Food production and cursed water resources: challenging trade diversification mechanisms

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Abstract

This paper investigates the impact of water endowments and water productivity on developing countries heavily relying on agriculture and struggling to diversify their exports and develop. We analyze food exports from 1994 to 2007 at a global level and find that growth and water availability have opposite effects: both food and virtual water exports concentrate along with GDP per capita but diversify with water availability. Furthermore, we find that water-intensive goods display lower subsistence in time when countries are water-scarce and have lower water efficiency than world average. In fact, water-scarce countries have unstable diversifying trade patterns with water-intensive goods disappearing and re-appearing throughout our period of study, revealing that the inefficient use of water resources is a main obstacle to sustainable trade diversification. We conclude that inefficient water management and insufficient investments in water efficiency are an obstacle to exiting water dependency by inducing similar economic impacts as those caused by "traditional" cursed resources such as oil, natural gas or minerals. We recommend that water-scarce countries focus on improving the water footprint of a small number of goods in order to trigger positive spillovers to other crops and other sectors of the economy in order to diversify.

JEL classification:

Keywords: Water Endowments, International Trade, Food Security

1 Introduction

In the attempt to understand the links between international trade and growth, much attention has been given to export and import patterns. Most studies have found that trade diversification is positively correlated with development (Haussmann & Rodrik, 2003; Klinger & Lederman, 2006; Parteka & Tamberi, 2013), challenging traditional theories of specialization according to comparative advantages and factor accumulation (Smith, Ricardo, Hecksher-Ohlin). In particular, studies have found a u-shape relationship between export/import concentration and gdp per capita (Cadot, Carrere & Strauss-Kahn, 2011; Mohan 2016)[1] suggesting that past a certain level of income, very rich countries undergo a reconcentration process. The resource curse literature has offered many insights into the economic mechanisms of countries featuring concentrated exports and slow growth at the very left of the curve. While some argue that heavily relying on natural endowments increases vulnerability in facing price and supply shocks, regulatory changes, and new competition (Prebisch, 1950; Sachs and Warner, 1995; Sala-i-Martin and Subramanian, 2003; Auty, 2000 and 2001), others bring forward that export concentration - and not resource endowments - endogenous to bad policies and institutional deficiencies, is in itself the cause of stagnating development (Maloney, 2007; Frankel, 2012).

Although the resource curse literature blames resource dependency for hampered growth an development, the debate has overlooked a traditional determinant of trade patterns, namely factor endowments (Cadot, Carrere & Strauss-Kahn, 2011). Given that 70% of water withdrawn in the world is for agriculture (FAO) and that the agriculture's sector share of GDP still exceeds 40% in many poor countries (such as the Central African Republic, Mali, Sierra Leone, or Togo), agriculture-dependence is water-dependence. While case studies have largely focused on oil, natural gas or minerals (REF), it is legitimate for water resources to be studied within the on-going resource curse debate. This article investigates the specific case of water dependency and the inability of water-scarce or water-inefficient countries with no other major

[1] They find a turning point around US$ 23,000 gdp per capita.

resources to develop and diversify. To do so, we rely on a measure of the Theil entropy index adapted to incorporate flows of embedded water used to produce the goods.

This study faces three major challenges, the first pertaining to the specific status of water resources and the absence of standard, global economic tools enabling similar analysis to the recourse curse literature. Water suffers from poor institutional background and proper regulation, unlike oil or gas, and as such is not properly priced (with very few exceptions with water markets in Australia, South Africa or California). In most developing countries, it is therefore withdrawn with little consideration for future needs and as such, high levels of agricultural concentration in poor developing countries are generally not determined by the extent of water availability but rather by a shortage of other production factors (Wichelns, 2010; El Fadel and Maroun 2003, Warner 2003, Novo et al. 2009). Water dependence is thus not chosen as a strategy per say but results from lack of alternatives. Furthermore, in developing countries where agriculture makes up for a large share of GDP, agricultural dependence is water dependence, regardless of water availability, a main difference with "traditional" cursed resources where resource dependence is based solely on availability. As such, we cannot explain failure to diversify with purely exogenous factors affecting the resource-based markets (as in the oil crisis). Equally complex, we cannot argue that agriculture dependence is crowding out manufacturing and hampering innovation because developing countries stuck in the primary sector (agriculture in this paper) generally do not overlook the industrial and services sector (Frankel, 2012).

Second, the choice of metrics and scale will be important to give an accurate picture of countries' water availability. Water abundant countries have large amount of water reserves in total, per capita and per hectare of land. Water scarce countries can be short of water per capita but abundant in water per hectare of land or all of the above. Metrics will affect the interpretation of our results leading to counterintuitive results (as suggested by Sachs and Warner, 2001 using natural resource exports as a share of GDP instead of net exports of resources per worker by Leamer in 1984). [2]

Our third challenge is that of dealing with a debate over trade diversification that still features weak theoretical guidance and focuses mostly on empirical methodology with little consensus over metric, scale or measures (Mau 2015). The difficulty lies mainly in isolating the causality mechanisms between export diversification and growth and there are several cases where causation runs from productivity to trade patterns (Ricardian models, Melitz, 2003; Feenstra and Kee, 2008), while trade is also shown to enhance productivity (Broda, Greenfield and Weinstein, 2006) when firms learn by exporting (see for instance Haddad, 1993; Tybout and Westbrook, 1995). The challenge of building a strong identification model will come from both GDP per capita and trade diversifcation being highly endogenous and this paper will test our arguments both with static and dynamic panel estimates (system GMM) to overturn these issues. Furthermore, by focusing solely on the agricultural sector, we are possibly better isolating economic mecanisms as opposed to much of the literature which generally looks at a high number of sectors or thousands or different product categories (Mau 2015).

We study global food exports from 1994 to 2007 using the BACI dataset for agricultural exports as developed in the CEPII report by Gaulier and Zignago (2010) and originally sourced from COMTRADE at the 6-digit (HS6) and 2-digit (HS2) levels, the FAO Aquastat data for water availability and crop prices and the Water Footprint Network for data on water efficiency at the country-product level. We investigate export concentration patterns using an adapted measure of the Theil index, build to account for the amount of water embedded in the exported goods based on their water footprint. Our results show that the Theil index for food exports has an inverted u-shape relationship with GDP per capita, as opposed to traditional results in the

[2] As an example, water availability per ha of land will put a country such as Singapore in the top ten although it is not highly diversified in food exports - thus denying the correlation between abundance and concentration - whereas water availability per capita will place it among the scarciest countries, thus over-estimating the positive correlation between scarcity and concentration.

literature for the whole of exports. The Water Theil index is not affected by GDP per capita. On the other hand, both the Theil and Water Theil index diversify along water availability, showing that endowments do affect countries' export strategies. We find that water-intensive goods display lower subsistence in time for than less water-intensive goods, a result emphasized when water is scarce and growth is low. Our results show that water scarcity and water inefficiency explains an important part of food export concentration and constitutes an obstacle to development and diversification for agriculture-dependent countries.

