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Can Input-Output Data Inform Agri-food Supply Network Reconfiguration? The Case of Water-Intensive Crop Production in Developing Economies

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Abstract

This paper identifies opportunities to facilitate agri-food supply network reconfiguration, using publicly available input-output data platforms to generate insights into the water intensity of crop production. Making reference to the Indian economy, it is shown that intuitive analytics can be rapidly developed to unravel complex patterns of production and consumption in global value networks, and the pressure exerted on freshwater resources at specific locations. The potential use of the evidence thus obtained to support alternative crop policy scenarios and agri-food supply network configurations is discussed, with an emphasis on the need to inform a possible transition away from highly specialized cropping patterns.

Keywords: Input-Output Analysis; Embedded Virtual Water; Agri-food; Supply Networks; India

1. Introduction

Understanding the pressure on freshwater resources as it changes over time is no longer the province of hydrological and climate modelling. In making global location and procurement decisions, businesses now engage more systematically in the assessment and disclosure of water-related risk across their supply chain operations. For example, with the aid of online water risk screening tools developed by the WWF (World Wide Fund for Nature), a major UK retailer reported that, in 2016, one in eight of its food suppliers were growing products in areas considered to be 'high risk', and acted upon it through targeted water stewardship initiatives within its operations (M&S, 2016). In principle, a number of tools provide accessible, geospatially specific information on water availability and water resource management at a global scale – for an early comparison, see WBCSD (2012). In practice, industry largely relies on expertise developed in-house when evaluating the interrelationships between their supply chain operations and the exposure to water-related risk at specific locations (South Pole Carbon Asset Management Ltd., 2017).

There seems to be no obvious alignment between information about the status of location-specific freshwater resources, referred to as 'background system', and information about the configuration and behaviour of product-specific supply networks, referred to as 'foreground system'. For example, in the agri-food industry a common way of mitigating water risk is through procurement practices that comply with third-party certified agricultural standards; yet, most standards fall short of ensuring that indirect water use along the supply chain is satisfactorily evaluated (Morgan, 2017). At the product level, the notion of 'water footprint' is often employed to express the use of freshwater across relevant production activities; however, its methodological consistency with assessments carried out at wider geographical scales is still debated (Fang et al., 2014).

The agri-food sector in India offers a prominent example where reaching better alignment between the aforementioned 'background' and 'foreground' system information can be particularly beneficial. In the late 1950s targeted technology interventions ruled out fears of having reached carrying capacity, ensuring unprecedented productivity of staple grains; however, mounting evidence suggests that excessive reliance on these measures has taken its toll on the natural environment, especially freshwater resources, besides proving inadequate to meet changing expectations in terms of livelihood and nutrition for the broader population – Pingali et al. (2019: Ch. 9), provide an overview. Alternative crop policy designs and agronomic practices are now expected to improve freshwater use, while enhancing farmers' livelihood through better coordination along the agri-food supply chain.

In the context outlined above, this paper aims to explore the untapped potential of publicly available data, and well-developed analytical frameworks to generate actionable knowledge about current or future agri-food supply network configurations, and the associated pressure on freshwater resources. To keep reasonable scope, the emphasis is placed on the agri-food sector in India. In the following sections, the need for a coherent, empirically-relevant analytical framework is discussed, identifying available data and approaches. Key concepts are illustrated through a simplified example, and the insights thus generated are discussed. The paper closes outlining possible developments within a collaborative research programme involving a wide network of UK and Indian experts with a focus on sustainable crop production and sustainable resource use.

Table 1. Exemplar uses of macro-level data to model supply networks quantitatively (non-comprehensive)

Reference	Sector/Commodity focus	Approach			Marco-level data		Geography focus
		LCA	IOA:EE/MR	Other	Source	EE Focus	
Rehkamp and Canning (2018)	Food basket/diet		●		Country-specific	W	USA
OECD (2018)	Agriculture and Food		●		GTAP[*]		IN
Acquaye et al. (2017)	Electricity		●		WIOD[*,†]	W,C	
Dalin et al. (2017)	Various crops			●	FAOSTAT[†]	W	
Genovese et al. (2017)	Waste cooking oil; chemicals	●	●		Country specific + GTAP[*]	C	UK
Lutter et al. (2016)	Various crops		●		EXIOBASE[*,†]	W	EU
Pelton and Smith (2015)	Breakfast cereals	●	●		Country-specific	W,C	USA
Backer and Miroudot (2013)	Hazelnut spread; chemical; electronics				OECD[*,†]		
Lenzen et al. (2013)	Various crops				EORA[*,†]	W	
Weidema et al. (2008)	Meat and Dairy		●		EUROSTAT[*,†]	C	EU

Notes: [*]Data provided as an input-output table; [†]Accessible free of charge; W: Freshwater; C: Greenhouse gases; LCA: Life Cycle Assessment; IOA: Input Output Analysis; MR: multi-regional; EE: environmental extensions.

