. Risk here is defined differently from above, when risk was linked to the stochastic nature of the provision of environmental services. In this literature, risk is linked to the possibility of being monitored. Choe and Fraser (1998), Ozanne et al. (2001) and Fraser (2002) analyse the potential trade-off between increased environmental benefits and increased cost of monitoring compliance. They find that higher degrees of farmer-risk aversion result in a reduction in the severity of the moral-hazard problem. The ability of compliance monitoring to resolve the moral-hazard problem effectively is therefore largely determined by the degree of risk aversion displayed by the agents and the cost structure of the monitoring process.

In the case of independent production, it is not often the case that the input activities of agents can be observed but outcome cannot. Due to the character of independent production, the outcome arises at the same locality as where the input measures are implemented and is therefore usually observable.

JOINT ADDITIVE PRODUCTION FUNCTION

A joint additive production function resembles the independent production function in that each agent contributes to the environmental function independently. But with joint additive production, the combined efforts of several agents produce a joint outcome. For instance, if several farmers reduce pumping of groundwater, the overall water level will rise. We assume here that the contribution of each agent is symmetric and additive. Thus if the outcome is lower than expected or specified in a contract, the principal knows that one or more agents have not contributed. The principal can only find out who by inspecting each agent. If the group of farmers is large, then the costs of inspecting each agent will rise accordingly.

This seems to be another moral hazard problem for which the solution is a contract that entails the right incentives to overcome this problem. But the common assumption in moral hazard is that outcome is freely observable and sufficiently informative about the agent's effort to warrant using it for contracting, which in the case of joint additive production is not tenable. In the above case, for instance, the outcome (overall water level) is not sufficiently informative about the individual agent's effort. In this case, some form of monitoring becomes necessary (Singh 1985; Baiman and Rajan 1994). The question now is how the principal should monitor the contribution of the agents. In a joint additive production function, it is possible to monitor the individual activities of the agents and the joint outcome, be it at a cost. There are two alternatives. The first is that the principal inspects all agents to determine who is shirking, and the second is that the principal contracts a group of agents and leaves it to the group of agents to monitor each other. We assume here that the activities of the agents can be observed, be it with (varying) cost.

Principal inspects agents

This situation leads to another form of asymmetric information, about the form and type of monitoring. The principal for instance may know when she will inspect the agent, but the agent does not. We will illustrate and analyse this problem by game theory. Inspection games have been applied to various problems, ranging from arms control to environmental regulation (Avenhaus et al. 2002) but could be applied to monitoring in PES too. We will briefly describe a simple inspection game (described in Fudenberg and Tirole 1991) and will then describe some extensions and their implications for the institutional setup.

We assume that there are two players, an agent and a principal. The agent can play two strategies – cooperate (stick to the agreement, denoted by C), or shirk (S). The principal has the choice to monitor and inspect the agent (I), or not to inspect (NI). The pay-offs to the agent and the principal depend on the costs of abiding by the agreement for the agent (*c*), which can be interpreted as the opportunity costs the agent needs to make to implement the contract, the value of the environmental service (*v*), the costs the principal needs to make for monitoring (*m*) and the payment the agent receives when he abides by the agreement (*p*). If the agent shirks and is detected by the principal he receives no payment. Satisfying the participation constraint means that $p > c$, otherwise the agent would not enter the contract. In many PES schemes, agents are paid only for their opportunity costs[5], which would imply that $p - c = 0$. This means that the agent is indifferent between entering the contract or not. To ensure participation however, we assume that *p* is slightly higher than *c*. The pay-off matrix is shown in Figure 2[7].

Agent \ Principal	I	NI
S	0, *m*	*p*, - *p*
C	*p* - *c*, *v* - *p* - *m*	*p* - *c*, *v* - *p*

Figure 2. *Pay-off matrix for monitoring game*

This game can be interpreted as a two-move or sequential game, in which the agent moves first, deciding whether to cooperate or shirk. The decision is made on the agent's expectation about being inspected by the principal. The move made by the agent is not observed by the principal, who decides after the move by the agent to inspect or not. The principal does not know whether the agent has cooperated or shirked. If the agent is found to shirk, the principal needs only to bear the monitoring costs (*m*) because the agent is not paid (receives 0). If the agent is found to cooperate, the principal needs to pay a reward plus bear the monitoring costs, and receives the environmental service (*v*-*p*-*m*). However, if the principal does not inspect and the agent shirks, the principal confers a payment (-*p*) which the agent receives (*p*), but there is no environmental service provided (0). If the principal does not inspect and the agent does cooperate, the target level is achieved and a reward is made (*v*-*p*) to the agent, who receives a payment minus costs made (*p*-*c*).