We start by providing a brief overview of virtual water issues and relating them to the many results within the resource curse and growth literature. We then explain our two models relating different diversification measures to growth according, water endowments and water efficiency.

2 Virtual Water flows and concentrated exports

This study is built upon the growing literature addressing trade diversification, the resource curse and virtual water trade. Virtual water is a concept coined by Tony Allan (1995) designating the amount of water (in liters per unit) required to produce a unit of good and virtually traded between countries through exports[3]. While the virtual water literature has addressed food production in relation to water as a comparative advantage (REF), it has not done so in the context of trade diversification patterns. From the resource curse literature perspective, focus has been mostly given to oil and mineral rich countries and how countries have failed or succeeded in combining growth and resource abundance (mineral abundance and growth in the US, Wright and Czelusta 2002; oil in Saudi Arabia; forestry in Scandinavia in Blomström and Kokko 2003). But no studies have specifically addressed how water en-

[3]Virtual water measures were estimated by the Water Footprint Network (Hoekstra and Hung, 2002, and further elaborated by Chapagain and Hoekstra, 2004) and have enabled to study the relationship between food exports, water productivity and water endowments.

dowments and water productivity relate to food exports and diversification. The afore mentioned reason is the lack of standard tools to study water from a global point of view: there are no water markets on a global scale, no water price and little information on water availability and provisions, preventing water resources from constituting a solid basis for food production strategies (Wichelns, 2010). This article relates two features of the trade diversification to water endowments and virtual water trade.

1. Slow growth and low diversification are related to resource dependence

Although the causality between export/import patterns and growth has not reached a consensus, diversification has been found to be correlated with increasing growth in gdp per capita, suggesting that import and export diversification stir local competition and innovation, enable knowledge accumulation, risk mitigation regarding price shocks and volatility, regulatory changes and new competitors. Imbs and Wacziarg (2003), later confirmed by Koren and Tenreyro (2007) demonstrated a u-shape pattern between production diversification and gdp per capita. The same u-shape was computed for exports (Haussman and Rodrik, 2003; Klinger and Lederman, 2006; Parteka, 2007; Cadot, Carrere and Strauss-Kahn, 2011; Mohan 2016) finding that as countries develop, exports diversify until reaching a certain level of income around US$ 22,000 to 30,000 gdp per capita (2005 constant PPP) above which they concentrate again. Most developing countries on the left side of the curve still heavily rely the agricultural sector, sometimes employing from 50-90% of the population (South Centre, 2001), out of which 70-95% are small holder farmers. These farmers traditionally survive on subsistence crops; while some have experimented with export crops (or "cash" crops) in the past two decades, they are less likely to access farming technologies to adapt their production to high-valued crops and benefit from increased exports. Small farmers rely on land and water availability to produce food, hence developing countries stuck in the primary sector are heavily dependent on water resources and are highly concentrated. The literature on virtual water trade has indeed shown that poor water-scarce countries were, counter-intuitively, producing agricultural goods although they have little comparative advantage in water (REF). Yet a thriving number of case studies have shown that countries do produce according to comparative advantage (REF) and were generally on the right track to development. It seems that if diversifying exports goes hand in hand with growth and development, it is necessarily correlated with an increase in comparative advantage, water efficiency and positive spillovers to other sectors of the economy.

2. Innovation and Positive Spillovers as a means to overturn the resource curse

Although the resource curse literature has identified the economic mechanisms behind successful trade diversification and growth, there is still much to be explained for countries on the left side of the u-shape. Poorer nations stuck in slow growth and highly concentrated production and export patterns have been the topic of intensive scrutiny (Sachs and Warner, 1995; Tornell and Lane, 1999; Gylfason, 2008; Martin and Mitra, 2006 among others). While some argue that concentrated exports increases vulnerability in facing price and supply shocks, regulatory changes, and new competition (Prebisch, 1950; Sachs and Warner, 1995; Sala-i-Martin and Subramanian, 2003; Auty, 2000 and 2001), others bring forward the endogeneity between concentrated exports and bad policies and how interaction with institutional deficiencies can, in itself, hamper production strategies and growth (Mehlum, Moene and Torvik, 2005, Brunnschweiler and Bulte, 2007, Areski and van der Ploeg, 2011). These arguments assume that natural resource availability is the cause itself of concentrated exports but Ledeman and Maloney (2007) and Frankel (2010) have suggested that it is not the resource but lack of investments and diversity within resource dependent production that causes concentration and slow growth. Concentration in itself is harmful to growth. Martin and Mitra (2001), Wright (2001), Irwin (2001) or Blomstrom and Kokko (2001) provide a more optimistic view and conclude that resource abundant countries are not doomed to have lower economic and political development, showing many cases of growth being stirred by exports and technological innovation within very concentrated economies such as forestry in Scandinavia or mining in certain US regions.

The pros and cons of natural resource availability for growth lead to one important conclusion: resource abundance is not the culprit for slow growth but how countries structure their economies around them and whether they invest in will be. In the case of water resources, technologies enable more efficient consumption and use by increasing water productivity (the amount of good produced per liter of water consumed) and water savings. They help us consume the right amount of water at the right time and right place. Product-water footprints differ across the globe as they depend on exogenous (climate, soil, water) and endogenous factors (human input, technology). Technology is generally available to farmers in rich countries and large agrifood companies operating in developing regions, inducing lower water footprints and therefore relative comparative advantage in producing food products. This relates to Bonaglia and Fukosaku (2003) who suggest that natural resources today can stir technological content, able to generate the development of upstream and downstream activities.

This is true for water: countries who have invested in water technologies have succeeded in making water dependence a driver for innovation, with important spillovers into the manufacturing/industrial sector sectors (such as Israel or Singapore), an argument also supported by Martin and Mitra (2001). Although the largest food producers in the world - India, Brazil, the United States, Australia and China - are currently suffering from serious groundwater depletion, water shortages and droughts because of increased demand for good and variety (Krugman 1979) and unregulated water policies leading to common-pool resource problems (Tornell and Lane, 1999), water issues are being addressed through technology. Unfortunately, India and China are still largely disadvantaged in terms of water productivity. Nations heavily relying on agriculture and water, therefore, are not doomed to slow growth patterns, but require investment, intensification of production and diversification. In their case, water efficiency is the first challenge they meet which argues that water productivity is a main determinant of production and export intensification.

