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Analysis

Crop Production, Export of Virtual Water and Water-saving Strategies in Arizona

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ABSTRACT

Growing world population and the uncertain hazards that accompany climate change put an increasing pressure on the management and sustainability of scarce environmental resources, notably water. In spite of its water scarcity, the state of Arizona permits as much as 73% of its water to be consumed by a single sector, crop production. Since 79% of such crop production is not consumed in Arizona, it corresponds to exporting up to 67% of the water available in the state to the rest of the country and abroad. It has certain and glooming consequences on the availability of water for a state expected to see its population grow and its climate get drier. Based on input-output techniques, we simulate three scenarios aiming at saving 19% of the water available, a figure set by the first of them based on improving the efficiency of the current irrigation system. The same savings could also be reached by a twenty-seven-fold increase in the price of water or a 19.5% reduction in crop exports. Estimates indicate that the least costly solution is a more efficient irrigation system while export reduction is the second-best choice.

1. Introduction

Climate change and population growth are seen as two majors threats for water availability in arid and many semiarid regions (Christensen et al., 2004; Grimm and Fisher, 1992; Ribot et al., 2005; Vörösmarty et al., 2000). As such, several virtual water flow analyses have been performed on these regions to understand better the magnitude and nature of the imbalance between water use and water availability. Started during the 1980s when Israel realized that its agricultural export meant less of its scarce water was available for other uses (Allan, 1993, 1994; Allan, 1998; Fishelson, 1994), the concept of virtual water has since been applied to the regions of China (Guan and Hubacek, 2007; Han et al., 2014; Wang and Wang, 2009; Wang et al., 2013; Zhang et al., 2011b), the UK (Yu et al., 2010), and Spain (Cazcarro et al., 2013; Dietzenbacher and Velázquez, 2007; Lenzen, 2009; Velázquez, 2006) among others. The conclusions of the virtual water flow studies above highlight two important facts. First, irrational patterns of virtual water flows by which a water-scarce region is a net exporter of virtual water are not uncommon (Dietzenbacher and Velázquez, 2007; Finster, 1971; Guan and Hubacek, 2007). We call such patterns "irrational" because they go against the fundamental Heckscher-Ohlin principles of economic trade theory according to which a place should specialize in and export goods of which production factors are locally abundant. Second, once all the rounds of transactions necessary for the production of a commodity have been accounted for, agriculture is always found to consume a greater amount of water than either the industry or the services sectors (Velázquez, 2006; Zhang et al., 2011a; Zhang et al., 2011b; Zhao et al., 2010). Naturally, all such studies advocate for an improvement in the efficiency of water use in agriculture.

The paradox of water-scarce regions exporting water through their production and trade has also been highlighted in the U.S. For instance, Mubako et al. (2013) have analyzed the bilateral virtual water trade between California and Illinois across 8 sectors. Their article echoes the concerns expressed about California's water shortages and the even more dramatic drought of 2013–2014 (Howitt et al., 2014; Swain et al., 2014). Another recent contribution is Marston et al. (2015) who focus on groundwater originating from three aquifers (the High Plains, the Mississippi Embayment and the Central Valley) of which (over)exploitation for irrigation purposes may threaten national food security and be challenged by future droughts. Dang et al. (2015) take on a different approach by examining the virtual water content (VWC) for each food commodity group provided in the U.S. Commodity Flow Survey. When they compare it to the values at the international level,

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their results indicate that the VWC in the U.S. alone is as much as 51% of the international flows. It is much higher than the mass or value share of the U.S. market. The difference comes from the disproportionate amount of water-intensive meat commodities that are traded in the country.

In this paper, our aim is, first, to uncover how much water is embedded in the products and services made in Arizona and is "virtually" traded with its U.S. and foreign partners. Arizona is an interesting case in that it receives less media coverage than its drought-prone neighbor California; yet its water export was already pointed out as a critical issue by Finster (1971) more than three decades ago. The latter contribution focuses on the 1958 structure of Arizona's economy and on its trade pattern with the rest of the country. The author finds that, at that time, Arizona was a net exporter of 2.24 million acre-feet of water with respect to the rest of the U.S. but, unlike our paper, he does not highlight that agriculture is responsible for it. While a recent and rapid population growth (from 1.3 million in 1960 to 6.7 million today) has undoubtedly contributed to an increased demand for water, it is the well-developed agricultural sector of the State that takes the largest portion of responsibility for it. Using 35% of Arizona's land and having exports ranked 33rd in the nation in terms of value in 2012 (USDA, 2012), agriculture has been able to strive thanks to the water it has been diverting from the Colorado River for decades. Indeed, the lack of local rainfall and groundwater is compensated by artificial reservoirs and the Central Arizona Project. However, these heavy irrigation requirements impose huge water demand stresses on the ecological system of the State to the point where one has to wonder for how long crop production can keep engulfing 75% of the water used in Arizona (IMPLAN, 2010; USGS, 2010). This figure is disproportionally high since only 30% of the crops produced in Arizona are consumed locally, which implies that Arizona exports a significant amount of much-needed water.