The preferred strategies of the principal and agent depend on the monitoring costs *m*, payments *p*, costs of input *c* and value of environmental service *v*. If we assume that the monitoring costs are very high and larger than the payments made to the agent ($m > p$), then the principal would prefer not to inspect. If the agent is aware of this, he will choose to shirk, and the equilibrium outcome is (S, NI). Clearly this would undermine the PES scheme. If we assume that monitoring costs are not very large (at least smaller than the payments made to the agents) there is no pure strategy equilibrium for this game. If the principal does not monitor, the agent would prefer shirking. Therefore, the principal is better off by monitoring. However, if the agent knows the principal is guaranteed to monitor, and the agent will therefore choose to cooperate, the principal is better off by not inspecting (thus saving monitoring costs). The solution is a mixed strategy, which means that the principal must randomize, so that the probability of monitoring is between 0 and 1. Similarly, the agent must randomize, which means that his probability of cooperating is between 0 and 1. Thus it depends on the probabilities of the fact that the principal will monitor the agent's compliance that determines whether an agent will cooperate or shirk. Mixed strategies are not as intuitive as pure strategies because people do not take random actions. A mixed strategy here can be interpreted as a principal and a number of agents, where the principal selects at random an agent to monitor, with a certain probability. Vice versa, each of the agents chooses to shirk some x percent of the time, and cooperate 100 – x percent of the time. Then x/100 is the probability that an agent will shirk (Rasmusen 2007).

Avenhaus et al. (2002) discuss several variations of the inspection game. In the simplified game above, it is assumed that if there is an inspection, the principal knows whether the agent has shirked or not. However, in practice, this may not be easily verifiable and there may be measurement problems on the input side, while the outcome is difficult to measure, or does not reflect the input (the production function is stochastic). The game is extended with the possibility of the principal inspecting, making an error and calling a *false alarm*, accusing the agent falsely of shirking[8]. The pay-offs of this option depend on the situation. If the agent can show that the principal accused him wrongly, the pay-off to the principal can be a penalty to be paid to the agent. If, for instance, the detection of a shirking agent represents a 'failure of safeguards' and the principal would prefer to avoid such a bad reputation this could be seen as an additional cost. This makes it unattractive for the principal to monitor.

The above game has been modelled as a one-off game, which can, of course, be played several times. However, sequential games may have different implications. Dresher (1962) introduced an inspection game with a number of stages which can be defined as recursive models. Thus the information problem that existed in the above game is partly solved, because the principal and the agent know what each did in the previous round and can base their expectations on this. Avenhaus et al. (2002) discuss this game and combine it with the leadership principle, which states that it can be advantageous to announce one's strategy and then commit to playing it. This ties in with the 'optimal' contract of Fudenberg and Tirole (1991), which maximizes the pay-offs for the principal and agent. They show that when the principal commits to a monitoring level (i.e., the principal chooses and announces a probability *y* of inspection), the principal and the agent can actually increase their pay-off. The principal needs to set the probability of inspection *y* at a level whereby the agent will always choose to collaborate (i.e., probability of cooperation is 1).

Another interesting variation of this game is explained by Rasmusen (2007)[9]. An institutional arrangement is possible whereby the principal does not inspect herself but hires an 'auditor'. The principal now has an additional asymmetric information problem with the auditor because she does not know whether the auditor will report truthfully or not. The auditor may receive side-payments from the agent not to report shirking or may save on monitoring costs and report that the agent is cooperating without verifying this. This may be a genuine problem in developing countries, where the institutional framework for resorting to legal action may involve high transaction costs. There are various optimal auditing schemes explored in game theory and principal-agent theory (see Dittmann 1999). One of them includes the idea of cross-checking whereby the principal hires a second auditor and asks him to report simultaneously. If both auditors report the same they are rewarded, but if they report different values they are both punished. This is a solution that will increase truthful reporting, and although monitoring costs will obviously increase by hiring two auditors, this may be the cost that needs to be paid to get information (Dittmann 1999).