3. Using the proper tools to analyze diversification of exports

Most empirical analyses on trade diversification rely on three different measures of diversification and concentration: the Herfindahl index, Theil's entropy index and the Gini index. High values for these indices indicate high concentration patterns at the chosen level of disaggregation. This article focuses on the Theil index because it can be decomposed into extensive and intensive margins. Two mechanisms can induce diversification of exports:1) an increase in the number of new goods exported (or active lines) from one year to another, or the extensive margin and 2) an increase in the quantity of goods already being traded or the intensive margin. The intensive and extensive margin are essential in understanding what happens when countries diversify: new products might say something about local economic and institutional conditions such as more entrepreneurs risking to export new products, inside-the-frontier innovations (Klinger and Lederman, 2006) or copying existing products abroad.

Evenett and Venables (2002), Brenton and Newfarmer (2007) and Cadot et al (2011) show that the intensive margin makes up for most of trade growth (around 80%) but that variations in concentration and diversification are mostly driven by the extensive margin. As poor countries develop, the number of active lines as well as the number of destination for exports increases. Above the turning point, concentration changes occur at the extensive margin, where rich countries tend to forgo products with lower added value and focus on goods for which they are highly productive. We will use the decomposition of the Theil index, bearing in ming that these indicators fail to provide any analysis of the determinants of concentration and diversification. Our measure of the Water Theil index will provide information on water productivity and water use by indicating how resources are spread across different categories of products.

3 Export concentration, agricultural dependence and water resources

3.1 Data

Our food trade data is taken from the BACI dataset, as developed in the CEPII report by Gaulier and Zignago (2010). We chose the BACI data over the FAO trade statistics for agricultural commodities because is deals with missing data by employing a reconciliation methodology[4]. Indeed, missing values of trade for a specific product can occur if one or both of the countries fail to report their trade flows. BACI utilizes the double information available on each trade flow to provide a unique "reconciled" value for each flow reported by at least one of the partners, providing more complete data[5]. Using the BACI data also enables to be consistent with the study from Delbourg and Dinar (Working Paper) on virtual water flows and relative water efficiency. The data provides production data in quantity and value at the highest level of product disaggregation, 6 digits Harmonized System (HS) code from 1994 to 2007.

Actual renewable water resources per year in $m^3/year/person$ are taken from the FAO Aquastat dataset and arable land data is provided by the World Bank indicators[6]. Total renewable water resources are the sum of Internal

[4]Reconciliation provides an explanation for the discrepancy between the import and export statistics of trading partners by identifying conceptual reasons for them and explaining differences in data collection and processing. See United Nations (2004). Similar to COMTRADE, BACI does not report zero values of trade because of computational issues. It also does not report zero values for products no longer, but previously, traded between two countries, raising the issue of selection bias. Furthermore, a missing observation is considered a zero when at least one of the trading partners reports its trade to the UN. If both partners are not reporting, the missing observation is considered a true missing value.

[5]See Gaulier and Zignago (2010) for more detailed explanations

[6]Visit http://www.fao.org/nr/water/aquastat/dbase/index.stm and

Renewable Water Resource (IRWR)[7] and External Renewable Water Resource (ERWR)[8] where IRWR and ERWR are computed in the following way:

$$IRWR = R + I - (Q_{OUT} - Q_{IN}) \tag{1}$$

where R is the surface runoff (long-term average annual flow of surface water generated by direct runoff from endogenous precipitation), I is groundwater recharge generated by precipitation and Q_{OUT} is groundwater drainage into rivers and Q_{IN} is seepage from rivers into aquifers.

$$ERWR = SW_{IN} + SW_{PR} + SW_{PL} + GW_{IN} \tag{2}$$

where SW_{IN} is the surface water entering the country, SW_{PR} is the accounted flow of border rivers, SW_{PL} is the accounted part of shared lakes and GW_{IN} is the groundwater entering the country.

The water footprint in m^3/ton is provided by the Virtual Water Footprint network, in particular the articles of Mekonnen and Hoekstra (2011) and Chapagain and Hoekstra (2003). We use their data for 690 products (crops and livestock prducts) - which correspond to 24 different major categories (HS2). Appendix A provides a detailed description of the crops and livestock products we cover in this analysis. If we were to look at HS2 category 9 ("Coffee, Tea, Mate and Spices") the HS6 level would distinguish "roasted, not decaffeinated coffee" (HS6 090121) from "roasted and decaffeinated" (090122). The HS2 category 10 ("Cereals") separates "durum wheat" (HS6 100110) from "corn seeds" (100510) and "maize" (100590). We limit our data for products with available water footprints.

http://data.worldbank.org/indicator

[7]Long-term annual flow of rivers and recharge of aquifers generated from endogenous precipitation

[8]Resources not generated in the country, including inflows from upstream countries, border lakes and/or rivers; takes into account the quantity of flow reserved by the upstream or downstream country through formal or informal agreements

3.2 The Theil and Water Theil index

We base our analysis on the Theil entropy index (Theil, 1972) and the number of actives export lines at the country-year level and at the product-country level.

Let n be the total number of potential export lines (active and non-active) for country i in year t and x_{itk} the export quantity of product $k \in [1, n]$. Theil's index is defined as:

$$T_{it} = \frac{1}{n} \sum_{k=1}^{n} \frac{x_{itk}}{\mu_{it}} \ln(\frac{x_{itk}}{\mu_{it}}) \tag{3}$$

where $\mu_{it} = \frac{1}{n} \sum_{k=1}^{n} x_{itk}$.

The Theil index can be decomposed additively into within-groups and between-groups components. Let n_j be the number of export lines in group j The between-group component of Theil's index is defined as:

$$T_{it}^{B} = \sum_{j=0}^{J} \frac{n_j}{n} \frac{\mu_j}{\mu} ln \left(\frac{\mu_j}{\mu} \right) \tag{4}$$

and the within-group component is defined as follows:

$$T_{it}^{W} = \sum_{j=0}^{J} \frac{n_j}{n} \frac{\mu_j}{\mu} T_j \tag{5}$$

where

$$T_{it}^{W} + T_{it}^{B} = T_{it} \tag{6}$$

Cadot, Carrere & Strauss-Kahn (2011) partition their groups into two groups, one made of active export lines and one made of inactive export lines. Given this partition, changes in the within-group Theil index measure changes at the intensive margin (changes in concentration among active lines) and changes in the between-group Theil index measure changes at the extensive margin (changes in the number of active lines).

In this study we will compute two Theil index: one fitting the above description, and one replacing the exported quantity of product k at year t by country i, namely x_{itk}, by its associated volume of embedded water, or its water footprint, expressed in m^3/ton and computed in the following way:

$$WFP_{itk} = x_{itk} * WFP_{ik} \tag{7}$$

The Water Theil index is defined as:

$$WaterTheil_{it} = \frac{1}{n}\sum_{k=1}^{n} \frac{WFP_{itk}}{\mu_{it}} \ln(\frac{WFP_{itk}}{\mu_{it}}) \text{ with } T \in [0, +\infty] \tag{8}$$

where $\mu_{it} = \frac{1}{n}\sum_{k=1}^{n} WFP_{itk}$.

