Vulnerability of the Belt and Road Initiative to External Water Dependency

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Abstract. The Belt and Road Initiative (BRI) was proposed by China, aiming to promote multilateral cooperation with the world. However, existing studies have shown the external water dependency of the Initiative on the rest economies (Non-BRI), which may enhance the vulnerability of production activities in BRI. To understand the vulnerability of the BRI to water scarcity in Non-BRI, this study evaluates the impacts of water scarcity in Non-BRI on BRI by using a multi-regional input-output model. Results show that among all BRI, China, South Korea, Russia and India were most vulnerable to water scarcity in Non-BRI, especially Spain, Sudan, the United States and Australia. Water scarcity to Agriculture sectors of Non-BRI exerted widespread influences on the BRI trade system. This study analyses the vulnerability of the BRI induced by water dependency on Non-BRI by identifying critical nations and sectors, and informs stakeholders of the BRI to pay attention on the water scarcity of their upstream to mitigate the supply chain risk, and thus achieve sustainable development.

1. Introduction
External water dependency and water scarcity are supposed to make water scarcity risk (WSR) a supply chain threat [1]. In globalized economy, increasing dependencies on external water resources through importing virtual water from elsewhere have been an international trend [2-4]. Unfortunately, this trend is unsustainable due to increased water scarcity faced by exported regions [5]. Water scarcity in these regions, induced by various drivers including population growth, economic development, and climate change, may lead to insufficient physical water resource input for the production of exported products. The impacts of local water scarcity (i.e., local water scarcity risk, LWSR) can transcend geographical boundaries through global supply chain and exert potential influences on far distant regions, which is referred to virtual water scarcity risk (VWSR) to these regions. In other words, downstream economies are vulnerable to the water scarcity faced by their upstream suppliers as a result of water resource dependency. Due to imports of food irrigated from rapidly depleting aquifers, America, Mexico, Iran and China, are particularly faced with VWSRs and there exist some possibilities of food shortage caused by the suppliers’ lack of water resources [6]. In such circumstances, local water-related issues have an effect on global economic system.

However, the majority of researches on trade and water resource focus on the impacts of trade on water resource environment [7-9], without further exploring the impacts of water-related issues on the considered economic system, which could reveal the additional risk faced by a region due to water
scarcity in other regions. Considering the importance of water resource to economies, Qu et al. [10] investigate the influences of LWSR to the global trade system, and identify top sectors in certain nations which are vulnerable to water scarcity in distant nations by employing an extended method based on multi-regional input-output (MRIO) models [11]. Based on this method, Zhao et al. [12] evaluate the potential impacts of climate change on the global trade system through decreasing water supply in regions of the world. Given the great pressures on water resources of China induced by its rapid economic growth, Zhao et al. [13] measures the influences of LWSR on inter-provincial trade system using China’s MRIO data. Results based on these researches reflect the transboundary influences of local water-related issues, and reveal the need for nations as well as regions to collectively manage water resources.

The Belt and Road Initiative (BRI), namely, the Silk Road Economic Belt and the 21st century Maritime Silk Road, was proposed by China in 2013 [14], which aims to promote trade cooperation with the world. Since it was put forward, more and more scholars pay attentions on its sustainable development from the perspective of trade and resource environment. Specifically, given the uneven distribution of water resource, Fang et al. [15] investigate virtual water trade between BRI countries and the rest economies, and show BRI’s dependencies on water resource of the rest. Water dependencies on the rest may increase the vulnerability of the BRI trade system to water scarcity, and become an obstacle for its sustainable development. Thus, it is urgent to analyze the impacts of the dependencies.

The objective of this study is to explore the impacts of LWSR in Non-BRI to BRI countries (table 1) based on a method developed by Qu et al. [10], namely the distribution of VWSR from Non-BRI to BRI. In this study, we identify the critical nation-sectors in VWSR exports (local water scarcity risk in each economy transmitted to others through its exports) to BRI, as well as top nation-sectors among BRI countries in VWSR imports (the vulnerability to external water scarcity risk through global supply chain). Results of this study can provide suggestion for strategy development to mitigate the supply chain risk.