Agents monitor each other, principal monitors group

The principal may prefer to establish a contract with a group. This makes it possible for the principal to reduce monitoring costs by transferring these costs to the agents. This is appropriate when monitoring costs are high for the principal but lower for agents. One could think of agents who are neighbours and who can easily observe each other's activities. The principal can then choose to inspect the group, which brings us back to the above situation, where the group can be considered as one agent.

Establishing a contract with a group of agents has a fundamental difference with the principal-agent relationship in the sense that group relationships entail the problem of free-riding since the effect of a reduction on effort (e.g., the principal punishes the whole group) is shared by all agents (Macho-Stadler and Pérez-Castrillo 2001). This problem can be modelled as a non-cooperative game, whereby the players choose between the strategy 'cooperate' and put in the required effort levels, or 'shirk' and free-ride on the other agents. There are two conditions that enable an agent to free-ride: first, the principal cannot detect who is free-riding and second, the principal pays the group of agents according to outcome and this is shared equally between group members.

The extent of the free-rider problem thus depends on the measurability and observability[10] of the agents' efforts. This model assumes that agents will always try to shirk when it increases pay-off. It is interesting that in social-psychology literature, various other motivational reasons for shirking ('social loafing') have been found, such as the lack of identification of individual contributions in a group effort, difficulty to establish a relationship between input and output, and a minimum of evaluation potential (Vermeulen and Benders 2003). This suggests that measurement difficulties and the complexity of input–outcome relations in PES actually contribute to shirking in groups!

If agents monitor each other they can only reduce free-rider behaviour if they also have the means to enforce cooperative behaviour. If they do not have these means, they can detect free-rider behaviour but cannot do anything about it, leaving the principal with a reduced outcome. Such a PES setup would not work: when monitoring and enforcement of activities are very costly, the situation can become a prisoners' dilemma game. In this game, we assume two players, agent 1 and agent 2. If they both cooperate, they obtain the highest payment (p) from the principal, which both share. Their net pay-off is this pay-off minus the costs (c) they make to implement the contract, where $½p - c > 0$ (participation constraint). If one player cooperates and the other one shirks, they receive a reduced pay-off, the total payment reduced by a fine for instance, (*p*-*f*) where $p > f$ (the fine is always smaller than the payment), which they share. Since the one who shirked did not make any costs, he will receive a higher net payment. If they both shirk, they get no payment. See Figure 3 for the game.

Agent 1 \ Agent 2	C	S
C	½p - c, ½p - c	½(p - f) - c, ½(p - f)
S	½(p - f), ½(p - f) - c	0 , 0

***Figure 3**. Prisoners' dilemma*

Because $\frac{1}{2}(p - f) > \frac{1}{2}p - c$, both players will choose strategy S (shirk) and end up not receiving any payments. This situation only occurs when the principal cannot detect who shirked, and the players cannot enforce cooperation or punish each other for shirking. However, in reality, this situation usually does not occur, and agents can enforce cooperation (Hargreaves Heap and Varoufakis 2004). Agents would not enter into a group contract if they could not enforce cooperation. Enforcement mechanisms do not need to take the form of punishment such as imposing a fine. There are various reasons why people will cooperate. This can be morality (people do what is morally right regardless of what others do), altruism (people are selflessly willing to contribute to a public goal) or inequality aversion (people feel guilty when they disadvantage others). However, Barron and Gjerde (1997) find that what they call 'peer pressure' does not always have a positive outcome when agents engaged in group production can detect and punish shirking (see also Kandel and Lazear 1992; Huck et al. 2002 on peer pressure). They describe for instance that there may be a conflict between the principal and the agents as to the optimal norm or sanction. The potential punishment agent 1 imposes on agent 2 benefits 1 if it induces greater effort by 2. But agent 1, unlike the principal, may not take into account the cost of such punishment in terms of deterioration of the work environment or psychological cost (such as guilt) for agent 2.

