Global Environmental Change 29 (2014) 22–31

Contents lists available at ScienceDirect

Global Environmental Change

journal homepage: www.elsevier.com/locate/gloenvcha

International trade buffers the impact of future irrigation shortfalls

Jing Liu [a,*], Thomas W. Hertel [a], Farzad Taheripour [a], Tingju Zhu [b], Claudia Ringler [b]

[a] Department of Agricultural Economics, Purdue University, 403 W State Street, West Lafayette, IN 47907-2056, USA
[b] International Food Policy Research Institute, 2033 K Street, NW, Washington, DC 20006-1002, USA

ARTICLE INFO

Article history:
Received 25 October 2013
Received in revised form 2 July 2014
Accepted 24 July 2014
Available online

JEL classification:
C68
D58
Q01
Q17
Q25
Q56

Keywords:
Irrigation availability
International agricultural trade
Water–food nexus
CGE modeling

ABSTRACT

There is increasing interest in the water–food nexus, especially the restrictive effect of water on food production in hot spots where irrigation stress is growing. However, little is known about the larger-scale implications of future irrigation shortfalls for global trade and economic welfare, as well as of the potential buffering impacts of international trade on the local impacts of irrigation shortage. In this paper, we utilize a recently developed model, GTAP-BIO-W, to study the economic effects of changes in irrigation outlook for 126 river basins, globally by 2030. Projected irrigation availability is obtained from the IMPACT-WATER model, and imposed upon the present-day economy. Irrigation availability in 2030 is expected to drop by 30–60% in several key rivers basins, including: Hai He, Indus, Luni, and the Eastern Mediterranean basin, leading to significant output declines in China, South Asia, and the Middle East. We find that the regional production impacts of future irrigation water shortages are quite heterogeneous, depending on the size of the shortfall, the irrigation intensity of crop production, the possibility of expanding rainfed areas, as well as the crop mix. These changes in regional output significantly alter the geography of international trade. To compensate for the loss of productivity caused by the irrigation constraint, an estimated 7.6 million hectares of cropland expansion is needed to meet the demand for food. In spite of the remarkable reduction of irrigation in some basins, the resulting welfare impact is relatively modest as a result of the buffering capacity of global markets. The global welfare loss amounts to $3.7 billion (2001 prices) and results from a combination of the reduction in irrigation availability as well as the interplay with agricultural support policies.

1. Introduction

Agriculture is by far the largest user of the world's water resources, with 70% of global freshwater withdrawals being directed to irrigation (Molden, 2007). Agriculture's heavy reliance on water is largely driven by climate – in arid and semi-arid regions production would not be possible in the dry season without irrigation, by intensification needs on smaller land areas (irrigation often allows to grow a second crop) and by the type of crop grown (rice thrives under irrigated conditions). Indeed, 60% of cereal production in the developing world originates from irrigated lands (Bruinsma, 2009). However, when faced with water shortages, irrigated agriculture is also the most likely candidate for water rationing or is sometimes even abandoned (California's Colorado River Water Use Plan, 2000; Rosegrant and Ringler, 2000). Irrigators typically pay a small fraction of the water price charged to residential, industrial and commercial uses (Cornish and Perry, 2003), suggesting a relatively low-value use, at the margin – another factor pointing to irrigation as the balancing variable when supply shortages arise. This raises an important question: As competition for water intensifies in many parts of the world over the coming decades, what will be the impact on irrigated cropping, agricultural trade and food security?

The world appears to be facing a looming water challenge. By 2030 global water requirements are likely 40% greater than current supplies, and one-third of the world's population, mostly in developing countries, might live in areas where this deficit is larger than 50% (Addams et al., 2009). Alexandratos and Bruinsma (2012) argue that global water resources will be sufficient to feed the world, but the ''devil is in the details'' with water shortages causing high stress in specific localities. Falkenmark et al. (2009) argue that water shortages in some countries could be offset by food imports from water rich countries. In this vein, there is an emerging body of literature documenting the role of ''virtual water trade'' as a vehicle for achieving global water savings in the face of local shortfalls (Konar et al., 2013; Dalin et al., 2012; Lenzen et al., 2013).

Fig. 1 offers a conceptual overview of the water–food nexus. Most of the existing literature in this area focuses on some subset of the linkages portrayed in this figure. One set of studies, denoted by the blue arrow, aims to assess water footprints of agricultural

* Corresponding author. Tel.: +1 765 494 4321; fax: +1 765 496 1224.
E-mail address: liu207@purdue.edu (J. Liu).