2. Literature overview

A comprehensive overview of the structure of agri-food supply chains in India is provided by OECD (2018). The management of backward and forward linkage along the Indian agri-food supply chains is a crucial aspect of the debate on a possible transformation of the current agricultural landscape away from staple grains through targeted technological and institutional interventions. The downstream supply chain is a blind spot for farmers, who have high transaction cost and low bargaining power in highly mediated markets – a configuration that ultimately can be detrimental for produce quality (Gardas et al., 2019). Upstream, vertical coordination through contract farming, digital platforms and the organised aggregation of farmers is regarded as crucial for improving livelihood, linking smallholders to markets and suppliers more effectively (Pingali et al., 2019: Ch.8). From an environmental resource perspective India's agriculture make up nearly 90 % of water use, with deteriorating water availability, and lack of clear incentives for the efficient use of water (OECD, 2018).

Besides Country-specific issues, the geographical dispersion of specific agri-food supply networks, and the potential intricacies of international trade further complicated estimating the overall repercussions of structural changes and alternative crop policies. At the macro-level, a number of high-resolution maps of the networked world economy capture interdependencies between countries, sectors and the natural environment. Whilst coarser than data commonly employed by supply chain analysts, these maps generate tremendous insights into the structure of global value networks, irrespective of environmental considerations (Backer and Miroudot, 2013). With specific regards to India's agri-food sector, an exemplar application can be found in OECD (2018). Environmentally-extended Input Output Analysis (EE-IOA) further expands these datasets through satellite accounts, enabling the evaluation of environmental pressures exerted by product-specific supply chains. For example, by taking into account the interdependencies between national economies and individual sectors within an economy, it was estimated that in 2007 the EU was the larger importer of embodied freshwater, whereas most of the uptake occurred in the Asia Pacific region (Tukker et al., 2014). Consumption of processed crop products was identified as being by far the largest contributor to the foreign share of freshwater consumption in the EU, with spatially-specific repercussions traced all the way back to distant watersheds such as the Indus and the Ganges (Lutter et al., 2016). Conversely, in the supply chain and operations management (SC&OM) domain it is not uncommon to centre the analysis on the focal company and its most immediate tiers, while maintaining a fairly agnostic perspective with regards to how certain environmental aspects are attributed to specific products or processes – see for example Schaefer et al. (2019). Similarly, water footprint assessment is key in investigating the relationship between supply network configuration and sustainable practices, but only in terms of the maturity achieved by individual organisations (Srai et al., 2013). This methodological agnosticism is perhaps not too surprising considering that approaches such as LCA are mainly regarded as means to 'quickly' achieve greater scope in capturing environmental impact metrics, without imposing on specific supply chain actors the burden of gathering primary data they may be reluctant to share (Pagell and Shevchenko, 2014). The use of quantitative insights into global value networks, and the broader economic landscape remains an exception in SC&OM.

While methodological comparisons are beyond the scope of this paper, Table 1 summarises selected applications that deploy macro-level data to introduce a broader perspective on specific supply chains, capturing key structural aspects, highlighting when possible the available datasets, and whether these are readily accessible.

3. Simplified case development: approach and key findings

The aim of this section is to illustrate the use of existing Input-Output data platforms to gain insights into the current-state configuration of global value networks for specific agri-food product families and geographies. Discussion of the results thus obtained will provide directions on informing the design of alternative configurations enabled, for example, by innovative agronomic technologies and practices. Achieving this aim involves the formulation of concise, replicable and actionable indicators unravelling key structural interdependencies within and between national economies for exemplar agri-food supply networks; as well as quantifying and visualising virtual water embodied in such network, capturing the direct and indirect pressure on freshwater resources. Whilst relevant data may be readily accessible, ad hoc analytics need to be developed. These are further discussed in dedicated sub-sections below.