Enforcement in terms of imposing a punishment on the other player is made possible when the prisoners' dilemma is played several times. The strategic behaviour of the players can change because in this case, players do get information on what the other players are likely to do and can punish the other player. In fact, the optimal strategy is now 'tit-for-tat' (Axelrod 1984), which implies that a player (1) should play cooperatively in the first round, thus signalling to the other player (2) he is willing to cooperate. If player 2 reciprocates and also plays cooperatively, then both will get the highest pay-off. If they continue to do this, they will receive the highest pay-off for the entire game. However, if player 1 tries to maximize his pay-off at the expense of 2 (and defects), then 2 will punish 1 by defecting in the next round and both players find themselves in the sub-optimal pay-off situation (see also Radner 1981; Barron and Gjerde 1997). There are several variations of this repeated game that also take into account the discount factor of the players.

Several authors have analysed the role that punishment, trust and reciprocity play within game theory (Carpenter et al. 2004; Cox 2004; Engle-Warnick and Slonim 2006; Brosig 2002; Gintis 2000) and in common-pool resource settings (Castillo and Saysel 2005; Cárdenas and Ostrom 2004). Repeated cooperation leads to players acquiring a reputation of being cooperative. This leads to trust, other players expect a player with a reputation of being cooperative to be cooperative also in the future. They then feel confident to reciprocate and also cooperate. The more repeatedly cooperative behaviour is displayed, the higher levels of trust are attained. However, if players defect and obtain a reputation for being cheats, other players lose trust in them and will no longer be willing to cooperate. The more a player cheats, the less cooperation will be achieved.

JOINT MULTIPLICATIVE PRODUCTION FUNCTION

A joint multiplicative production function is characterized by the interdependence of production functions of different agents. Besides the fact that natural processes play a role, the activities of the agents influence each other. Their combined activities, no longer independent, lead to a joint outcome. For instance, the effect of the activities implemented in a certain field under an agri-environmental scheme that aims at improving biodiversity (plants, birds etc.) depends very much on what happens in neighbouring fields. The implementation of agri-environmental schemes on a small number of interspersed fields, as compared to a scattered distribution of isolated fields, can improve the effectiveness of conservation measures by providing stepping stones for species dispersal (Kleijn 2006). Parkhurst et al. (2002) explored the possibility of achieving adjoining fields through an agglomeration bonus.

If it is not just a matter of joining fields but if specific activities of adjoining agents influence each other, it makes sense to contract a group[11] so that agents can coordinate activities. However, this type of group will be slightly different from what we discussed in the previous sections and has been labelled team production. As Robbins (1996, p. 293) described team production: “One of the truly remarkable things about work groups is that they can make 2 + 2 = 5. Of course, they also have the capability of making 2 + 2 = 3”. The difference with the type of groups we described above is that these make ‘2 + 2 = 4’. In team production the individual contributions add up to 5 or 3. Who contributed to the additional unit gained or lost is not clear. Alchian and Demzetz (1972, p. 779) were the first ones to describe team production: “With team production it is difficult, solely by observing total output, to either define or determine each individual’s contribution to this output of the cooperating inputs. The output is yielded by a team, by definition, and it is not a sum of separable outputs of each of its members”. Alchian and Demsetz thus make a distinct separation between joint additive and joint multiplicative production functions (p. 779):

"Team production of Z involves at least two inputs, X_i, and X_j, with $\partial^2 Z / \partial X_i \partial X_j \neq 0$. The production function is not separable into two functions each involving only inputs X_i, or only inputs X_j. consequently there is no sum of Z of two separable functions to treat as the Z of the team production function. (An example of a separable case is $Z = aX_i^2 + bX_j^2$ which is separable into $Z_i = aX_i^2$ and $Z_j = bX_j^2$ and $Z = Z_i + Z_j$. This is not team production.)".

Thus, joint additive production is not team production. After the seminal paper of Alchian and Demsetz, team production has been analysed by several authors (specifically Holmström 1982; McAfee and McMillan 1991) and has been applied to many different settings.

Alchian and Demsetz emphasize that in team production the marginal products of cooperative team members are not so directly and separably (i.e., cheaply) observable. Because measuring each agent's marginal productivity and making payments in accordance to this is much more costly than under joint additive production, monitoring of activities is no longer feasible. Some authors have studied team production with the possibility that agents *can* monitor each other (Kandel and Lazear 1992; Barron and Gjerde 1997; Moisan-Plante 2003). If this is possible, we are back to the group setting discussed above, where team members can use different sticks and carrots (or peer pressure) to enforce cooperation.