http://dx.doi.org/10.1016/j.gloenvcha.2014.07.010
0959-3780/

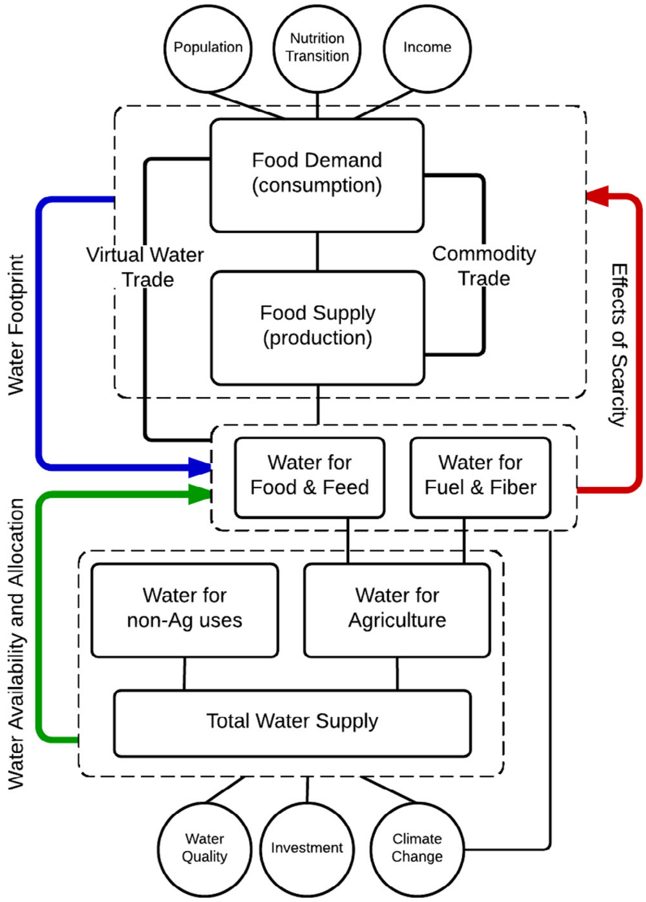

Fig. 1. Conceptualizing the water–food nexus.

production for domestic consumption and export at the global (Hoekstra and Mekonnen, 2012), national (Fader et al., 2011; Hoekstra and Chapagain, 2007) and city levels (Hoff et al., 2013). Because the assessment is based on the concept of a crop's virtual water content, this line of research often contains discussions about virtual water trade. The second key linkage in the water–food nexus focuses on water use for food production and factors that potentially exacerbate or mitigate the future water availability for food production (Gerten et al., 2011; Rosegrant and Cai, 2002). This is denoted by the green arrow in Fig. 1. Among these factors, agriculture's considerable dependence on irrigation has been a long-standing concern, which is drawing greater attention as more water is being claimed for municipal, industrial and environmental uses, thereby posing serious threats to water for food (Strzepek and Boehlert, 2010). Moreover, during the past decade, there has been a surge of interest in climate change and its impact on long-term and interannual variability of water demand and supply (Hejazi et al., 2013a,b; Kummu et al., 2013). More recently, the Renewable Fuel Standard enacted in 2005 and 2007 added a bioenergy link to water consumption, and started research on the "blue impacts of green energy" (De Fraiture et al., 2008; Gerbens-Leenes et al., 2009, 2012; Rosegrant et al., 2012a). Moreover, in water-stressed regions water resources are often already subject to degradation of water quality, thereby exacerbating shortages (Pereira et al., 2009). To address these growing shortages, investment in water infrastructure and on-farm technologies, crop breeding strategies, implementation of innovative water conservation measures and changes in policies can increase water use efficiency in both the agricultural and non-agricultural sectors, which, in turn, can make more water available for food (Rosegrant et al., 2009; De Fraiture and Wichelns, 2010).

Research related to the themes of water footprints and water availability and allocation aspects usually leans heavily on hydrological modeling (e.g. the LPJmL model by Gerten et al. (2004), CLIRUN-II by Strzepek et al. (2011) and WGHM by Döll et al. (2003)) or water management models (e.g. GCWM by Siebert and Döll (2010) and IWSM by Zhu et al. (2013)) to answer the questions "will there be enough water for food" and "what to do to secure the future of water for food". In contrast, the objective of this study is to explore a third aspect of the water–food nexus denoted by the red arrow in Fig. 1. Specifically, we seek to evaluate the impact of projected irrigation shortfalls on the overall economy and international trade in food products as well as on patterns of food production and demand. Understanding these broader impacts of irrigation stress is important since the large gaps between irrigation demand and supply in key producing regions will have to be closed by trade, and investment in and adoption of technologies; all of which will come at a cost. Thus, the consequences of less available irrigation will not only be felt at the local but also at the macro-economic level, the focus of this study.

We are aware of a few global-scale modeling studies that have attempted to understand the impacts of water availability through an integrated hydrologic–economic analysis approach, but most of them are partial equilibrium models which take macro-economic activity as given. These include: IMPACT (Rosegrant et al., 2012b), GLOBIOM (Schneider et al., 2011; Havlík et al., 2013), MAgPIE (Lotze-Campen et al., 2008; Schmitz et al., 2012) and WATERSIM (De Fraiture, 2007). Although a partial equilibrium model can provide excellent sectoral detail, it does not account for interactions across the economy through labor and capital markets or inter-industry linkages. These models also treat international trade in a simple way and abstract altogether from international capital flows. In seeking to overcome these limitations, Calzadilla et al. (2010) disaggregate irrigation in the GTAP global general equilibrium model. However, this pioneering work had serious limitations. Firstly, rainfed and irrigated production were treated as part of the same aggregate, national production function. So it was not possible to shut down irrigation in one region in favor of rainfed agriculture, or expanding irrigation in another region. Secondly, the model ignores the competition for rainfed land between agriculture and forestry. Thirdly, by specifying aggregate production relationships at the national scale, the model is unable to deal with scenarios in which different river basins in one country/region are differentially affected. As we will see below, this is a very common situation.

In this study, we first use the IMPACT-WATER model to assess the degree of irrigation stress at the scale of individual river basins, and then (in a sequential fashion) we embed these estimates within an extended version of the GTAP model GTAP-BIO-W to explore how changes in future irrigation availability for irrigation will affect crop production, food prices, and the resultant effects of these changes on bilateral trade patterns (Fig. A1). (Note that irrigation availability is defined as the share of potential irrigation demand realized through actual consumption, and it is estimated using the 1951-2000 monthly climatology representing average climate condition over that period.) Compared with previous studies, our approach allows for new interactions across sectors, which includes inter-sectoral linkages through intermediate inputs and competition for land, water, labor, capital and energy. Moreover, the model we proposed has the special advantage of analyzing bilateral trade flows and providing macro-economic impacts of irrigation shortfalls.

2. Methods

2.1. Model

The standard GTAP model is a multi-region, multi-sector, computable general equilibrium model, with perfect competition