2. Materials and methods

2.1. Quantifying local water scarcity risk

In the globalized economy, water scarcity risk to a certain nation includes direct and indirect parts. The direct part refers to the potential economic output losses due to local water scarcity, namely, local water scarcity risk (LWSR), and the indirect part is the potential output losses due to water scarcity in its upstream suppliers, namely, VWSR imports. LWSR at sector level is evaluated in relative rather than absolute terms, and is mainly related to three factors, freshwater consumption, available surface and groundwater, as well as the related economic production, as shown in eq.1, proposed by Qu et al. [10]:

\[
LWSR_{s,n} = WDR_n \times WD_{s,n} \times x_{s,n}
\]  

where \(LWSR_{s,c}\) refers to the possible direct economic production losses of sector \(s\) in country \(c\) due to local water scarcity. \(WDR_n\) (water deprivation risk of nation \(n\)) is defined as the potential proportion of declined water use caused by water scarcity. \(WD_{s,n}\) (water dependency in sector \(s\) of nation \(n\)) refers to the share of economic production losses induced by one percent water deprivation. \(x_{s,n}\) represents the total economic production in sector \(s\) of country \(n\), when any water deprivation doesn’t occur.

The indicator WDR (\(\in[0,1]\)) is built from a probabilistic view, and is converted by the Water Stress Index (WSI) through dividing water consumption by potential water supply at nation level. Let the ratio of available water resource to total water consumption in a certain particular spatiotemporal unit be a random variable \(X_n\), which is assumed to correspond to lognormal distribution, with the median value of the availability-to-consumption at nation level (inverse of \(WSI_n\)), and standard deviation \(\sigma\). The function of WDR at national level is built by Qu et al. [10], as shown in eq.2:
$WDR_n = f_{WDR}(WSI_n; \sigma) = \begin{cases} 0 & \text{if } X_n \geq 1 \\ \frac{1}{E(1 - X_n)} & \text{if } X_n < 1 \\ \end{cases}$

where $u_n = \log \frac{1}{WSI_n}$. In this study, the standard deviation $\sigma$ is 1.5 to control the heterogeneity of WDR among nations.

The indicator WD ($\in [0, 1]$) is converted from sectoral water intensity ($WI \in [0, +\infty)$), which refers to consumptive water use for unitary economic output at sector level [10]:

$WD_s = f_{WD}(WI_s; \beta) = \frac{1}{1 + e^{-\beta WI_s^{1.001}}} \tag{3}$

where $WD_s$ and $WI_s$ refer to water dependency and water intensity of sector s. And $\beta$ (=14 in this study) is used to control the critical value of WI based on which WD grows quickly close to 1.

2.2. Quantifying virtual water scarcity risk

For quantifying VWSR, the Ghosh inverse matrix [16] is employed to evaluate the impacts of LWSR on a certain economy [10]:

$\Delta X = diag(LWSR) \times (I - B)^{-1} \tag{4}$

where $\Delta X$ is a matrix, elements in each row of which refer to the economic output changes in each nation-sector caused by LWSR of the row sector, and elements in each column of which refer to the economic output changes of the column sector induced by LWSR of sectors represented by each row. $diag(LWSR)$ is the diagonalization of vector LWSR. $G = (I - B)^{-1}$ refers to the Ghosh inverse matrix [16], which is converted from the MRIO model, and can measure the supply-driven effects in the economy.

To quantify VWSR exports and imports of each nation, let the global economies include n nations, and M be an nxn matrix, each element ($n_{kl}$) in which refers to the impact of LWSR in nation k on the economic output of nation l. Thus, $n_{kl}$, VWSR exports ($VWSR_{k}\text{ex}$) and imports ($VWSR_{k}\text{im}$) for a nation can be written in eq.5, eq.6 and eq.7, according to Qu et al. [10], respectively:

$n_{kl} = \sum_{i \in \text{nation } k} \sum_{j \in \text{nation } l} n_{ij} \Delta x_{ij} \tag{5}$

$VWSR_{k}\text{ex} = \sum_{k \neq l} n_{kl} \tag{6}$

$VWSR_{k}\text{im} = \sum_{l \neq k} n_{lk} \tag{7}$

where $\Delta x_{ij}$ is the impact of LWSR in nation-sector i on the economic production of nation-sector j.