As a result, the second objective of this paper is to determine whether significant water savings could be achieved through 1) a more efficient irrigation system, 2) an increase in the price of water, and 3) a reduction in crop exports. Beyond the logic of avoiding specialization and trade of goods of which production factors are not locally abundant (Heckscher and Ohlin, 1991), this exercise is motivated by three elements that may threaten the continuity of water availability. First, Arizona's population is expected to double by 2050 (AZDOA, 2012); second, various climate models anticipate more droughts in the state in the future (Dominguez et al., 2010) and, third, Arizona relies heavily on the Colorado River for irrigation surface water even when its source is located beyond the state's borders.

In order to investigate these issues and shed some lights into Arizona's current virtual water flows, we offer in Section 2 a review of the concept of virtual water flow, price elasticity and input-output model. Section 3 presents the economic and water data that are used in Section 4 to calculate the water content of Arizona's exports and imports. The results are provided across eight sectors of the state's economy. Section 5 reports the cost that three different water-saving strategies would have on the economy. Finally, the last section summarizes the most important results of this paper and provides some concluding remarks.

2. Methodology

2.1. The Concept of Virtual Water Flow and Economic Input-output Model

The input-output framework developed decades ago by Leontief (Leontief, 1964; Leontief, 1936) in that it allows consideration of both traded final goods (e.g. cattle) and also all intermediate goods (e.g. water and hay fed to cattle) used in the production process of the former, thereby avoiding the risk of double counting. This approach permits accurate measurement of the total amount of water embodied in trade. Virtual water is defined as the volume of water embodied in the production process of a good (Hoekstra and Hung, 2002). It is analogous to the 'water footprint' idea introduced later on by Hoekstra and Hung (Hoekstra and Chapagain, 2007), except that their study focuses on freshwater sources only and the national level.

Assuming n economic sectors in the local economy and noting x_i as the total output of sector i that satisfies intermediate demand of the sectors j (z_{ij}) and final demand f_i:

$$x_i = \sum_{j=1}^{n} z_{ij} + f_i \tag{1}$$

Then we can denote the technical coefficients of production (a_{ij}) as z_{ij}/x_j. They correspond to the dollar value of z_{ij} needed for the production of \$1 of x_j. Eq.(1) can therefore be rewritten as:

$$x_i = \sum_{j=1}^{n} a_{ij}\, x_j + f_i \tag{2}$$

In matrix notation, Eq.(2) becomes:
$\mathbf{X} = \mathbf{AX} + \mathbf{f}$; hence,

$$\mathbf{X} = (\mathbf{I} - \mathbf{A})^{-1}\mathbf{f} = \mathbf{Lf} \tag{3}$$

where A is the direct input coefficient matrix and $\mathbf{L} = (\mathbf{I} - \mathbf{A})^{-1}$ is known as the *Leontief inverse matrix. The elements of* l_{ij} represent the total (direct and indirect) output of sector i that is required to satisfy \$1 of final demand in sector j.

In the input-output terminology, the amount of water used in the production process of a sector, noted $y_j = w_j/x_j$, is a direct water input coefficient. It allows us to calculate the quantity of water consumed by sector i to satisfy \$1 of final demand in sector j. The latter is called total (direct + indirect) water input coefficient or virtual water multiplier $\varepsilon_j = \Sigma_i y_i l_{ij}$.

2.2. Virtual Water Input-output Model and Price Elasticity

In order to calculate the virtual water flows associated to Arizona's (net) trade, we first define the direct water input coefficients of Arizona's imports as the technology, regulations and industry-mix of its trade partners may differ from its own. Let $\tilde{y}_j = \tilde{w}_j/\tilde{x}_j$ be the rest-of-the-U.S. (N) and rest-of-the-world (W) direct water input coefficients that we both approximate by the measurements on the U.S. as a whole. Since we have access to the list of imports of intermediate goods and of final goods (or institutional goods), we decide to report them separately. The net virtual water flows are thus $\sum_i y_j l_{ij} e_j - \sum_i \tilde{y}_j \tilde{l}_{ij} m_j$, where e_j is the amount of exports in sector j, m_j is the amount of imports in sector j and $\tilde{l}_{ij}$ is the ijth element of the Leontief inverse of the U.S. matrix. If we define the direct value-added coefficient as $va_i = v_i/x_j$ and the direct employment coefficient as $o_i = s_i/x_j$ then an decrease in crop exports leads to the following decreases in value added (Eq.4) and in employment (Eq.5):

$$\sum_i va_i l_{ij} (\Delta f_i^N + \Delta f_i^W) \tag{4}$$

$$\sum_i o_i l_{ij} (\Delta f_i^N + \Delta f_i^W) \tag{5}$$

Note that value added in Eq.(4) does not include employment compensation.

Ultimately, a lesser local production requires less imports. If we define the direct import coefficient as $ma_i = m_i/x_j$, then Arizona's regional trade balance can be define as:

$$\left(1 - \sum_i ma_i l_{ij}\right)(\Delta f_i^N + \Delta f_i^W) \tag{6}$$

Additionally, we develop below a set of equations based on a theoretical $\$1/m^3$ increase in the price of water as in an input-output framework the underlying assumption is that the physical unit of