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A theoretical model of water and trade

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ABSTRACT

Water is an essential input for agricultural production. Agriculture, in turn, is globalized through the trade of agricultural commodities. In this paper, we develop a theoretical model that emphasizes four tradeoffs involving water-use decision-making that are important yet not always considered in a consistent framework. One tradeoff focuses on competition for water among different economic sectors. A second tradeoff examines the possibility that certain types of agricultural investments can offset water use. A third tradeoff explores the possibility that the rest of the world can be a source of supply or demand for a country's water-using commodities. The fourth tradeoff concerns how variability in water supplies influences farmer decision-making. We show conditions under which trade liberalization affect water use. Two policy scenarios to reduce water use are evaluated. First, we derive a target tax that reduces water use without offsetting the gains from trade liberalization, although important tradeoffs exist between economic performance and resource use. Second, we show how subsidization of water-saving technologies can allow producers to use less water without reducing agricultural production, making such subsidization an indirect means of influencing water use decision-making. Finally, we outline conditions under which riskiness of water availability affects water use. These theoretical model results generate hypotheses that can be tested empirically in future work.

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1. Introduction

We live in an increasingly globalized world [12,21], where trade in water-intensive commodities, such as agricultural products, represents an important interaction between people and water resources [1]. The relationship between international trade and water resources is an issue of great interest in the literature [11,17]. A number of empirical studies have made reference to classic international trade models, but it is not always clear what the theoretical foundations of the models are and whether they are useful for the case of water [28]. Some studies have argued that economic models are inadequate for explaining virtual water trade [2], while others have sought to clarify the role of economics as it relates to this issue [20]. Many studies focus on the relationship between trade and virtual water resources [10], without direct consideration of domestic, physical water resources. A theoretical model that incorporates domestic water use in production – in addition to the consumption and trade of water-intensive commodities – would contribute to this growing literature. As such, the main goal of this paper is the development of a trade model that addresses these relationships through the explicit inclusion of water resources.

In this paper, we develop a theoretical model designed to emphasize several tradeoffs in water use. First, the model captures competition for water among different sectors. Second, the model allows for the possibility of factor substitutes for water, in the form of alternative production technologies. An example is capital-intensive efficient irrigation technologies and crop varietal improvements, a situation where increased use of one resource (in this case capital) may be able to offset or substitute to some extent for water use. Third, we allow for production and consumption to be substituted across locations in space through trade. Fourth, we explicitly capture farmer risk aversion to variable water supplies, as compared with traditional profit maximizing behavior.

The main goal of our model is to gain generalizable insights into the interactions between people and water in a trading economy. Transferable understanding is often difficult to obtain when more realistic, but heavily parameterized, models are used to inform management of site-specific water resources. Hydroeconomics has long been interested in the interactions between people, water resources, and economics [9], though with a focus

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on finding feasible and optimal solutions to concrete problems, i.e. a ‘normative’ approach to model development [25]. This differs from the development of models in the realm of coupled human and natural systems [18], from which socio-hydrology stems [26], which tend to focus on understanding what is happening in the system and why, following a ‘positive’ approach to model development [25]. In this way, our model complements existing hydro-economics models, which are typically parameterized to capture local dynamics and inform management [7]. Our modeling approach parallels that of socio-hydrology, yet we help to broaden socio-hydrology through the incorporation of economics. By modeling domestic water use, agricultural production, and trade, we also present a theoretical foundation for the virtual water trade literature. In this way, we aim to contribute to further integration of hydro-economics, socio-hydrology, and virtual water trade research.

The model is inspired by contemporary contexts – such as the current drought in California – where water is a scarce resource. In this setting, in which there is much agricultural production, competition exists between the agricultural sector and other parts of the economy for scarce water resources. Additionally, uncertainty about the future supplies of water resources impacts farmer decision-making. In contexts such as this, it is critical to understand the ramifications of trade in water-intensive goods, as well as how various policies may impact water use, agricultural production, and economic welfare. For this reason, a model that can provide insight into these issues may be of interest to governments, planning authorities, and non-governmental organizations dealing with scarce water resources. However, it is important to recognize that theoretical models are necessarily abstractions of the real world and are not intended to inform policy makers in a specific situation, unlike site-specific integrated water resources management approaches [14].

