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# Gains from trans-boundary water quality management in linked catchment and coastal socio-ecological systems: A case study for the Minho region

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ABSTRACT

In trans-boundary catchments, national welfare maximizing rates of water quality improvement differ across nations as benefits and/or costs from water quality improvement accrue to multiple nations. Hence we need to differentiate between intra- and trans-boundary catchments because benefactors and beneficiaries from water quality improvement are not one and the same. In this paper we develop a deterministic optimal control approach to explore national and trans-national welfare maximizing rates of water pollution abatement in linked catchment and freshwater/coastal socio-ecological systems. For a case study of the Minho region (Iberian Peninsula), we estimate nation-specific water pollution abatement cost functions (based on management practice adoption) to determine and compare national and trans-national welfare maximizing rates of water pollution abatement and corresponding welfare implications. Results show that national welfare maximization leads to increased rates of water pollution (+5%), while trans-national welfare maximization leads to significant reductions in rates of water pollution (−14%) and largest

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welfare gains (+1.4%). Partial non-cooperation in trans-national water quality management leads to increased rates of water pollution (up to +12%) and welfare losses (up to −0.9%), though providing national welfare gains for defecting nations (up to +3.8%).
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## 1. Introduction

Freshwater and coastal ecosystems are affected by point- and diffuse-source water pollution originating from rural, urban and industrial land uses in coastal river catchments (e.g. [10]), even though these ecosystems are of vital importance from an environmental as well as an economic perspective (e.g. [5]). Sustainable economic development of catchment regions requires balancing of the marginal costs from catchment water pollution abatement and the associated marginal benefits from freshwater/coastal resource appreciation [15,12,26]. In doing so, however, we need to differentiate between intra- and trans-boundary catchments as benefactors and beneficiaries from water quality improvement are not one and the same [1,40]. In trans-boundary catchments the national welfare maximizing rates of water quality improvement differ across nations as benefits and/or costs from water quality improvement accrue to multiple nations.

Economic incentives and market-based instruments can be used to internalize these beneficial spill-overs from water quality improvement, such that market behaviour could lead to welfare maximizing outcomes [34,32]. This would, however, require international treaties and regulations that allow for international financial transfers of these welfare gains and that are based on verifiable water pollution measures or proxies thereof [10,40]. Provided full cooperation of all involved water polluting countries, market behaviour would then lead to efficient outcomes where marginal abatement costs and marginal abatement benefits are equal across all water polluting nations [12].

The majority of studies on catchment water quality management do not take into account the downstream costs from water pollution and, thus, do not go beyond the usual cost-effectiveness analysis based on tolerable or target levels of pollution (see e.g. [10,17]). Some of these studies carefully relate land use location and associated bio-physical conditions to economic production potentials, but ignore or do not explicitly account for spatially dispersed environmental impacts (e.g. [18,30,14]). Other studies carefully relate land use location and associated bio-physical conditions to environmental impacts, but in that case ignore or do not explicitly account for spatially distributed economic impacts (e.g. [33,24,21]). Only few of these studies integrate economic models with hydrological and/or soil models to explore opportunities for cost-effective water quality improvement through, for example, targeting of best management practices, land retirement and riparian buffers at the catchment scale (e.g. [3,20,42,27]).

There are a number of studies that do take into account the relationship between catchment water pollution and subsequent downstream costs from water pollution, while only a limited number of studies also consider the trans-boundary water management issues in these linked catchment and coastal ecosystems [2,10,40]. Earlier studies from Hawaii, the Caribbean, the Maldives and Australia are essentially numerical (e.g. [16,31,13,35]), whereas more recent studies also consider the underlying analytical features to water quality management in linked catchment and coastal ecosystems (e.g. [11,15,26,28]). Only sparsely these optimal control approaches are extended to the case of water quality management in trans-boundary catchments, thus establishing to what extent welfare gains can be obtained through water pollution abatement across nations (e.g. [1,12]).

In this paper we develop a deterministic optimal control approach to explore national and trans-national welfare maximizing rates of water pollution abatement in linked catchment and freshwater/coastal socio-ecological systems. The developed approach goes beyond these earlier, abovementioned, studies as it allows to assess optimal rates of water pollution abatement across nations for boundary as well as non-boundary situations—i.e. situations where downstream benefits from water quality improvement are either or not shared between nations. For a case study of dissolved inorganic nitrogen (DIN) water pollution by the key agricultural land uses in the Minho region (Iberian

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