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When water saving limits recycling: Modelling economy-wide linkages of wastewater use

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ABSTRACT

The reclamation of wastewater is an increasingly important water source in parts of the world. It is claimed that wastewater recycling is a cheap and reliable form of water supply, which preserves water resources and is economically efficient. However, the quantity of reclaimed wastewater depends on water consumption by economic agents connected to a sewage system. This study uses a Computable General Equilibrium (CGE) model to analyse such a cascading water system. A case study of Israel shows that failing to include this linkage can lead to an overestimation of the potential of wastewater recycling, especially when economic agents engage in water saving.

1. Introduction

Water scarcity is an emerging global problem. Population and income growth are increasing demand appreciably. At the same time, the supply of water from traditional sources is failing to keep pace, and is being constrained by environmental and other concerns that are limiting the expansion of storage capacity and restricting extraction from aquifers. Moreover, the quality of freshwater resources is deteriorating as they are increasingly polluted, resulting in the spread of waterborne diseases (Jimenez and Asano, 2008) and limiting usefulness of the water. Consequently, societies have to recognise that water is an economic good that is costly.

There are multiple approaches to address water scarcity with all of them involving increased costs. The rate of demand growth can be limited by increases in efficiency, e.g. drip feed irrigation systems, reductions in transmission losses, etc., and/or by encouraging users to conserve water, e.g. using showers rather than baths. Supplies can be increased by using non-traditional sources (e.g. seawater desalination), increased purification of traditional sources, and/or by the recycling of wastewater, which includes the treatment of wastewater (reclamation) and its use in economic activities. The balance between the different approaches depends upon country-specific circumstances. This study is concerned with the economic implications of recycling wastewater: how its collection, (partial) purification and reuse interact with other sources of water in the system. Because of the complexity of water systems, and the extent to which water is integrated within economic systems, the analyses require the use of a framework (model) that captures these interactions.

Most wastewater, for reclamation, is collected through the sewage system. Given the origin of reclaimed wastewater and the costs of purification, most reclaimed wastewater is used for the irrigation of non-food crops and industrial processes, especially cooling, that do not require high levels of purification. Thus, wastewater recycling for irrigation is a potentially important as well as relatively low cost source of water and therefore is used in more than 40 countries (Jimenez and Asano, 2008). Typically, the ratio of recycled wastewater to total water extraction is low, although in countries facing severe water shortage it is already quite high, e.g. it is 35% in Kuwait and 18% in Israel (Jimenez and Asano, 2008). A major issue for water authorities contemplating recycling wastewater is that, as water becomes scarcer, programs are developed to increase the efficiency of water use and the price of water to consumers increases: both serve to lower the amount of wastewater available. For example, in Beijing rapidly increasing

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potable water prices have induced companies to invest in internal recycling facilities, lowering the potential for communal wastewater recycling (Yang and Abbaspour, 2007).

The analyses reported in this paper derive from a water-focused Computable General Equilibrium (CGE) model, STAGE_W (Luckmann and McDonald, 2014), which has been extended to encompass recycled wastewater by linking the supply of reclaimed wastewater to the quantity of wastewater available. The advantages of using a CGE model are that this class of models can capture the complex interactions within water systems and the demand for water, both as an input to production as well as consumption by households. Equally important is the fact that prices within a CGE model are variables. This means that any changes in water, and other, prices have direct impact on the decisions of agents in the model, whether these price changes are exogenously imposed, e.g. through government policies, or solved endogenously within the model. Hence, the model generates shadow prices for wastewater to inform governments and pricing decisions. The analyses are implemented using data for Israel, although the framework is generic and applicable in any country for which the requisite data are available.

The rest of the paper is structured as follows. Section 2 reports a review of existing approaches to model wastewater recycling from an economic perspective. Section 3 contains a description of the STAGE_W model and its extension. A description of the water system in the Israeli economy and the data used for the empirical application are provided in section 4. The simulations are reported and the results are analysed in section 5. While the final section 6 contains conclusions that are specific to the situation in Israel but also regarding the treatment of wastewater recycling in simulation models in general.