The within and between components of the WaterTheil are build as above in equations (4) and (5). Given their construction, using the water footprint of products will leave the between-groups component unchanged but will alter the within-groups component of the Theil index.

3.3 Descriptive statistics

The baseline sample covers 195 countries across 13 years from 1994 to 2007 and unlike Cadot, Carrere and Strauss-Kahn (2011), we include micro-states with population below 1 million as these countries face many similar water issues (such as scarcity and pollution) and are in many cases as diverse in agricultural production as larger countries. Our sample has 2,723 observations at the country-year level when there is no distinction of products and 875,589 when there is.

Our countries are divided into four different water categories according to the water availability indicator (Falkenmark) and into four income categories according to the World Bank Atlas method? Table 1 shows how our countries are spread throughout both categories: 25% of countries are high-income, 41% are low-income and the rest is roughly divided between upper-middle and low-middle income.

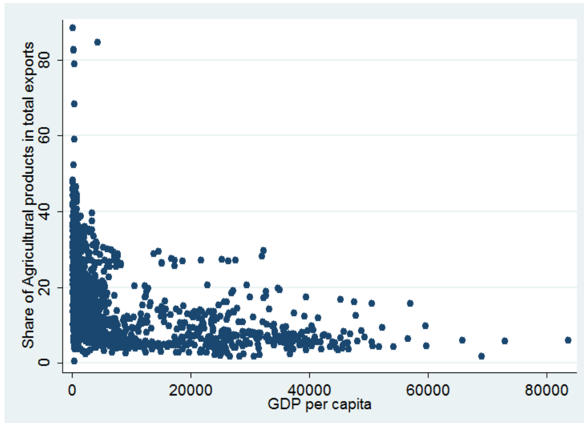
Table 1: **Number of countries in water and income categories**

Water Category	**HI** $> 12276\$pc$	**UMI** $[3976, 12275]\$pc$	**LMI** $[1006, 3975]\$pc$	**LI** $< 1005\$pc$	Total
Absolute Scarcity $< 500m^3$pc	91	0	13	47	145
Scarcity $\in [500, 1000]m^3$pc	340	184	395	671	1590
Stress $\in [1000, 1700]m^3$pc	18	0	10	35	63
No Stress $> 1700m^3$pc	52	24	31	88	195
Total	501	208	449	835	1993

Source: Author statistics

To understand the extent of water dependence, we look at the share of agriculture in total exports which spans from 1.6% (reached by Honk-Kong and Singapore) to over 88% in Malawi until 2004. Figure 1 shows the share of agriculture in total exports against GDP per capita for our 147 countries. It shows a fairly distinct pattern where countries with a large share of agricultural products are low income ones. 25% of our sample has a share of agricultural exports over 20% of the total and in 2007, countries with the highest share were all African countries: Malawi, Guinea-Bissau, Benin, Ivory Coast, Senegal, Kenya and Niger. Argentina and Uruguay also display a high agricultural share in exports (30%), just as New Zealand (over 25%) the only high-income country to feature in this category.

Figure 1: Share of agriculture in total exports against GDP per capita, 1994-2007



We relate the share of agriculture in total exports again water availability per capita and per ha of land. Figure 2 shows that the patterns are very distinct as well: countries with the largest share of agricultural exports are also the scarcest. As a matter of fact, the same countries resurface for both measures of water availability on the left side of the graphs: Malawi, Guinea-Bissau, Benin and Senegal, among the least endowed countries in water resources, although they are not considered at risk in terms of water availability per capita (definition of the Falkenmark indicator). We use two measures of water availability to overcome the errors induced by water abundant small countries (such as the Netherlands - which happen to be re-exporters of agricultural products although they produce very little locally).

Figure 2: Share of agriculture in total exports against water resources, 1994-2007

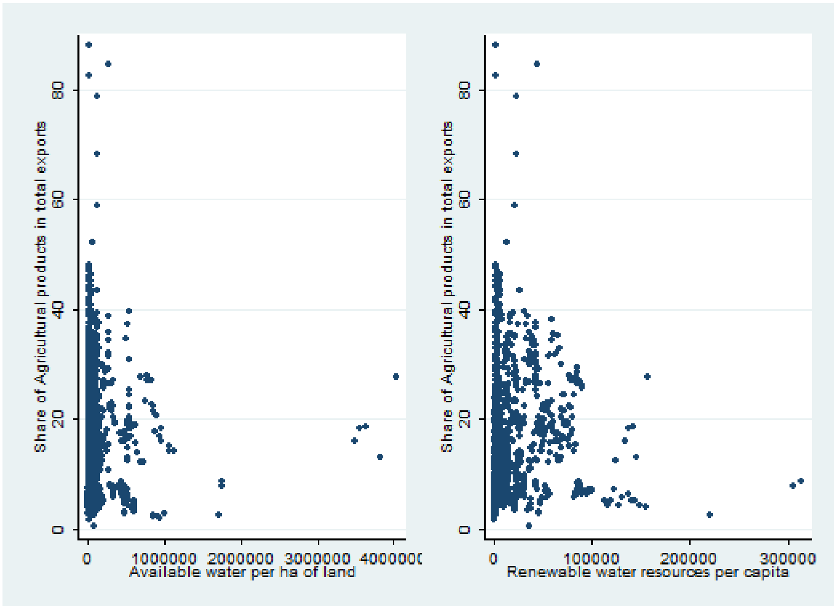


Table 2 displays summary statistics for our variables of interest from both samples: the disaggregated dataset at the product-country-year level and the aggregated data at the country-year level.

Table 2: Summary statistics

Variable	**Mean**	**Std. Dev.**	**Min.**	**Max.**	**Data**
Theil	3.678	0.963	1.4	6.645	Aggr.
WaterTheil	3.88	1.218	1.759	6.899	Aggr.
TBetween	1.429	0.819	0.09	5.724	Aggr.
TWithin	2.303	0.815	0	5.40	Aggr.
WaterTB	1.429	0.819	0.09	5.724	Aggr.
WaterTW	2.476	1.127	0	6.216	Aggr.
$ActiveLines_{i,t}$	80	80.2	1	433	Disaggr.

Continued on next page...