3.1. Linkage-based segmentation of agri-food sectors

Most real-world systems of national accounts can be described by means of Input-Output tables (IOT) portraying the supply and use of goods and services in a National economy. This specific representation captures in an empirically-relevant fashion the 'networked' nature of an economy, enabling the development of metrics that concisely express the economic connectedness of specific sectors. In particular, measures of inter-sectoral *backward* and *forward* linkage can be used to summarise, respectively, the strength of a given sector's reliance on inputs provided by the rest of the economy, and the support provided by a given sector to the rest of the economy through its output. These measures are further distinguished as either direct or total, depending on whether only direct economic linkage between sectors (similar to 'tier 1' in a supply chain) is considered, or not.

With specific reference to the Indian economy Figure 1, left-hand side, illustrates the combination of forward and backward linkage indicators to obtain a segmentation of 30 agri-food sectors. Indian IOTs provide greater detail into Agriculture, closer to individual crops. Due to space constraints, detailed computations are omitted. Standards notions of backward and forward linkage apply (Miller and Blair, 2009: Ch. 12), and publicly available data were used (Central Statistics Office India, 2012). Singh and Saluja (2018) discuss some limitations of the official data available for India, and update the analysis to include more recent years.

The 2-by-2 classification matrix in Figure 1, left-hand side, shows that, despite being tied up in a major crop rotation, wheat and rice (paddy) are structurally different as they fall, respectively, in the 'Generally independent' and 'Dependent on interindustry supply' quadrants. For wheat, both backward and forward linkage in the domestic supply chain are weak compared to other agri-food sectors (i.e. their normalised values are less than one), whereas rice (paddy) relies more strongly than other sectors on a domestic supply base (i.e. normalised backward linkage is greater than one). Most aggregate crops sectors are generally independent: 65 % considering direct linkage only (i.e. tier-1 suppliers); and 80 % considering total linkage. Only 10 % of agri sectors (2 crops: paddy and jowar) are capable of generating some 'pull' for the rest of the Indian economy if an expansion in their output occurs, as these are dependent on inter-industry supply. Finally, the agri sectors' output provide limited support to the rest of the economy, as only one fourth have normalised direct forward linkage above one (only jute and rubber based on total linkage). Conversely, most food sectors are generally dependent on inter-industry supply, with the exception of egg and poultry. Figure 1, right-hand side, highlights 'key' agri-food sectors, that is, those sectors that are relatively more important for, than reliant on the rest of the economy.

It is worth noting that backward/forward linkage analysis has also been applied at the State level – for example Saluja and Sarma (1991) compare the structure of Punjab and Assam economies. However, IOT at the State level are the mainly produced by individual research groups, and hence sporadically available.

3.2. Water embodiment in agri-food networks

The analysis presented in the previous sub-section has emphasised some aggregated measures of the 'importance' of agri-food sectors for the rest of the Indian economy based on each sector's input structure determined through economic transactions. This purely economic perspective can be complemented by a "water footprint" that accounts for all the water inputs along the supply chains of the goods finally consumed in a country, thus providing an estimate of the pressure on the global hydrological system due to such consumption – Fang et al. (2014) review this concept in greater depth. In practice, the evaluation of freshwater use across economic production and consumption activities may operate at multiple scales: country/region (macro); company/supply chain (meso); and individual product (micro). From a methodological perspective, there seems to be greater consensus around data and approaches developed at the 'extremes' of this spectrum, in particular Life Cycle Assessment (LCA) at the micro-scale, and environmentally-extended Input Output Analysis (EE-IOA) at the macro-scale; whereas at the meso-level, methodologies are less likely to align (Fang et al., 2014). Hence micro and macro perspective are often juxtaposed to expedite hotspot identification across the supply chain –see Pelton and Smith (2015) for an application to food products.

While multiple data platforms for EE-IOA-type analysis are available, some of which are mentioned in Table 1, they all rely on the same coherent, empirically-driven analytical framework – Tukker et al. (2014) introduce the key principles to the general reader, while providing key indicators by Country, including India.