2. Literature overview

Water models for economic policy analyses have developed greatly in the last 25 years (Booker et al., 2012), but the economics of the recycling of wastewater remains underdeveloped (Molinos-Senante et al., 2011).

A key issue is the economic viability of wastewater recycling, conditional upon different treatment levels and uses, e.g. irrigation vs. river disposal. Irrigation with reclaimed wastewater subject to secondary treatment can yield positive net economic benefits in Israel depending on the conveyance distance (Haruvy, 1997) Thus, there may be positive returns to increases in wastewater recycling. The key determinants will be the economic costs of wastewater recycling and the desalination of reclaimed water so that long-run chloride concentrations in the soil are stabilised (Haruvy et al., 2008). It has been argued that if reclaimed wastewater is treated to the highest sanitary and lowest salinity levels (including tertiary treatment), the net economic benefits exceed those from lower treatment levels; although the economically optimum levels of treatment will vary across regions (Lavee, 2013).

The distribution of reclaimed wastewater between producers of wastewater (municipalities) and consumers of reclaimed water (farmers) is problematic as reclamation of wastewater is a public good for the wastewater producers and a private good for the farmers: therefore, market failure exists and optimal allocations are not realised. If the polluter pays principle is applied and municipalities pay the full costs of wastewater reclamation, an (economically) efficient allocation of reclaimed wastewater is unlikely (Feinerman et al., 2001). Hence, there is a *prima facie* case for government intervention. In a game theoretic regional model total benefits are greatest if there is information symmetry, which supports cooperation and agreements between economic entities regarding the allocation and price of the reclaimed water (Axelrad and Feinerman, 2010).

Increases in the prices of potable water will induce firms to invest in water recycling and thereby reduce outflows of wastewater (Yang and Abbaspour, 2007). Thus, dependent on the relative costs of internal water recycling compared with freshwater supply and discharge costs, it may be economically viable for firms to invest in such water-conserving technologies (Rivers and Groves, 2013). This may lead to considerable water savings, since investments in internal wastewater recycling by industries may reduce their freshwater intakes by up to 95% (Levine and Asano, 2002). Unsurprisingly CGE-based studies of water pricing conclude that if firms are charged for extracting water, e.g. from a river, that is returned to the source after use, then the rate of self-recycling will increase (Rivers and Groves, 2013). Such analyses do not encompass any users of the wastewater, which may make sense in countries that have abundant water supplies, e.g. Canada, but not in water scarce regions.

One approach to consider a cascading water use is to allow substitution possibilities between reclaimed wastewater and freshwater in a dynamic optimisation model. If the marginal provision cost for reclaimed wastewater is constant and potable water and reclaimed wastewater are perfect substitutes, then the use of reclaimed wastewater for irrigation becomes a backstop technology. Thus, if the unit price of potable water reaches the marginal cost of reclaimed wastewater farmers will choose to irrigate with reclaimed wastewater (Roumasset and Wada, 2011). If the marginal provision costs of reclaimed wastewater are increasing then it becomes a supplemental resource (Roumasset and Wada, 2011). However, in all previous studies, it has been assumed that the supply of wastewater is unlimited, which may be a misleading assumption when considering conditions of water scarcity (Park et al., 2008).

This study contributes to the literature by improving the modelling of wastewater recycling through endogenously connecting the provision of wastewater to the water consumption of economic entities in an economy-wide framework. The model presented in this paper builds on Luckmann et al. (2014), which is the first CGE model including a wastewater reclamation activity allowing for the transfer of reclaimed wastewater to other economic activities.

3. Model description

The model used for this analysis makes the production of reclaimed wastewater dependent upon the endogenously determined supply of wastewater. This requires the simultaneous determination of the supply of sewage, which is a function of the demand for water by activities producing sewage, and the supply and demand for reclaimed wastewater. Consequently, the model must encompass the entire water system of an economy and how the economy reacts to changes in the water system or changes in water policies, which is what water-focused CGE models are designed to do.

The model is a development of the STAGE_W model, which is documented in Luckmann and McDonald (2014). Hence, the description of the base model here is limited. STAGE_W is a Social Accounting Matrix (SAM)-based single country CGE model, which includes non-linear and linear relationships governing the