... table 2 continued

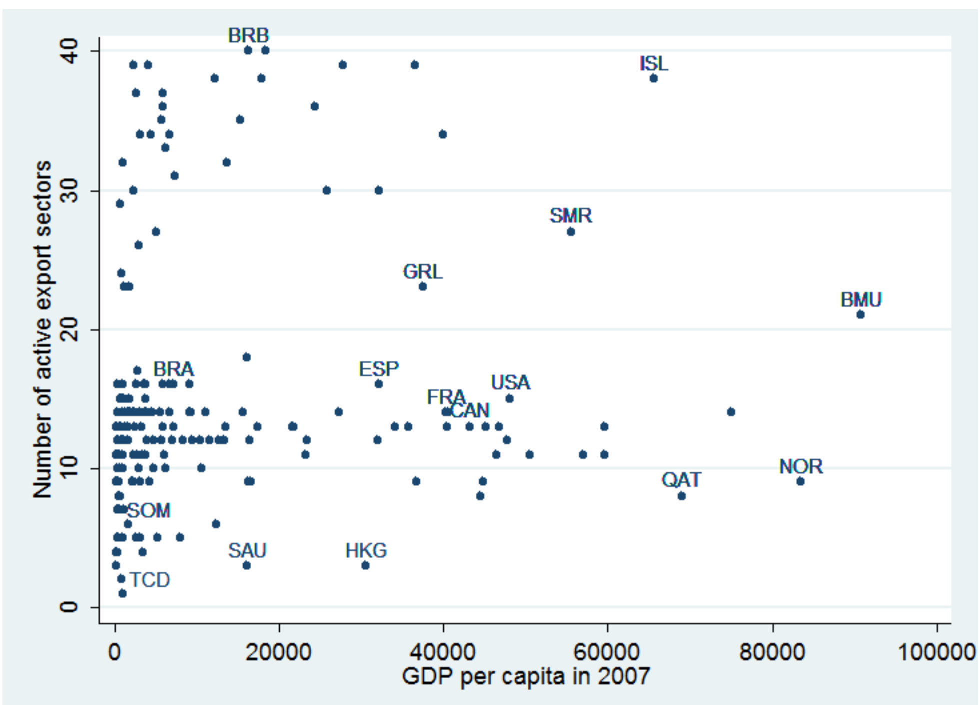
Variable	**Mean**	**Std. Dev.**	**Min.**	**Max.**	**Data**
Sectors	13.202	5.9	1	24	Disaggr.
$Subsistence_{p,i}$	4.21	5.07	0	14	Disaggr.
ShareAgr (%)	15.802	10.367	1.649	88.324	Aggr.
GDPpc	8553.498	14289.287	64.81	170632.956	Aggr.
Waterpc	17232.328	32805.698	7.828	314221.094	Aggr.
WaterLand	123141.528	371361.856	345.168	4150259	Aggr.

The Theil index is computed at the most disaggregated HS6 level, featuring a large number of export lines with small trade values. The index spans from 1.4 (reached by Afghanistan in 1994, China until 1996 and Benelux and Spain until 2006 to 6.6 (in Guinea-Bissau in 1999 and Chad in 2005). The highest level of food export concentration at the HS6 level are achieved by Burundi, Cuba, Gabon, Guinea-Bissau, Iraq, Rwanda and Chad.

The number of annual active export lines per country/year reaches over 400 mostly for small countries (Bihar, Island, Guyana, Fidji, Cyprus and Barbados). The maximum is reached for Fidji in 2006. It is very low, with a minimum of 3, for poor developing countries such as Angola, Armenia, Eritrea, Liberia, Chad or Guinea-Bissau from 1994 to 2007. On the other hand, top exporters have around the average number of active lines with very little variation over the years: in the USA, the number of active lines varies between 116 and 119; in France, between 90 and 95 and in China between 136 and 139. The average number of export lines is at 80 per country, a third of the maximum, which means that there is room for diversification at the extensive margin for developing countries.

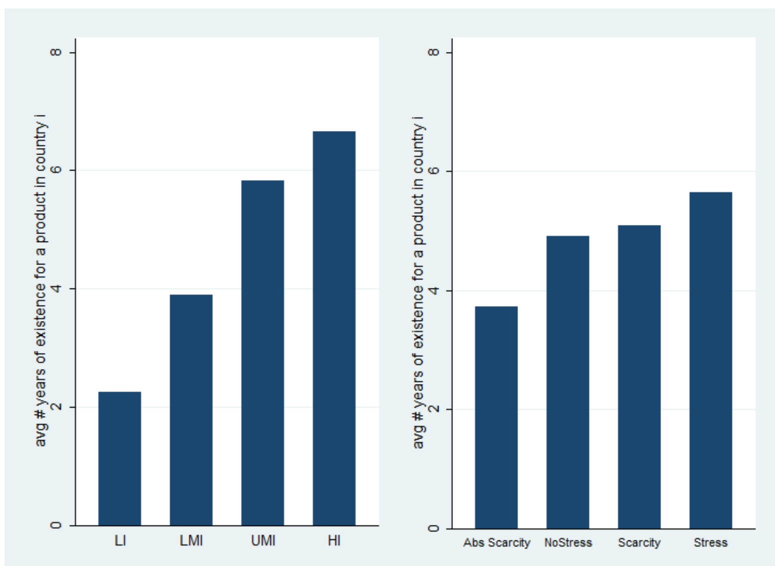
An interesting feature is that the wealthiest countries display stable export patterns in comparison to developing or water-scarce nations. The number of sectors (HS2 level) that the top 10 exporters are active in is lower than the average of 13 remains stable over the years (from 13 to 16 for the USA, France, Brazil, Canada and Australia and China) while small countries such as Barbados, Fidji Islands and Cyprus, or water-scarce nations such as Qatar, vary from 10 to 40 sectors. Very poor and water scarce nations such as Armenia or Somalia even started off with a minimum of one export sector in 1994 (HS2 22 category "Beverages, spirits and vinegar" for Armenia and HS2 41 products "Raw hides, skins and leather for Somalia) but never exported within more than 8 sectors until 2007. Figure 3 shows the average number of active export sectors per country from 1994 to 2007 against GDP per capita;

Figure 3: Number of active export sectors according to GDP per capita from 1994-2007



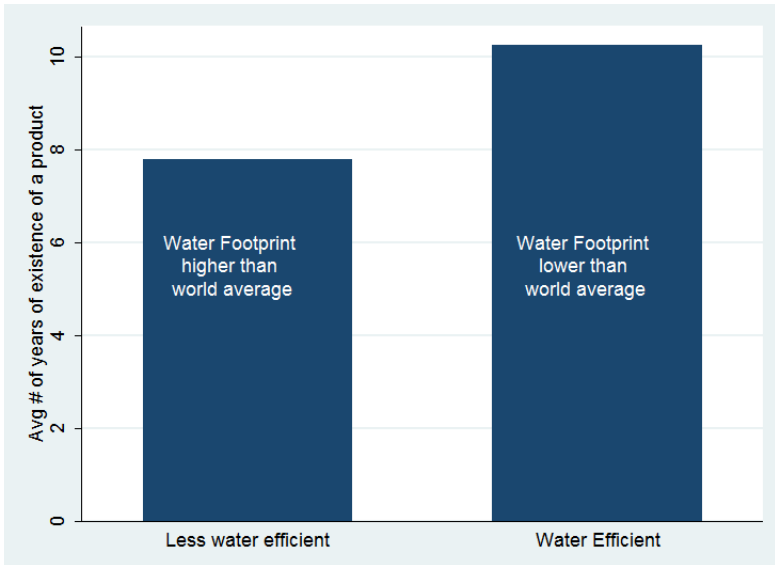
Product subsistence, namely the number of non-consecutive years that a product has been exported by country i also provides information on the stability of production and trade patterns. Products live for an average of 4.9 years between 1994 and 2007 but Figure 4 shows that products have a higher life subsistence in High Income countries than in Low Income nations, 6.2 vs 2.2 years. On the other hand, there is little difference between water categories: lowest subsistence is for absolutely scarce countries (a little less than 4 years) and highest is for countries under water stress (a little less than 6 years). Since the number of years are not necessarily consecutive, disappearing products are perhaps still being produced in the country but not exported during a specific year.