If we take the strict definition of team production however, and assume that it is not possible to observe the cooperation (i.e., marginal productivity) of team members, neither the principal nor the agents can enforce cooperation based on monitoring individual input. This again runs the risk of becoming a prisoners' dilemma in which the Nash equilibrium is shirking by all players. Holmström (1982) has shown that under certainty[12], team incentives alone can remove the free-rider problem. Such incentives require penalties that waste output or bonuses that exceed output. The principal either enforces penalties or offers bonuses. This role is what Holmström calls 'breaking the budget-balancing constraint'. The free-rider problem is not only the consequence of the inability to observe actions, but equally the consequence of imposing budget-balancing. Breaking the budget constraint will permit team penalties that are sufficient to police all agents' behaviour. For a PES scheme, it could be envisaged that agents are paid a flat-rate minimal compensation fee and are given a team bonus to be paid if a certain target is obtained. Imposing a penalty can be interpreted in several ways. In a dynamic context, which most PES schemes find themselves – the agreement between a principal and an agent's cooperation runs several years – the penalty can be a threat to discontinue cooperation. Holmström (ibid.) shows that enforcing team penalties cannot be imposed by the team itself. When less than the target level is produced, it is not in the interest of any of the team members to waste some of the outcome on a penalty. So when it is expected that the penalties will not be enforced, the free-rider problem reappears, because the situation is again similar to the budget-balancing one. Therefore the enforcement problem can only be overcome by bringing in an outside party (principal) who will take on the residual of the non-budget-balancing sharing rules.

Although the role of the principal as a budget breaker is certainly a solution to the free-rider problem in the case where agents' activities cannot be monitored, Rojahn and Engel (2005) point out that this type of collective punishment has several disadvantages. Most importantly, it might be perceived as unfair because it could lead to a situation where complying agents are forced to make up for their free-riding agents to avoid punishment. Bowles (2004) adds to this that when there are significant stochastic influences on the level of performance of the team, which is very possible in PES schemes, Holmström's solution becomes unfeasible. However, it is difficult to find an alternative solution to the case where shirking cannot be detected, and this is why Holmström's contribution is so important.

A more fundamental point of criticism is that Holmström's model assumes that the principal and the agents have conflicting interests. However, one could assume that agents will not enter into a voluntary PES contract under a team production scheme when they do not agree with the goals the principal has set. This will be true for some PES settings, especially when PES contracts only pay the opportunity costs such as in many agri-environmental schemes in Europe. Changing the conflicting-goals assumption changes the uncooperative situation to a cooperative model. More recent literature analysed moral hazard with several agents under a cooperative model (see Che and Yoo 2001 for an overview).

Macho-Stadler and Pérez-Castrillo (1993) analyse such a model and explore a situation in which cooperation between agents is possible and not detrimental to the principal's interests. The effort supplied by each agent is not observable, but outcome can be measured. The degree of cooperation between agents depends on both the incentive scheme they face, and the extent to which there exists a group culture that makes it possible for group members to commit credibly to the implementation of cooperative solutions. The authors make a distinction between groups and teams, similar to Alchian and Demsetz (1972) and in line with the distinction between joint additive production and joint multiplicative production. A team consists of a number of agents who, due to their continuous and close relationship, can reach cooperation on non-verifiable variables such as collaboration and effort. Macho-Stadler and Pérez-Castrillo (ibid.) show that a team is more profitable for the principal than a group of individuals without any commitment capacity.

Cooperation between agents thus depends on whether there exists a group culture or cohesion within a team. This can be achieved by the incentive scheme. According to Harkins et al. (1980; cited in Vermeulen and Benders 2003) rewarding and punishing agents should be based on group outcomes because the individual efforts are not visible. Group rewards are seen as an important determinant for cohesion, as collective rewards increase the 'group feeling'. Itoh (1991, p. 613) analyses the role of cooperation in teams, in the form of help that agents give each other, and finds that: "… teamwork is optimal if own effort and helping effort are complementary so that an agent responds to an increase in help from the other agent by increasing his own effort". An institutional arrangement that stimulates cooperative behaviour can initiate a positive sequence of cooperative behaviour. 'Help' as described by Itoh can take the form of sharing experiences and learning in a PES scheme, which will enhance trust but can also stimulate learning on how best to provide the environmental service together. Case studies in the area of the provision of water-related services by farmers in the Netherlands have demonstrated that interactive learning processes among area-based stakeholders can function as an effective governance mechanism in the water sector (SLIM 2004a; b).