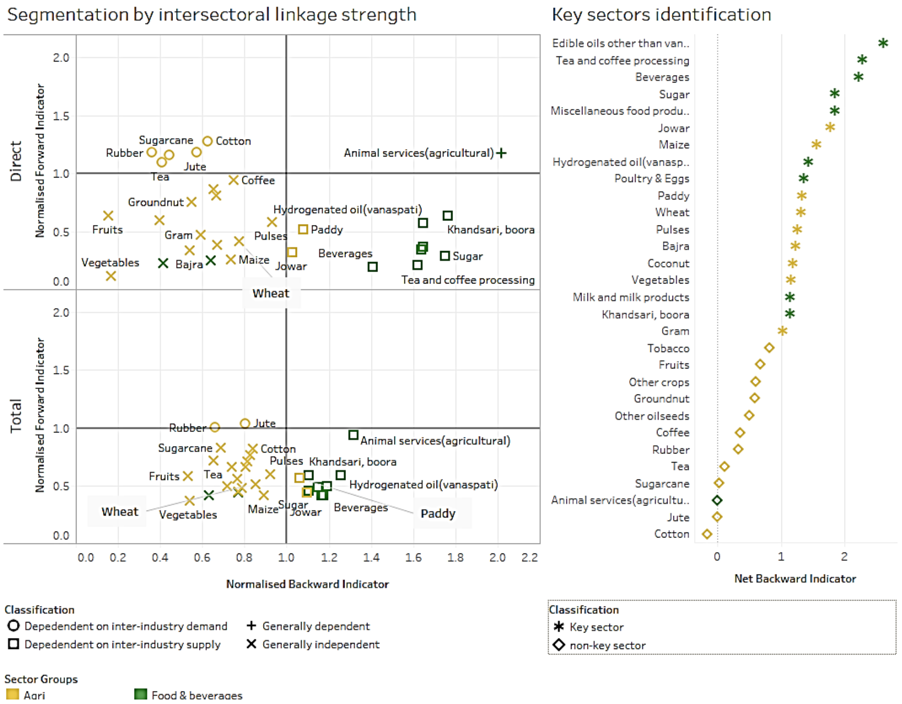

Figure 1. Segmentation of Indian agri-food sectors based on combined backward/forward linkage using Country-level Input-Output data for the year 2007-08. Raw data source: Central Statistics Office India (2012).

For the purposes of this research, EXIOBASE 3 (Stadler et al., 2018) was chosen as a data platform, since it offers an IOT time series with the highest level of granularity for the agriculture sector (8 crop products, with distinct indication of wheat and paddy rice) across 40+ Countries, including India, and over 17 years. To operationalise the concept of 'water embodiment', economic transactions are valued using 'virtual' water as a currency. In principle, this is analogous to a standard Leontief price models, whereby the unit worth of each sector's output must equal the value of the inputs received from any other sector (their unit worth being determined simultaneously) and the sector's value added – see Miller and Blair (2009: Ch 2). However, in this case water consumption satellite accounts are used instead of a sector's value-added vector. A key assumption of this method is that the allocation of water resources is proportional to the monetary inter-industry flows captured by IOTs.

For illustrative purposes, Figure 2 shows the results obtained for a subset of transactions between the UK and India with virtual water ≥ 5 m^3. As before, computations are not disclosed due to space constraints. From Figure 2 it can be noted that the food service sector in India is the most connected node in terms of number of virtual water-valued inbound and outbound links, including links with the UK's Chemicals and fertilisers and food products not elsewhere classified (n.e.c.). Most water-intense flows can be identified from the thickness of the arrows in Figure 2, including the input of 1) crops n.e.c. from India into the UK's tobacco products, food products n.e.c., cattle, and raw milk; and 2) Chemicals n.e.c. into the UK Health and social services. There is also a significant link between India's processed rice sector and the UK food services and process foods sectors.

4. Discussion and future directions

Findings from the previous section combine elements of global value network analysis and water intensity analysis for a simplified case based on India's national economy. Publicly available data were used to show how structural differences across agri-food sectors determine their ability to support or generate an expansion in other sector's output. It was also shown that these economic dependencies can be valued in terms of virtual water flows that they directly and indirectly embody. Despite the level of granularity being coarser compared to what is typically expected in SC&OM, the chosen data platform provides unprecedented opportunities to identify key structural aspects of agri-food supply networks (see e.g. Backer and Miroudot, 2013).

With specific regards to India, the need for a transition away from highly specialized cropping patterns has fuelled the debate on alternative crop policy designs and agronomic practices such as Sustainable Intensification and Conservation Agriculture (Pingali et al., 2019: Ch. 9). To date, only few studies offer data-driven insights into the broader context of global value networks e.g., OECD (2018). In term of the analysis of water embodied in agri-food products, India is typically addressed as a 'final receptor' of environmental pressures caused by distant consumption patterns – see, for example, Lutter et al. (2016). This work has emphasised the interface between modelling water use for sustainable livelihoods, and the design of alternative agri-food supply network configuration models, while retaining the necessary clarity to inform targeted regional interventions.