Figure 4: Average subsistence years for a product in each country according to income and water categories, 1994-2007



In terms of water footprint, Figure 5 shows that, on average, the same products last longer in countries for which they are more water efficient than average (lower water footprint) than in countries where the water footprint for these specific products is relatively higher. Lower footprint means a comparative advantage in producing a good and countries seem to be inferring production strategies from this.

Figure 5: Average years of existence for a product depending on whether countries' water footprint are higher or lower than the world's average



4 Regressions and parametric evidence

We specify two different regression models, the first one explaining the Theil and Water Theil index and the second featuring the number of subsistence years for a product in a given country from 1994 to 2007.

4.1 Theil, Water Theil and water-dependence

To explain food export diversification, we follow Cadot, Carrere and Strauss-Kahn (2011) and perform quadratic polynomial regressions of the Theil and Water Theil index and number of active export lines on per capita GDP using fixed effects according to the following:

$$Y_{it} = \alpha_0 + \beta.Z_{it} + \epsilon_{it} \tag{9}$$

where:

Y_{it} is alternatively the Theil and the Water Theil index and their associated between-groups and within-groups components

i is the exporter country

t is the year $\in$ [1994 , 2007]

α_0 is the intercept which captures country-year effects

ϵ_{it} error term, assumed to be normally distributed with zero mean and constant variance for all observations (it is also assumed that the errors are pairwise uncorrelated)

We assume here that the slope coefficients are constant across country pairs and over time. The 1 x k row vector Z_{it} comprises all of our explanatory bilateral variables which are the following: $GDPpc_{it}$ and $GDPpc_{it}^2$, $Waterpc_{it}$ and $Waterpc_{it}^2$ which is the actual water resource in m^3 per capita in year t for country i at the linear and quadratic level and $ShareAgr$ which is the share of agriculture in GDP.

Results for the agricultural sector are reported in Table 3 for within effects: columns 1-3 show coefficients for the Theil index against GDP (column 1) and water availability per capita (column 2) and then considering them together, adding an interaction term (column 3). Columns 4-6 show similar regression coefficients for the Water Theil index.

Our first result is that GDP per capita and the Theil index for food exports have a non-linear relationship in the form of an inverted u-shape, unlike previous results in the literature for the whole of exports. This means that countries concentrate their food exports as they develop and, past a (relatively high) threshold of US$ 39,016 of GDP per capita start diversifying again. This non-linear relationship disappears when controlling for water resources and becomes strictly positive, suggesting that keeping water availability constant, countries keep concentrating their food exports along with growth.

On the other hand, the Theil index has a u-shape relationship with water availability: food exports seem to diversify along with water abundance, before re-concentrating again above a very high threshold of $170,316 m^3/pc$,

Table 3: Within Regression results for the Theil index and the Water Theil index

	(1) Theil	(2) Theil	(3) Theil	(4) WTheil	(5) WTheil	(6) WTheil
GDPpc	0.0000238***		0.0000190*	0.000000599		-0.00000796
	(5.57)		(2.21)	(0.10)		(-1.41)
$GDPpc^2$	-3.05e-10***		-2.26e-10	2.19e-11		5.84e-11
	(-9.96)		(-1.87)	(0.31)		(0.66)
Waterpc		-0.0000140*	-0.0000156*		-0.0000170***	-0.00000425
		(-2.13)	(-2.32)		(-3.35)	(-0.92)
$Waterpc^2$		4.11e-11**	4.44e-11**		4.39e-11***	2.18e-11
		(2.63)	(2.82)		(3.66)	(1.90)
GDPxWater			1.28e-10			1.73e-10*
			(1.18)			(2.07)
_cons	3.233***	3.670***	3.599***	3.617***	3.784***	3.481***
	(59.53)	(33.80)	(31.81)	(72.12)	(45.19)	(45.32)
Turning point	US$ 39,016	170,316m^3/pc	/	/	193,621m^3/pc	/
N	2594	1964	1950	2447	1958	1944
R^2	0.066	0.023	0.027	0.025	0.028	0.008
adj. R^2	-0.013	-0.062	-0.059	-0.061	-0.057	-0.072

Period	1994-2007				
Countries on the right of turning point US$ 39,016 in 2007	Andorra	Austria	Australia	Belgium	Bermuda
	Canada	Germany	Denmark	Finland	France
	Great Britain	Ireland	Island	Koweit	Luxembourg
	Netherlands	Norway	Qatar	San Marino	Switzerland
	Sweden	UAE	USA		

t statistics in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

above which we find only one country, Congo. When omitting Congo from the data, the Theil index is negatively correlated with water availability and the non-linear relationship disappears. Hence countries with abundant water use it to diversify their production and food exports. The interaction term between GDP and water availability is not significant for the Theil index which is likely due to omitted variables affecting the relation between growth and water use such as institutions, geography and climate. Performing a quick quadratic regression of GDP per capita against water per capita suggests that water is non-linearly correlated to GDP in the form of an inverted u-shape but the statistical correlation between the two variables is close to null, meaning that we cannot infer a sufficiently strong relation between both variables (mainly because of many cases of economically successful and water-scarce nations in Asia and the Middle East).

Our Water Theil index is not significantly correlated with GDP per capita, but displays a strongly significant u-shape relationship with water availability, even when controlling for gdp per capita. This means that countries are diversifying their water use across agricultural goods as they are water abundant until a very threshold where they re-concentrate. This time, omitting Congo will maintain the non-linear relationship but will lower the turning point to $135,779m^3/pc$ above which we find Papua New Guinea and Gabon. When controlling for GDP per capita, only the interaction term is positively and significantly correlated with the Water Theil index. GDP does not have an effect of Water Theil when water availability is null (which is never the case) and vice-versa, but they do have a positive effect as they interact, which means that growth and water availability will mostly lead to concentration in water use for food exports.

We find 24 countries on the right side of the turning point, among which oil-rich and water-scarce nations such as the United Arab Emirates, Koweit and Qatar; small countries with little land such as Austria, Benelux countries, Denmark and Singapore; and among the top 2 producers in the world, the USA and Canada. Food exports in these countries are concentrating towards fewer lines, following the global trend towards agricultural intensification.

