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Sharing the costs of cleaning a river: the Upstream Responsibility rule

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ABSTRACT

The cleaning up of waste present in transboundary rivers, which requires the cooperation of different authorities, is a problematic issue, especially when responsibility for the discharge of the waste is not well-defined. Following Ni and Wang (2007) we assume that a river is a segment divided into several regions from upstream to downstream. We show that when the transfer rate of the waste is unknown, the clean-up cost vector provides useful information for estimating some limits in regard to the responsibility of each region. We propose a cost allocation rule, the *Upstream Responsibility rule*, which takes into account these limits in distributing costs "fairly" and we provide an axiomatic characterization of this rule via certain properties based on basic ideas concerning the responsibility of regions.

1. Introduction

Motivation The presence of waste in river channels is a major environmental problem faced by authorities since, on the one hand, waste can pollute water, which can be harmful for people, plants and animals, causing serious diseases and affecting ecosystems. As a consequence, the inhabitants of a region with more waste in its part of the river confront a cost: they consume lower quality water and/or face higher water depolluting costs. On the other hand, the presence of accumulated waste in a river is known to have a substantial effect on the probability of flooding when there is heavy rain, so it seems advisable to clean river channels regularly to reduce this danger. Around the world, about 200 rivers (see Ambec and Sprumont, 2002 and Barrett, 1994) flow across national borders, and a much greater number across borders between regions or municipalities. All the activities for cleaning transboundary rivers may require cooperation on the part of the different authorities involved and coordination of efforts if they are to be effective. However, the distribution of the costs of these activities among the different regions may be a problematic issue, particularly when the extent to which each region is responsible for the waste discharged is not well-defined.

As far as we know, the first paper to analyze the problem of sharing the costs of cleaning a river among different regions from a theoretical point of view is that of Ni and Wang (2007). They model a river as a segment which is divided into subsegments from upstream to downstream such that each region is located in one of them. They assume that there is a central agency that determines the cost of cleaning each of these segments and they axiomatically propose two methods for allocating the total cleaning costs among all regions along the river. The first method, called *Local Responsibility Sharing*,

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establishes that the total cost that each region should pay is directly the cost of cleaning the segment in which this region is located. The second method, called *Upstream Equal Sharing*, states that the total cost that each region should pay is obtained by distributing equally the cost of cleaning each segment among the region in that segment and all the regions situated upstream from it.[1] We show that neither of these methods allocates the costs in a way that reflects the responsibility of each region in producing the waste present in river channels. The first does not take into consideration that the water of a river flows from one segment to another, taking part of the waste with it. The second implicitly assumes that the region in a segment and all the regions situated upstream from this have the same degree of responsibility for the waste present in the segment in question. However, this would only be "fair" if all regions have discharged exactly the same quantity of waste of the one present in that segment, which is not necessarily the case.

Overview of results In this paper, we seek to develop an alternative rule to the methods proposed by Ni and Wang (2007) which takes into account the responsibility of the regions for the presence of the waste. We explicitly introduce into our model the fact that the waste is transferred, with the water, from upstream to downstream at a particular rate, an idea that is implicitly assumed in Ni and Wang (2007). If the social planner knew this rate, she could use the cost vector to accurately calculate the amount of waste discharged by each region into the river, and the costs could thus be distributed according to their actual responsibilities. However, in practice, the transfer rate may be unknown.[2] In that case, we show that the social planner could estimate certain limits of that rate from the cost vector. Those limits provide useful information for distributing the costs fairly, since they enable certain limits of responsibility to be inferred for each region. We show that the rules that naturally adapt the methods proposed by Ni and Wang (2007) do not always assign costs in the intervals constructed with these limits, thus violating this basic principle of fairness.

We introduce a set of desirable properties taking into account this information concerning the responsibility of each region in discharging the waste. Those properties are: (*i*) *Limits of Responsibility*, which requires the cost paid by each region for cleaning its own segment always to be within its limits of responsibility; (*ii*) *No Downstream Responsibility*, which states that a region j situated downstream from another region i has no responsibility for the waste present in i and therefore does not have to pay anything towards the cost of cleaning it up; (*iii*) *Consistent Responsibility*, which ensures that the part of the cost of cleaning a segment paid by one region relative to the part paid by another region is consistent throughout all the segments situated downstream from both regions; and (*iv*) *Monotonicity with respect to Information on the Transfer Rate*, which states that when information on the transfer rate improves in such a way that it becomes natural to induce a higher (lower) estimated value for the real transfer rate, the amount of waste in any segment for which all its upstream regions are responsible must not be lower (higher) than before.

That set of properties characterize a new cost allocation rule, the *Upstream Responsibility rule*, which works as follows: first, it assigns to the region situated in a given segment the value of its responsibility taking as the transfer rate the mid-point in the interval between its lower and its higher limits. The remaining cost of cleaning the segment in question is divided among the upstream regions, maintaining the proportions of the allocation of the cost of cleaning the previous segment.

Related literature The study of allocation problems using game theoretical and/or axiomatic models to solve issues related to transboundary rivers has developed in two directions. On the one hand (the *harmful side*) some authors have developed models for studying how to share the costs of cleaning a river among the regions located along it. On the other hand (the *beneficial side*) some papers have analyzed models for determining how to share water resources among the different regions along a river.

Among the papers dealing with the harmful side, which is the body of literature into which our paper fits, there are two main approaches. Several papers, starting with Ni and Wang (2007) and including ours, consider a river as a segment divided into different regions and assume that the cost of cleaning each region is exogenously given. Along these lines, Ni and Wang (2007) propose and characterize the two methods – Local Responsibility Sharing and Upstream Equal Sharing – described above. They also defend these methods as the Shapley values of two appropriately defined TU games and as solutions belonging to the core of this problem. Van den Brink and van der Laan (2008) show that these additional results are particularizations of certain well-known results of cooperative game theory (in particular, the problem is essentially an airport cost game, see Littlechild and Owen, 1973) and they provide an alternative axiomatic characterization of these methods. This model is extended by Dong et al. (2012) by considering a river as a network. Based on a different principle (the "polluter-pays" principle), Gómez-Rúa (2013) defines water taxes according to regions' responsibilities for pollution and characterizes several cost allocation methods based on properties of those taxes. Other papers such as Gengenbach et al. (2010) and van der Laan and Moes (2012) take a substantially different approach by assuming that the cost allocation method adopted may affect the decision of each region about how much waste to discharge.

On the beneficial side, papers generally analyze water allocation problems and the fair distribution of the welfare resulting from distributing the water of a river among different regions. Based on cooperative game theory, Ambec and Sprumont

[1] These methods are based on the theories or principles of Absolute Territorial Sovereignty and Unlimited Territorial Integrity, respectively (see Godana, 1985 and Kilgour and Dinar, 1996).

[2] This uncertainty about the transfer rate is usually assumed in the literature on non-point source pollution (see Segerson, 1988).