Land Use Policy 65 (2017) 128–134

Contents lists available at ScienceDirect

Land Use Policy

journal homepage: www.elsevier.com/locate/landusepol

A simple compensation mechanism for flood protection services on farmland

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ARTICLE INFO

Keywords:
Flood protection
Payments for hydrological services
Incentives for optimal land use
Risk sharing
Environmental policy instruments

ABSTRACT

Reservoirs for the transient storage of water in order to lower river flood peaks would usually be built on farmland and used in case of a serious flood event. Farmers' willingness to have their lands included in a reservoir critically depends on the compensation they will obtain. Our paper proposes a new compensation scheme that consists of an unconditional annual payment and a reparation payment conditional on flooding. We determine the properties of an optimal contract offered by the river authorities to farmers that specifies the compensation scheme and the rules for the use of the reservoir. The two-tier payment scheme induces crop choices of farmers that lower the damage profile of land use and it covers the long-term costs of land use change to ensure voluntary participation. We illustrate the working of the payment scheme using data from a case study from the river Tisza in Hungary.

1. Introduction

River floodplains are among the most productive agricultural areas. At the same time risk of flooding threatens agricultural production as well as the safety of the local population. Climate change exacerbates these risks that human civilisations have always been facing. Riverine flood risks can be managed with a variety of measures ranging from upstream river rehabilitation and wetlands restoration to the heightening of dikes (van der Pol et al., 2017; de Brito and Evers, 2016). As has been noted and discussed by Kenyon et al. (2008) and Wheater and Evans (2009) agricultural practices can play a major role in mitigating flood risks. Here we extend this discussion and consider specifically reservoirs for the transient storage of flood waters. Such reservoirs would usually be built on farmland and only used in case of serious flood events to lower the flood peaks. Lowering flood peaks can be very effective to reduce flood damages and maintain safety standards in downstream urban areas, since damages increase more than proportional in the depth of a flood (Jonkman et al., 2008). As peak river flows are projected to increase due to climate change in many world regions (IPCC, 2013), it will be of increasing importance to build reservoirs for flood protection with sufficient capacity. Such adaptation measures will be costly, but well-placed reservoirs and well-designed procedures and rules for their use will help lowering costs. For the choice of location of reservoirs geography and hydrology play a role. From an economic perspective extensive grassland is more appropriate than high value cropland. Co-benefits, like improvement of biodiversity or erosion protection, can also be important considerations. However, in this paper we focus on the socio-economic aspects, in particular the voluntary participation of farmers when the construction of a reservoir is proposed. Polman and Slangen (2009) argue – although in a different context– that farmers' participation will depend on the design of the compensation scheme. Voluntary participation of farmers will lower transaction costs by avoiding expensive and lengthy legal procedures of the authorities to acquire the necessary land use rights.

The novelty of this paper is that we apply tools of contract theory (Bolton and Dewatripont, 2005) to flood risk management. We propose a new compensation scheme for farmers who are asked to offer flood protection services on a voluntary basis and we examine the properties of the scheme. A compensation scheme is a contract between the river authorities and a group of farmers. Contract design in this context has three goals. First, since the flood protection service should be provided on a voluntary basis, remuneration for the service must generally be sufficient to fully compensate for lost harvests on farmland due to and conditional on flooding. Second, given the flood risks in the area that a reservoir covers, it will generally be inefficient to plant high value crops. An efficient contract will set incentives for farmers to reduce the value at risk. Third, efficient use of the reservoir must weigh damage on farmland in the reservoir against avoided downstream damage through lowering peak river flows when the flood gates of the reservoir are opened. The river authorities, however, might rather weigh compensation payments due against avoided damage when they have to decide whether to open the flood gates or not. Thus the third aim of the contract is to set the right incentives for the river authorities to use the reservoir efficiently. It is obvious that these three aims pull in different

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http://dx.doi.org/10.1016/j.landusepol.2017.04.006
Received 13 November 2015
Available online 10 April 2017

directions. The first asks for sufficiently high compensations. The second suggests that farmers should bear (some of) the risk in order to induce a “cautious” crop choice. The third implies to align compensations and crop damage. The contract we propose would implement a payment scheme that reconciles all three goals. Moreover, farmers can be assumed to be risk averse and we will show that the contract allocates risk efficiently to the river authorities who, as a government agency, are assumed to be risk neutral while farmers are fully insured.

Our study is motivated by the Hungarian experience with the use of reservoirs for flood protection along the river Tisza (Ungvári et al., 2013). Under the current scheme a compensation payment is due when the reservoir is flooded and it is based on an assessment of the actual crop damage. This implies that the current scheme offers full insurance to farmers who, therefore, do not have an incentive to switch to lower value crops. In addition damage assessment is costly and takes time, leading to a delay of payments which is an additional burden for farmers. In the scheme that we propose the level of payment is independent of the actual damage, so there is no need for expensive damage assessments. This lowers transaction costs and facilitates immediate payment following the opening of the flood gates. In addition there is less cause for dispute.

Our paper is structured as follows. The next section explains our compensation scheme in more detail and provides a micro-economic analysis to assess the contract design. Section 3 introduces the Hungarian case study that has motivated this research. Section 4 illustrates the effects of the proposed compensation scheme using data from the case study. Section 5 offers conclusions and further discussion.