Figure 6: Within and Between components of the Theil and Water Theil index, 1994-2007

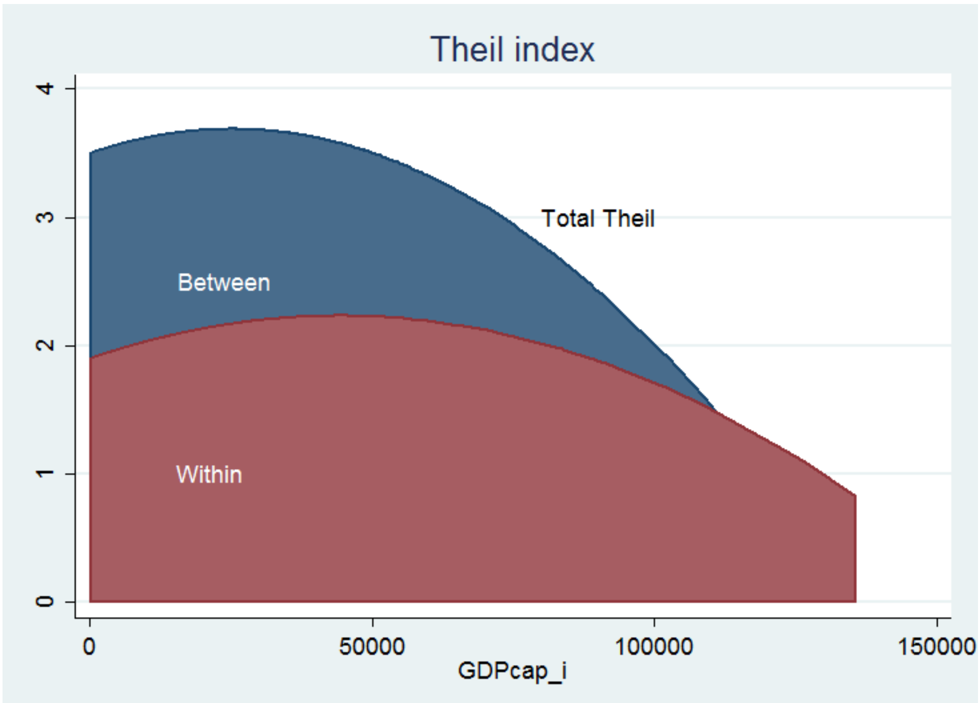


Figure 6 depicts the contribution of the between and within components to the overall Theil for food exports, worldwide, between 1994 and 2007 (within regression results are in table 6 in Appendix B). We observe that both components do not follow the same trend against GDP per capita: the between component has a u-shape relation with GDP per capita (diversification then re-concentration) while the within component first undergoes concentration and then re-diversification. Between and within components generally follow the same trend; the fact that they do not shows that there are two mechanisms at play: as countries develop, they increase efforts on existing crops, thus increasing the Theil intensive margin (within component). But as they do so, they also open new lines of product, responsible for the decrease in the

Theil extensive index. Beyond a high threshold, they close up new lines (increase of the extensive index) but export more of other existing lines (decrease of the intensive index). Countries are thus concentrating on a fewer goods as they develop, until the share of each good in total exports becomes more homogeneous.

What the decomposition of the within and between components of the Theil index tells us is that water-scarce countries follow two types of strategies:
1) the first one, at the within margin, they focus on products for which they have a relatively lower than average water footprint, namely some sort of comparative advantage in the use of water for agriculture. Given that they have low capital and complementary input factors, they naturally focus on those products which increases the within margin and increases production and thus export concentration patterns. As they develop, so does their access to technology, capital, human capital and control of water resources (through proper monitoring, water-saving technologies, etc.) inducing higher water efficiency. Countries can increase water efficiency of existing crops, thus decreasing the within component of the Theil index. Given love for variety (Krugman) and increased world demand, countries benefit from increasing production through water efficiency.

2) At the between margin: developing countries have an unstable pattern of diversification, as many water intensive goods are appearing and then randomly disappearing. As countries open new lines every year, even though they probably will not last long, this decreases the between margin and the Theil index. As countries develop, there is a natural selection of products (as we saw with the within margin) which induces the closing of several lines, just as in the traditional explanation.

We now estimate our model using the Generalized Methods of Moments (system GMM) following Roodman (2009) to overturn the absence of any outside instrument for GDP per capita for our large panel. System GMM will generate internal instruments by using past changes in variable values to predict their current levels. We use this approach to instrument GDP per capita which is assumed to be endogenous to diversification (Acemoglu and Zilibotti 1997; Hausmann and Rodrik 2003 among others). Water availability per capita is exogenous and thus treated as an external instrument. Our results are displayed in Table 4.

The system GMM confirms that GDP per capita is significantly correlated to the Theil index at the 1% level in the form of an inverted u-shape. This relation is maintained when controlling for water availability although with lower statistical significancy. The interaction term is not significant as earlier. We find a higher turning point for the Theil index of US$ 43,846, which points that the diversification phase in food exports concerns very few wealthy nations and occurs at a late stage in development. Water resources are still non-linearly correlated with the Theil index as well, in the form of a u-shape. The system GMM thus confirms that growth and water resources operate in opposite ways regarding product diversification.

In the fourth column, system GMM confirms that growth has no effect on virtual water diversification, but column 5 shows that water resources are still non-linearly correlated to the Water Theil index in the form of a u-shape. This relationship is maintained when controlling for growth; the interaction term is significant and positive, confirming that wealth and water availability interact so as to foster water concentration. Hence countries, as they develop, display a higher equality in virtual water share, suggesting that they focus on a smaller number of products, thereby increasing productivity and water efficiency for those products. Positive spillover to other crops in the use of water enable those countries to diversify at the extensive margin.

4.2 Food export diversification and water efficiency

We now focus our analysis on water efficiency at the country-product level. Each year, products are appearing and disappearing from countries' export

Table 4: System GMM regression results for agricultural exports, 1994-2007

	(1)	(2)	(3)	(4)	(5)	(6)
	Theil	Theil	Theil	WTheil	WTheil	WTheil
GDPpc	0.0000399***		0.0000291*	0.00000468		0.0000139
	(3.72)		(2.47)	(0.47)		(1.39)
$GDPpc^2$	-4.55e-10***		-3.59e-10*	-3.51e-11		-2.09e-10
	(-4.40)		(-2.55)	(-0.32)		(-1.84)
Waterpc		-0.0000175*	-0.0000176		-0.0000153*	-0.0000163*
		(-1.99)	(-1.71)		(-2.05)	(-2.17)
$Watercpc^2$		4.85e-11**	5.28e-11**		4.22e-11**	3.94e-11*
		(2.83)	(2.77)		(2.66)	(2.58)
GDP*Water			1.75e-10			2.08e-10*
			(1.21)			(2.01)
Turning point	US$ 43,846					
ar2	-1.219	-1.878	-2.060	-1.814	-1.894	-2.189
hansen	78.16	73.58	71.74	66.82	75.17	77.40
hansenp	0.348	0.492	0.553	0.711	0.440	0.371
Instruments	89	89	92	89	89	92
Groups	1812	1819	1799	1806	1812	1806

