Analysis

Are we in deep water? Water scarcity and its limits to economic growth

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\textbf{ABSTRACT}

Water is an important factor of production contributing both directly and indirectly to economic activity across all sectors and regions of the global economy. Water scarcity may therefore go beyond having important consequences for people, society and ecological systems but may also pose a threat to economic growth. Using the latest IPCC RCP projections and the OECD Shared Socio-Economic Pathways (SSPs) for population growth and economic output, we develop a multi-regional input-output model to estimate future demand for water resources across different countries and sectors of the global economy.

Model results show that most countries will experience declining water availability, particularly those countries that experience a confluence of factors including low fresh water availability, high climate change impacts, and growing consumption patterns. We show that virtual water trade and improved water efficiency has potential to alleviate the worst effects of water scarcity for wealthy countries but may have limited effect on poorer countries. The analysis concludes that the most important driver of future water scarcity is economic growth, which overwhelms any realistic savings that can be made from increased technological progress and improvements to water efficiency. Population growth and climate change are also shown to be important drivers of future water scarcity, particularly over the long-run.

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1. Introduction

Freshwater availability in sufficient quality and quantity is one of the major challenges that society will face this century. Freshwater represents just 2.5% of Earth's water and is increasingly threatened by human (economic) activity and climate change. Many studies have confirmed that water scarcity will increase significantly over the coming decades and this will bring problems for food security, environmental sustainability, and economic development (Alcamo et al., 2007; Ervin and Hoekstra, 2012; Hoekstra, 2014a,b).

The Intergovernmental Panel on Climate Change (IPCC) reported that unabated climate change has the potential to strongly impact freshwater resources with wide ranging consequences for societies and ecosystems (Murray et al., 2012; Pachauri and Meyer, 2014). At present about two-thirds of the global population presently live in conditions of severe water scarcity for at least 1 month of the year and half a billion people face severe water scarcity all year round (Mekonnen and Hoekstra, 2016). Climate change is predicted to exacerbate water scarcity even further. Hydrological cycles are predicted to undergo large changes and cause global shifts in precipitation patterns as well as increase the frequency and severity of extreme events (Bates and Kundzewicz, 2008). Significant regional differences exist across the globe leading to simultaneous increases and decreases in land-surface run-off depending on latitude, altitude, and other geographic factors. In general, wet areas will tend to get wetter and dry areas will get dryer, leading to less reliable water availability (Kumar et al., 2013). While there is considerable uncertainty in modelled precipitation and evapotranspiration projections at high resolution, regional trends allow the comparison of different climate change scenarios over time.
The frequency of heavy precipitation over most areas is predicted to increase with the consequences of rain-generated floods potentially overwhelming existing infrastructure leaving little opportunity for water storage. The likelihood of extreme droughts is also predicted to increase with a tendency for continental interiors to dry during the summer, especially in the sub-tropics and low and mid-latitudes. One recent example that has been attributed to global warming was the 2003 heat-wave in Europe (Schar et al., 2004) contributing to annual precipitation deficits of up to 300 mm and an estimated 30% drop in gross primary production of terrestrial ecosystems (Ciais et al., 2005). Events like this highlight the significant impact that water scarcity can have on economic productivity. Changes to the atmospheric water content, intensity of extremes, reduced snow cover, widespread melting of ice, changes in soil moisture and droughts are therefore predicted to exacerbate water scarcity problems in the 21st century (Bates and Kundzewicz, 2008).

This analysis uses the latest scientific evidence for quantifying the likely effects of climate change on water scarcity across the globe under different climate change scenarios (i.e., IPCC AR5). However, there are other dynamic factors that must also be considered, these include economic growth, technological progress, national water endowment, structure of production (at sectoral level), international trade, and population growth. This analysis captures the dynamic interaction of these different factors on water scarcity out to 2100. While most of the existing literature has focused on the link between water scarcity and economic activity this work highlights the importance of considering water scarcity in the context of climate change.