Macho-Stadler and Pérez-Castrillo (1993) find a trade-off between benefits of team size for the principal and agent. If the team reaches a symmetric equilibrium and shares the payments equally, then the expectation of the average wage level of an agent belonging to a team is a strictly decreasing function of the team size. This means that the larger a team is, the more attractive it is to the principal. However, it is possible that the cooperation capacity of the group of agents is a decreasing function of its size. The trade-off between both effects will determine the optimal size of the group (from the perspective of the principal). Olson (1965) has put forward that in collective action (e.g., team production), smaller groups can function more effectively than large groups.

The last case we will briefly discuss here is when joint output is costly to observe and input may also be costly to observe. We have not found many models that incorporate these restrictions. Gautier (1999) developed a model in which the agents and principal invest together to develop a product (in our case a certain environmental service). Agents are responsible for the production of the service, and the principal invests in monitoring. The level of effort by the agents is private information to each agent. The efforts determine, together with a random shock, the output's value. This value remains unknown until the product is brought on the market. Hence there is a time lag between input and outcome. For PES this can be a relevant model, as the outcome of activities implemented by resource managers often only appear after a certain period (in the case of watershed services appearing downstream, or number of birds after the breeding season) and are influenced by natural processes (which can take the form of a random shock). In the model, the principal can observe a signal about the outcome's quality. The accuracy of the signal is affected by the principal's monitoring decision. Without monitoring, the signals are distorted. By investing in monitoring, the principal can observe perfectly informative signals. For PES this may be interpreted as follows. The principal may observe some signal about the environmental service delivered without making too many costs (rule of thumb, for instance). However, in order to measure the environmental service precisely, the principal must invest in a costly measurement exercise: for example an extensive survey of agro-biodiversity in an area, or quantity of water downstream.

The model assumes that the monitoring decision and the signal are private information to the principal. Private nature of monitoring and signals implies that agents will form expectations about the principal's monitoring decision and base their effort on these expectations. Conversely, the principal decides to monitor, evaluating the costs and benefits of this decision according to her beliefs about the agents' unobservable efforts. The principal can decide to accept of outcome on the basis of an imperfect signal, or invest in costly monitoring and on the basis of this decide to continue the PES scheme or discontinue. Gautier assumes that the principal will discontinue the project when she receives a signal that the project might fail, thus risking discontinuing a successful project. We refer to Gautier

(1999) for the model development and will present some of its results. Gautier finds two sources of inefficiencies. First, the ex-ante contract may not be efficient, and second, the ex-post continuation decision may be inefficient. This inefficiency takes its source in the absence of precise signals. Monitoring can remove this be it at a cost. But ex-post efficiency is not the only role of monitoring. It also affects the ex-ante contract decision. The choice of production mode is affected by the accuracy of information about output, obtained through monitoring. Ex-ante inefficiency is not completely restored by monitoring. The absence of proper incentives implies payments of rents to agents, which distort the choice of production.

CONCLUSIONS AND DISCUSSION

Because the idea of PES is so appealing, many PES projects are being implemented around the world. The appeal of PES is enhanced by the fact it can provide poor resource managers an additional source of income, thus combining environmental and poverty-reduction goals. Since the *concept* of PES is widely accepted, it seems less of a concern to actually show the effectiveness of PES projects and measure the environmental services provided or monitor the activities implemented by the resource managers. However, showing the effectiveness of PES is crucial to its long-term success, especially when the private sector is going to buy into the concept and pay for the environmental services they benefit from.