### Table 1. The Belt and Road Initiative (BRI) countries

| Region | Countries |
|---|---|
| Asia 43 | Brunei Cambodia Indonesia Laos Malaysia Myanmar Philippines Singapore Thailand Vietnam Afghanistan Bangladesh Bhutan India Maldives Nepal Pakistan Sri Lanka Armenia Azerbaijan Bahrain Georgia Iran Iraq Israel Jordan Kuwait Lebanon Oman Qatar Saudi Arabia Syria Turkey United Arab Emirates Yemen Kazakhistan Kyrgyzstan Tajikistan Turkmenistan Uzbekistan China Mongolia South Korea |
| Europe 20 | Albania Belarus Bosnia and Herzegovina Bulgaria Croatia Czech Republic Estonia Hungary Latvia Lithuania Moldova Montenegro Poland Romania Russia Serbia Slovakia Slovenia Macedonia Ukraine |
| Africa 5 | Egypt Ethiopia Madagascar Morocco South Africa |
| Americas Oceania 2 | Panama New Zealand |

2.3. Data source

The Eora26 database (www.worldmrio.com) from 2001 to 2013 in base price is employed. Further, we choose the data in 2013 as the base year, and convert Eora database in all current-price in the investigated period to constant price in 2001. The consumptive blue water is from the Eora26 database,
and the water availability refers to “total renewable water resource \( (10^9 \, m^3/\text{year}) \)” in FAO. The BRI countries involved in this study and map of the BRI is shown in Table 1 and figure 1, respectively.

**Figure 1.** Route of the Belt and Road Initiative (BRI), namely, the Silk Road Economic Belt and the 21st Century Maritime Silk Road.

### 3. Results and discussion

**Figure 2.** Top ten countries ranked in VWSR imports from Non-BRI (A), and that in VWSR exports to BRI (B) during 2001 to 2013. Figure 2 reveals the trends of VWSR from Non-BRI to BRI during 2001 to 2013. According to figure 2A, VWSR imports were increasingly concentrated in a few BRI countries, with share of top ten BRI totally growing from 62.1% in 2001 to 71.5% in 2013. Individually, top importers differed significantly during the period. For instance, China, South Korea, Russia and India gradually occupied the largest share of VWSR imports from Non-BRI, with a share increasing from 11.7%, 5.7%, 3.3% and 5.2% in 2001 to 25.4%, 13.9%, 6.1% and 6.0% in 2013. However, it is the opposite to countries such as Turkey, the share of which decreased from 14.2% in 2001 to 3.5% in 2013. Similarly, VWSR exports to BRI significantly concentrated on a few Non-BRI countries, and the total share of top ten
exporters in each year during the investigated period was more than 90%, as shown in figure 2B. Individually, top countries ranked in VWSR exports differed during 2001 to 2013. Spain, Sudan, the United States and Australia increasingly had the top ranks in VWSR exports, with a share of 28.4%, 27.8%, 18.5% and 9.9% in 2013. However, countries like Libya, Cyprus and Tunisia dropped their position during the period.

**Figure 3.** Distribution of virtual water scarcity risk (VWSR) to major BRI in 2013. The width of arrows proportionate to the risk imported. Vulnerability index of each BRI refers to VWSR imports from Non-BRI normalized by the relative total outputs.

Figure 3 maps the distributions of VWSR to BRI in 2013, where the shades of color indicate the VWSR imports from Non-BRI per unit economic output of the related BRI. Generally, for the top importers among BRI countries, their VWSR imports mainly originated from a few Non-BRI countries. For instance, as the largest importer, more than 85% of VWSR to China was contributed by the United States (28.2%), Spain (26.2%), Sudan (19.5%), and Australia (11.4%). These four Non-BRI countries were also the top exporters to South Korea (the second largest importer), imports of which from them totally accounting for more than 92.6% of its total imports. For Russia, which was the third largest importer, 83.6% of its total imports was from Sudan (39.7%), Spain (36.1%) and the United States (7.8%). Similarly, India, as the fourth largest importer, imported VWSR mainly from Sudan (53.1%), Spain (20.5%), the United States (8.5%) and Australia (6.7%). To reveal the vulnerability of BRI to water scarcity in Non-BRI regardless of economic output, the vulnerability index from Non-BRI was used by normalizing the VWSR imports from Non-BRI by the economic output of the importer. Countries, such as Serbia, Montenegro, Belarus, Moldova and Bhutan were most vulnerable to water scarcity in Non-BRI. Results above identify major exporter to BRI, which should pay attention to water scarcity in these Non-BRI countries, and take measures to mitigate their supply chain risk by decreasing external water dependency and diversifying trade partners.