While the model is inspired by the real world, there is no validation because this is a theoretical model that abstracts the real world with necessarily restrictive assumptions. Our theoretical model is meant to provide a logically consistent framework for deriving results from first economic principles, that is, from the interactions of consumer and producer decision-making. For this reason, we employ many common assumptions of economic modeling, such as equilibrium prices, rational behavior, and profit maximization. These assumptions are pervasive in economic modeling, but rarely exist in the real world, making empirical validation difficult. For this reason, it is common for theoretical economic models to be developed without validation against existing data [6]. However, our model enables us to isolate some of the key parameters that can be empirically estimated in future work. Additionally, our theoretical model generates hypotheses that can be tested with data in specific circumstances in future research.

The approach undertaken in this paper does not involve prediction of bilateral trade patterns among multiple countries; rather it applies to a small, open economy, in which water is scarce. By ‘small’ we imply that we are concerned with a region that is not so important to international trade that it can significantly influence the prices it pays for inputs and the prices received for outputs; it takes these prices as given. By ‘open’ we imply that the economy is influenced by supply and demand as reflected in prices received for outputs in the rest of the world. Our approach builds from the traditional two-factor and two-good economic approach associated with Heckscher [8] and Ohlin [19], further refined and extended in Samuelson [22] and Jones [15]. In contrast to these general economics approaches, we allow for water as an additional factor of production, do not assume that capital is perfectly mobile between sectors, and allow for variability in water supplies and hence prices. We go beyond classic studies such as Howitt and Taylor [13] by considering an economy that is open to international trade and has more than one sector, both of which use more than one factor of production. We also relax the traditional profit maximizing assumption to allow for variation in producer attitudes towards risk.

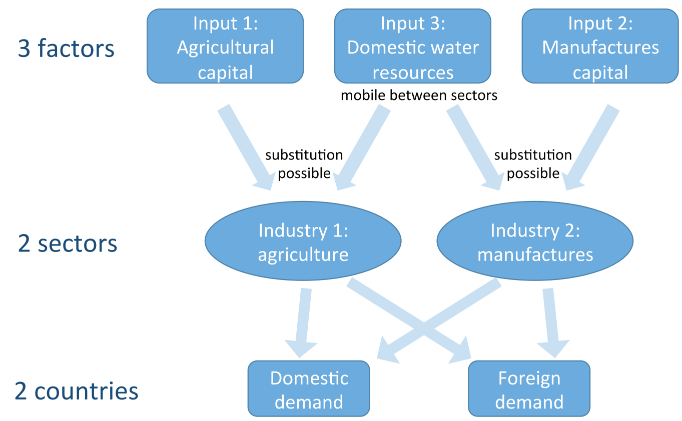

Fig. 1. Schematic of model framework.

The paper is organized as follows. We first develop the model in Section 2. We present two formulations: one that assumes profit maximization and one that enables farmer decision-making under uncertainty. Next, we examine scenarios and policy interventions of interest in Section 3. In Section 3, we ask the following questions: What happens to water use when there is agricultural trade liberalization? What are the consequence of policies to tax water and subsidize water-saving technologies? How does water supply variability impact water use? We conclude in Section 4.

2. Model framework

We develop a theoretical model that captures the water resources tradeoffs outlined above. This model stems from the classic 2 × 2 × 2 trade model, in which there are two regions, two factors, and two goods. The model has explicit treatment of only one small country, but has three factors, one of which is shared by the two sectors. We employ a static equilibrium framework. Equilibrium is reached when prices equilibrate quantity supplied and demanded across all markets in the economy [3]. Representative human agents operate in the model framework according to their objective, which is traditional profit maximization in Section 2.1 and maximization of expected utility under risk in Section 2.2. Under traditional profit maximizing behavior farmers choose among alternative techniques of production based upon the relative prices of inputs. Farmers choose the level of input wherein the price that must be paid for it equals the marginal value product of that input, which is the product of the extra output made possible by one more unit of input (marginal physical product), and the price of the output. This model does not explicitly model multiple regions and make bilateral trade predictions. It is a model of a domestic open economy, in which production and trade are driven by external prices received for goods.

A schematic displaying our model is provided in Fig. 1. We assume that there is a home country and the rest of the world. The country produces two goods: good 1 (agriculture) and good 2 (manufacturing), which are also the two sectors/industries in the economy. There are three factors in the model: factor 1 (agricultural capital), factor 2 (manufacturing capital), and factor 3 (water). Agricultural production requires agricultural capital and water, while manufacturing needs manufacturing capital and water. Water is mobile and costlessly re-allocated between the two sectors, while capital is a specific factor to each sector. Water use links sectors with one another, which is a unique feature of water [23]. In

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