The specific nature of environmental services makes monitoring a multifaceted issue. The institutional setup of a PES scheme depends on (i) the type of environmental service and its underlying production process; (ii) the extent to which the environmental service can be freely observed or measured; (iii) the extent to which activities of the resource managers who provide the environmental service can be freely observed; and finally (iv) the deterministic or stochastic nature of production processes, or put differently, the extent that natural processes determine the environmental service. Transaction costs arise when costs must be made to measure the activities of resource managers and the environmental services. If these are high, implementing a PES scheme may become infeasible. The institutional arrangements must therefore be such that they reduce transaction costs and maximize pay-offs to resource managers and the principal. This may be achieved by providing different types of incentives, which include payment arrangements and punishments, and different monitoring systems.

We have distinguished three different types of environmental-service production processes (following Rojahn and Engel 2005): independent, joint additive and joint multiplicative production. We have shown that there are different monitoring issues for the three production processes. For an independent production process, individual resource managers can provide separate environmental services. Usually the link between input activities and outcome are clear. Although measuring the environmental service may be simple (e.g., observing number of trees planted through remote sensing), there are always costs involved, especially when the number of participants in a PES scheme is large. When outcome can be easily measured (number of trees) but not input (e.g., proper tree management), the classical moral-hazard problem in principal-agent model arises, which can be overcome by the appropriate incentive structure. In many such models it is assumed that input measures cannot be observed at all, and therefore monitoring is not feasible. However, this assumption can be relaxed in many cases of PES. The optimal contract will then include a mix of incentive structure and the possibility of being monitored. This introduces the element of risk, whereby the attitude of the resource manager towards the risk of being monitored by the principal determines the optimal contract.

In the case of a joint additive production process, the activities of several resource managers lead to a joint outcome. For instance, several farmers implement practices that increase groundwater levels. It might seem that this is another classical moral-hazard problem, whereby the outcome can be measured but the individual activities cannot. However, in principal-agent models, it is assumed that there is a clear link between the (unobserved) activity of the agent and its outcome. In the case of a joint additive production process this link cannot be made: the observed outcome does not reveal who contributed to it. Therefore the solution to moral hazard by offering a contract with the appropriate incentive structure alone will no longer be sufficient. In this situation inspection of activities of resource managers becomes necessary, which requires a slightly different institutional setup than under independent production. The principal has various options. She can decide to inspect the agents with a certain probability. It can be calculated which probability will lead to the maximum pay-off for the principal. As under individual production, the attitude towards risk is important, although we have not explored this in this chapter. A more thorough analysis of the role of risk in PES schemes is certainly warranted.

The principal can also hire external inspectors, which introduces additional moral hazard because the principal does not necessarily observe the reliability of the external inspectors. When inspectors can be bribed or are prone to shirking, this may increase the monitoring costs. In developing countries, where the capacity of the legal system to deal with such cases is low or entails high costs, this may be a real problem. A third option consists of leaving the monitoring to the natural-resource managers themselves. Often it is the case that resource managers, who live and work in close proximity, can more easily observe each others' activities. Only if they also have the means to enforce cooperation (e.g., through punishment) they can overcome the free-rider problem. There has been extensive literature developed in this area, and this institutional arrangement may well fit many different PES schemes. It is, however, important to remember that all these institutional arrangements assume that the outcome of group effort can be measured. Thus, whatever institutional arrangement the PES scheme adopts to achieve compliance, there will always be additional transaction costs that have to be made to measure the outcome.

Joint multiplicative production processes occur when there is a synergy between the activities of resource managers that lead to a joint outcome. In the literature this production process has been labelled team production. In fact, many environmental services can be characterized by such a production process to a varying extent. The most applicable is the provision of biodiversity, as measures implemented in one field affect biodiversity in terms of quantity and types in another field. The effect is not additive but multiplicative. This is the most difficult to deal with, because when we assume that the principal cannot observe the contribution of each agent to the joint outcome and neither can the agents, monitoring becomes ineffective, and establishing the appropriate incentive scheme that solicits cooperation is extremely difficult. The only solution that avoids free-riding is a draconian one put forward by Holmström (1982), which punishes all team members severely if one team member shirks. However, the underlying assumption in this model that the principal and the agents have conflicting goals and that therefore agents will always try to shirk needs to be re-examined for some PES schemes.