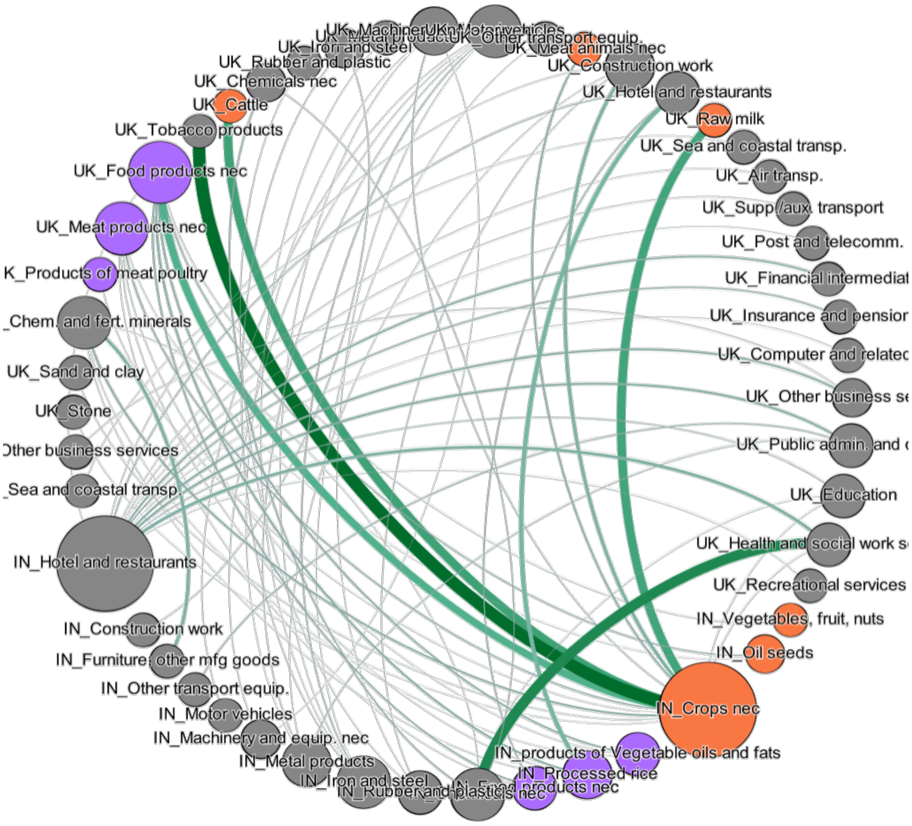

Figure 2. Water embodiment for a subset of UK-India transactions (reference year: 2011). Arcs weight proportional to virtual water intensity. Raw data source: Exiobase 3 MR-IOT (https://www.exiobase.eu).

In particular, by combining elements of global value network analysis and water intensity analysis for a simplified case based on India's national economy, the findings presented in the previous section align well with the remit of initiatives aiming at strengthening the dialogue between researchers, industry, government and NGOs in the UK and India, such as the TIGR^{2}ESS programme (https://tigr2ess.globalfood.cam.ac.uk/).

As greater emphasis is placed on striking a balance between improving freshwater resource use while ensuring farmers' livelihood, the scope of the analysis is likely to shift from Country-level to individual States to better capture spatially-explicit differences in terms climatic and agronomic features. State-level analysis can be quite rich when it comes to structural changes and natural resources – the case of Punjab provides a prominent example (Singh and Singh, 2016). However, multi-regional analysis capturing flows across States is not available for India. A closer look at State-level IOT, and their environmental extension to include the use of freshwater resources is beyond the scope of this work and should be addressed in future research.

5. Conclusions

This paper has touched on the need to evaluate targeted interventions aimed to improve water use in agri-food supply networks in terms of implications for the wider national/global economic system. Particular emphasis is placed on the importance of identifying and leveraging available datasets to bridge disciplinary silos, and to inform future policy interventions that are necessary for transforming livelihoods. While the chosen analytical framework pertains to the field of macroeconomic analysis, it is argued that suitable exploration of coarser, but promptly accessible data may benefit businesses examining natural resource-related constraints on alternative factory locations; as well as technologists and policy makers evaluating the broader repercussions of alternative agronomic technologies and practices. An example illustrated the use of data available for India to highlight differences across agri-food sectors in terms of their ability to support/generate an expansion in other sectors' output; and to visualise key dependencies in terms of virtual water intensity, between the UK and Indian economies. Future work should address State-level interventions more explicitly, to informing a more sustainable use of water, build resilience in supply chains for food producers and consumers alike.

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