2. The compensation scheme

In this section we present a simple hydro-economic model. The model aims to identify an optimally designed scheme for payments for flood protection services. We describe this problem as a contract design problem (e.g. Bolton and Dewatripont, 2005) where the contract regulates the use of the reservoir and determines the compensation payment. We examine a setting where the government has identified a suitable area for a reservoir where the expected benefits of downstream flood protection make up for investment costs associated with building the reservoir and the agricultural losses that are due to flood damages and farming adaptations (e.g. crop choice) that respond to higher flood risk in the reservoir. Here we are interested in contract design and we do not consider investment costs. Investment costs are sunk costs once a reservoir is built and they do not impact the contract design problem. Notice, however, that an ill-designed contract will make reservoir operations more expensive and may get in the way of implementing beneficial reservoirs.

Focusing on contract design, we consider three agents: (i) the government who offers a contract to farmers, (ii) the farmers who accept or reject the contract, and (iii) the river authorities who administer the contract, decide when the flood gates are opened and pay the compensation. We postulate three requirements of a contract and identify a contract that meets these requirements. We consider a group of farmers who operate on farmland that is hydrologically suitable to build a reservoir for downstream flood protection. In case the reservoir is flooded, farmers' crops will be damaged or destroyed. In order to make it worthwhile for farmers to provide their farmland for this purpose, farmers receive a compensation. Therefore, the first requirement is that the contract satisfies a participation constraint. In addition, we require an efficient adjustment of crop choice to the increased risk of flooding and an efficient use of the reservoir.

We start with a description of the hydrology, the risk of flooding and the associated damages. To do this we consider a given distribution of peak river flows (i.e. water levels l) with probability density function $g(l)$ and cumulative distribution function $G(l)$; see e.g. van der Pol et al. (2015) for an application of extreme value distributions to describe rainfall events. In the absence of a reservoir, flood damages are an increasing function of l whenever l exceeds a safe level l_s; see Hammond et al. (2015) for an overview of assessment methods. Hence, in the absence of any measures, damage occurs with probability $1 - G(l_s)$. Opening the flood gates of the reservoir would generally mean that the peak flow is lowered. In some range of the distribution $G(l)$ peak flows can be lowered below l_s such that all downstream damage can be avoided and the reservoir would be fully effective. For very large peak flows the capacity of the reservoir might be too limited to avoid all downstream damages but damages can still be reduced. The benefit B of the use of the reservoir is the reduction of downstream (urban) flood damage. We assume that downstream damage reduction, i.e. $B(l)$, is an increasing and convex function of the peak flow (c.f. Jonkman et al., 2008 for an empirical approach to flood damage estimation). Optimal operation of the reservoir requires that the flood gates are opened whenever

$$B(l) \geq D(x), \tag{1}$$

where $D(x)$ is the damage to crops in the reservoir. Crop damage depends on intensity of farming x. Here, for simplicity, we represent farming intensity by the value of the crop and, hence, we have $D(x) = x$ when the crop is lost due to flooding of the reservoir.

Turning to farmers' crop choice we assume, for the moment, a given risk of flooding of the reservoir p − but note that p will depend on the river authorities' decision when to open the flood gates. As discussed in the introduction we consider a compensation scheme that consists of an unconditional (fixed) annual payment a and a conditional reparation payment r. The total expected monetary compensation is

$$M = a + pr. \tag{2}$$

Considering risk neutral farmers, a simple model of farmers' crop choice considers the value of harvest x (where the price of the crop equals 1), the cost to produce it $c(x)$, the risk of flooding of the reservoir p and the compensation scheme M. We assume an increasing and convex cost function. Farmers' crop choice problem can then be written as follows

$$\max_x [(1 - p)x - c(x) + a + pr]. \tag{3}$$

Analysing a general compensation rule where a and r may depend on x, we obtain the first order necessary condition for optimal crop choice

$$(1 - p) + a'(x) + pr'(x) = c'(x). \tag{4}$$

It is worth noticing that if there is no compensation, $a + pr = M = 0$, then we have $(1 - p) = c'(x)$ implying that farmers adapt to higher risk with planting lower value crops. In this case the farming intensity adopted by risk neutral farmers is also optimal from a social welfare perspective. Farmers maximise expected net benefits from agriculture under a given flood risk p. We use $x^*(p)$ to refer to the efficient level of intensity of farming.

Next, turning to risk averse farmers, we use u to denote farmers' utility function. Farmers are risk averse when u is concave in farmers' income (see Pratt, 1964; Arrow, 1970). The maximisation problem becomes:

$$\max_x ((1 - p)\cdot u[x - c(x) + a] + p\cdot u[-c(x) + a + r]). \tag{5}$$

We prove in the Appendix A that if there is less than full compensation, risk averse farmers would choose a lower intensity of farming than risk neutral farmers. The intuition is that risk averse farmers prefer to have less value at risk, i.e. they sacrifice some returns for a reduction of vulnerability. Risk neutral farmers would simply maximise expected returns. Now, observe that if compensation covers the crop damage $r = x$, then farmers are fully insured. With full insurance they would ignore the flood risk in their crop choice and farming intensity would be higher than the efficient level x^*. We use x_F