Natural-resource managers may not necessarily participate in PES schemes merely for the payment. In fact, in Europe, farmers only receive compensation for their opportunity costs when they participate in agri-environmental schemes or water-related services schemes (Van Moorsel et al. 2006). Thus principal and agents may well share the goals of contributing to environmental services such as conservation of biodiversity. In this case, cooperative models need to be applied. The degree of cooperation between agents depends both on the incentive scheme they face, and the degree to which there exists a group culture that makes it possible for group members to commit credibly to the implementation of cooperative solutions. The principal now needs to contribute to an institutional arrangement that enhances group culture. It is important to note that feed-back on the performance of the team, thus feed-back on to what extent the team is successful in providing the environmental service, can enhance group culture. Measuring the environmental service is again necessary, be it for another reason than under non-cooperative situations. In the context of cooperative team production, the principal needs to implement an institutional arrangement that is not geared towards agents monitoring each other to detect shirking, but to agents sharing information to learn and to help each other.

To what extent the interests of the principal and agents are similar in PES schemes will differ from case to case. In PES schemes where the goal is to provide poor resource managers an additional income through PES, the priority of the resource managers may not lie in providing an environmental service, but in receiving additional income. Also in the case where the environmental service is not a public good but a private good benefiting a private company for instance, the interests of the agents may not overlap those of the principal. This is of course completely acceptable, but in the case of an environmental service that has a joint multiplicative production this may pose enforcement problems that are not easily overcome.

We have reviewed here the implications of measurement issues in PES and in doing so have glossed over many important issues. The role of risk was already mentioned, but the issue of uncertainty[13] is equally important, especially in situations where the link between the activities implemented by agents and the outcome, the environmental service, is stochastic. Uncertain outcomes can be perceived as environmental services that cannot be measured, or can be measured only after the investment has been made. What type of institutional arrangement needs to be put in place to manage uncertain outcomes, especially with respect to how the upfront investments and uncertain pay-offs are shared between the principal and agents is a topic for further research.

NOTES

[1] We define institutions as rules here and not organisation. Thus an institutional arrangement specifies a certain set of rules that applies for those involved in a contract.

[2] We therefore do not investigate adverse selection, although this is an important issue in PES (Ferraro 2005). More attention has been given to adverse selection problems in agri-environmental schemes, compared to moral hazard problems (Ozanne et al. 2001).

[3] Landell-Mills and Porras (ibid) also identify landscape beauty, but we will disregard this service for simplicity, as it is often combined with biodiversity protection.

[4] Although increasingly, consumers care about the production process: whether it was environmentally friendly, or socially acceptable for instance.

[5] Ozanne et al. (2001) define imperfect monitoring as the inability of the principal to detect cheating. Two types of imperfect monitoring are possible, (see Polinsky and Shavell 2000): the Type I error as assumed by Ozanne et al. and the type II error, which is the inability to identify accurately whether or not a farmer has complied and may include "false alarms". We will briefly discuss these in a later section on inspection games.

[6] For agri-environmental schemes, the EU allows only payments that cover opportunity costs and transaction costs that farmers need to make to participate (see Van Moorsel et al. 2006).

[7] Following game theory, the pay-offs for the principal are in the columns after the comma, and the pay-offs for the agent are in the rows before the comma.

[8] Choe and Fraser (1998) include this option in their model. However, Ozanne et al. (2001) argue that this is unrealistic in agri-environmental schemes.

[9] Rasmusen uses the term auditing game, which is often used in principal-agent models.

[10] Observability can be interpreted as a dichotomous variable, the agent cooperates or not. Measurability can be interpreted as a continuous variable, which gives an insight into the extent to which the agent cooperates (from 0 to 100% for instance). In the prisoners' dilemma we assume a dichotomous variable.

[11] In the Netherlands, farmers have organized themselves into such groups. The European Union has recently allowed that farmers can participate in groups in agri-environmental schemes (Van Moorsel et al. 2006).

[12] Although group incentives can also work under uncertainty, their effectiveness will be limited if there are many resource managers and if the resource managers are risk-averse. In this case, the need for monitoring arises.

[13] Whereby we make the distinction between risk and uncertainty following Knight (1921): '*risk*' refers to situations where the decision-maker can assign mathematical probabilities to the randomness which he is faced with. In contrast, Knight's '*uncertainty*' refers to situations when this randomness 'cannot' be expressed in terms of specific mathematical probabilities.

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