At sector level, VWSR exports of Non-BRI focused on a few sectors, as shown in Figure 4. Specifically, 66% of their exports to BRI was contributed by their Agriculture sectors, among which Spain accounted for 26.7%, followed by the United States (17.5%), and Australia (9.5%). Notably, the second largest export sector in Non-BRI was Financial Intermediation and Business Activities, with a share of 8.1%. The phenomenon mainly caused by water scarcity to this sector of Sudan, which accounted for 7.3% of Non-BRI’s total exports. Instead, VWSR imports of BRI from Non-BRI were widespread among sectors (Figure 4). The largest import sector was their Food & Beverages (18.8%).
followed by Petroleum, Chemical and Non-Metallic Mineral Products (10.6%), Electrical and Machinery (9.2%), Textiles and Wearing Apparel (6.8%), Agriculture (6.1%), Construction (5.7%), and Metal Products (5.7%). The import share of each of the rest sectors was less than 5%. And individually, for each sector in every BRI country, the import share in total imports of BRI overall was less than 4%. Overall, water scarcity in Non-BRI countries can pose widespread risks on the BRI trade system.

Figure 4. Sector distribution of virtual water scarcity risk from Non-BRI to BRI in 2013. Further, Table 2 also shows top sector linkages in VWSR flows from Non-BRI to BRI, and reveal that the destinations were widespread, while the origins concentrated on a few nation-sectors. By analyzing top VWSR transmission linkages at nation-sector level, water scarcity to Agriculture sectors in the United States and Spain can pose significant impacts on manufacturing sectors in various BRI countries, including Food & Beverages sector in China, South Korea and Poland, and Electrical and Machinery, Petroleum, Chemical and Non-Metallic Mineral Products, Construction, Agriculture and Textiles and Wearing Apparel in China. Thus, firms in destinations should recognize the water scarcity of the upstream suppliers in the origins. For instance, firms in Food & Beverages sector in South Korea should focus on water scarcity of Agriculture sectors in the United States and Spain. Similarly, enterprises of China belong to the Electrical and Machinery sector should recognize and take measures to mitigate the potential supply chain risks originating from water scarcity in Spain’s Agriculture sector. According to the sources of the supply chain risks, strategies for mitigating VWSR can be divided into two categories. For VWSR originating from sectors such as Agriculture which is related to direct trade, BRI countries may simply turn to the international market and find other suitable partners to mitigate this kind challenges to their trade system. However, if the VWSR flows are from other sectors such as Financial Intermediation and Business Activities, the transmission routes of which may go through several manufacturing sectors as intermediate sectors, it is hard for the importers to look for solutions in the global markets. As the intermediate inputs are produced based on signed contracts, which have made rules in special design and functions, resulting that there exist difficulties to produce them in short time. Thus, it is vital for the downstream economies to
decline water dependency on water scarcity regions, and enhance cooperate with upstream suppliers in water resource management.

### Table 2. Top sector linkages in virtual water scarcity from Non-BRI to BRI.

| Rank | Origin         | Destination                           | Contributions to Total |
|------|----------------|---------------------------------------|------------------------|
| 1    | USA: Agriculture | South Korea: Food & Beverages         | 1.66%                  |
| 2    | USA: Agriculture | China: Food & Beverages               | 1.14%                  |
| 3    | Spain: Agriculture | China: Electrical and Machinery     | 0.99%                  |
| 4    | Spain: Agriculture | Poland: Food & Beverages             | 0.92%                  |
| 5    | Spain: Agriculture | China: P and N Products              | 0.77%                  |
| 6    | USA: Agriculture | China: Construction                  | 0.71%                  |
| 7    | USA: Agriculture | China: Agriculture                   | 0.65%                  |
| 8    | Spain: Agriculture | South Korea: Food & Beverages      | 0.65%                  |
| 9    | USA: Agriculture | China: P and N Products              | 0.64%                  |
| 10   | USA: Agriculture | China: Textiles and Wearing Apparel  | 0.63%                  |

P and N Products: Petroleum, Chemical and Non-Metallic Mineral Products

### 4. Conclusions
As increasing water dependency and water scarcity, one nation’s economic activities may be vulnerable to water scarcity in distant regions. This study estimates the vulnerability of the Belt and Road Initiative to external water dependency by quantifying the impacts of LWSR in Non-BRI on BRI countries. Results reveal that VWSR to BRI mainly originated from Agriculture sectors in major economies such as Spain, the United States and Australia, which can exert widespread impacts among sectors in BRI, especially in China, South Korea, Russia and India. We also identify origin-destination sector pairs in VWSR flows from Non-BRI to BRI. This study reveals the additional risks of the BRI from the world due to their external water dependency, and can lay the foundation for policy-making to mitigate the supply chain risk, and then enhance the resilience of the Belt and Road trade system to water scarcity.

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