The novelty introduced by the present study is given by the combination of two measures of water scarcity, which take into account the social needs (i.e., providing enough water for social and economic requirements) and the physical constraints imposed by water availability, driven by climate change. We assess the social and economic effects of water scarcity by country and by sector, applying a multi-regional input-output model (MRIO), extended with water intensity coefficients. It goes beyond the previous global water demand scenario studies because the MRIO approach allows the recovery of the whole supply-chains, both at national and global levels, and to calculate both the direct and indirect feedback effects due to inter-industrial linkages in the global economy, between now and 2100. In the analysis that follows we disentangle these different effects and identify the main drivers of water scarcity over the next century. Using four different climate change scenarios and data on global trading patterns we assess the respective social and economic effects of water scarcity by country and by sector. We proceed with a multi-regional input-output model (MRIO) extended with water intensity coefficients and calculate both direct and indirect water consumption between now and 2100. We then apply sectoral production functions to describe the trade and production relationships for 35 sectors across all major OECD countries, their major trading partners and a selection of large emerging economies.

The main research questions we aim at answering include (i) what are the main drivers of water scarcity over this century?, (ii) what will climate change have on water scarcity?, (iii) can virtual water trade and technological progress stem the economic impacts of scarce water?, and (iv) what sectors and regions are most impacted by water scarcity?

The paper proceeds in Section 2 with a short review of the literature. Section 3 describes the main methods that were used and Section 4 gives details on the data and various definitions. The mathematical models are derived and presented in Section 5. The discussion of the results is given in Section 6, while Section 7 develops the sustainability assessment and it provides the implied technological progress. Section 8 briefly explains the main uncertainties and limitations. Finally, Section 9 discusses the implications of the main results for future water management and policy.

2. Review of Literature

Existing studies have largely used the concepts of virtual water (VW), introduced by Allan (1993), and “water footprint” (WF) (Hoekstra et al., 2011) to study the changing global landscape and the embodied trade of scarce water resources. The former (VW) returns the water embodied in traded goods outside national borders and excludes domestic consumption. The latter (WF) includes the water embodied in goods throughout the entire supply chain on a consumption basis.

One commonly used method to calculate VW trade and WF is the multi-regional input-output (MRIO) model. IO tables express the monetary value of economic transactions occurring across sectors of an economy to account for sectoral interdependencies in the economic system. MRIO models have been widely used to calculate the consequences of international trade on regional water footprints (e.g., Antonelli et al., 2012; Duarte and Yang, 2011; Lenzen et al., 2013). These studies are particularly useful as they assess the effect of international trade on domestic water resources, the effect of water availability on international trade, and the consequences of international trade to improve or worsen the effects of global water scarcity (Hoekstra et al., 2011).

Recently, the attention is shifted from an ex-post static calculation towards an ex-ante scenario analysis for enhancing the policy relevance of water scarcity under different climate change scenarios. Alcamo et al. (2007) analysed the change in blue water (surface and groundwater) withdrawals for two alternative trajectories for population and economic growth, based on the A2 and B2 IPCC scenarios, finding that the principal cause of increasing water stress is growing domestic water use stimulated by income growth. De Fraiture (2007) elaborated four alternatives scenarios for 115 countries in order to provide alternative strategies for meeting the increasing demands for water and food by 2050. Energy production, local action, and climate change were found to be the most crucial variables for improved water management. Erinc and Hoekstra (2012) developed four virtual water footprint scenarios, until 2050, based on population and economic growth, production/trade patterns, consumption patterns, and technological development. They stated that reducing humanity’s water footprint, to sustainable levels, is still possible even under the assumptions of increasing population, provided that consumption patterns change. Dalin et al. (2012) estimated the evolution of the virtual water trade network, using as control variables GDP, rainfall on agricultural area and population. They found that few importing countries are likely to concentrate a significant portion of virtual water trade through food commodities. Konar et al. (2016) projected international staple crop trade and the related water footprint under climate and policy scenarios for the year 2030. They found that trade liberalization should lead to increasing water exploitations with higher WF.

In the context of IO modeling, most of the scenario analyses have been devoted to the estimation of future carbon emissions (e.g., Koning et al., 2016; Lutz and Wiebe, 2012; Scott et al., 2013), to the economic effects of climate change (e.g., Dellink, 2013), or to the impact of the power sector on water resources (e.g., Wan et al., 2016). The aim of this paper is to apply the MRIO approach to compare future scenarios (e.g., Duchin and Levine, 2016) on scarce water resources. To the best of our knowledge, this is the first time an MRIO model has been used to assess the sustainability water resources considering the multiple confounding factors of economic growth, technological progress, water availability, population dynamic, and climate change based on the most recent IPCC AR5 projections.

3. Method

In line with best practice in climate change research, we use pre-defined IPCC climate change scenarios to explore the long-term
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