t statistics in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

tables and we can associate each line with its own water footprint. We perform our second regression model at the country-product level (there is no time dimension here) and our dependent variable is the number of years that a product is exported by a country from 1994 to 2007 (its subsistence in time). Since our dependent variable ranges from 0 to 14, we perform a negative binomial regression as follows:

$$Subsistence_{ip} = \alpha_0 + \beta_1.WFP_{ip} + \beta_2.IncomeCat_i + \beta_3.WaterCat_i + \epsilon_{ip} \quad (10)$$

where i is the exporter country, p is the exported product, WFP_{ip} is country i's product water footprint in m^3/ton, $IncomeCat_i$ is the income category of the country from 1994 to 2007 and $WaterCat_i$ is its water category over the same period. The intercept captures country-product effects and the error term ϵ_{ip} is assumed to be normally distributed with zero mean and constant variance for all observations. It is also assumed that the errors are pairwise uncorrelated. We take the "High Income" and "No Stress" categories as references to avoid multi-collinearity between our independent variables. Our coefficient results for our categories must thus be interpreted as the difference between each category and the omitted category represented by the constant.

Results are reported in table 5 and all showh high levels of significancy. In all three columns, we see that the water footprint of products is negatively correlated with their subsistence in time, meaning that products tend to disappear faster if they are water-intensive. A high water footprint revealing poor water efficiency, this means that water is indeed a constraining factor of production and contributes to changes in the extensive (within) margin.

In column 1, the coefficient on high income is significant at the 1% level and equal to 1.691, meaning that all other coefficient are positive as well and that subsistence of products is correlated with wealth. In column 2, all coefficients are positive but again, the coefficient is for countries with little or no water stress. As such, products live longer in relatively more abundant water countries. In column 3, controlling for both income and water categories increases

Table 5: Negative binomial regression of export product subsistence from 1994 to 2007

	(1) Subsistence	(2) Subsistence	(3) Subsistence
Water Footprint	-0.00000349***	-0.00000352***	-0.00000332***
	(-5.48)	(-5.61)	(-5.14)
Low Income	-0.708***		-0.791***
	(-20.24)		(-22.36)
Low-Middle Income	-0.135***		-0.170***
	(-3.59)		(-4.51)
Upper Middle Income	0.0382		-0.0467
	(0.90)		(-1.10)
Abs Scarce		-0.762***	-0.916***
		(-13.87)	(-16.72)
Scarce		-0.0103	0.0654
		(-0.13)	(0.87)
Stress		0.110*	0.153***
		(2.34)	(3.30)
_cons	1.691***	1.483***	1.767***
	(62.10)	(98.13)	(62.81)
lnalpha	1.33	1.35	1.31
	(0.012)	(.012)	(.012)
_cons	1.336***	1.366***	1.317***
	(105.07)	(108.29)	(103.03)
N	23687	23687	23687

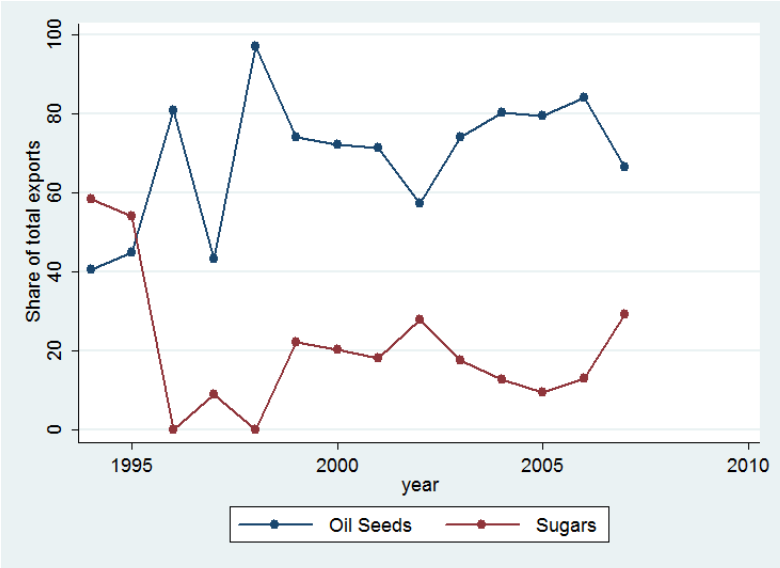
t statistics in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

the intensity of coefficients. Water intensive products are less likely to subsist than relatively less water-demanding ones, a result which is emphasized in low-income and absolutely scarce countries. This result is fairly intuitive and reveals that water resources do constrain production and food exports. If water-intensive goods do not subsist long in water scarce countries, it means that they are replacing those products with other goods.

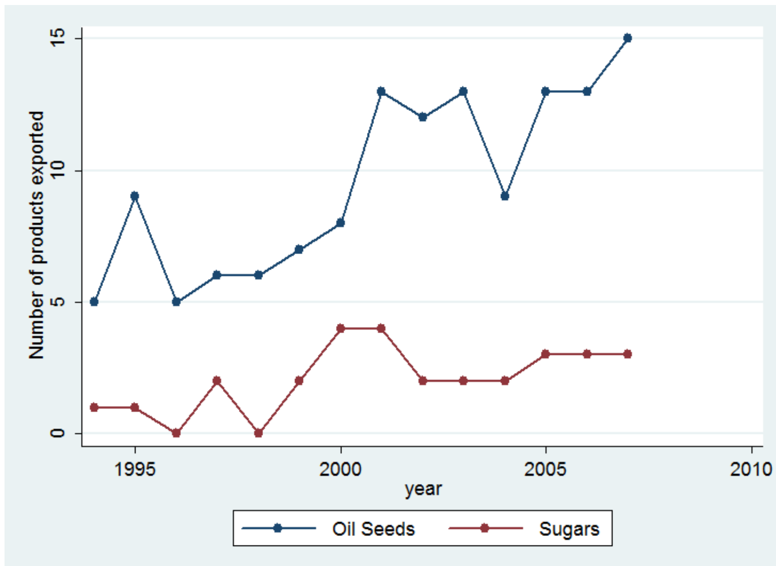
We illustrate this point by taking the case of Ethiopia whose Water Theil index has been varying between 1994 and 2007 (as illustrated in appendix C in figure 10). Ethiopia's main export sector in 1994 was HS2 17 "Sugars" which represented almost 60% of exports followed by HS2 12 "Oil Seeds" with 40% of total. In 2007, the trend was inversed, Oil Seeds became the first export sector with a 66% share in 2007 and Sugar was second with a 30% share. Within the "Oil Seeds" sector, Ethiopia exports 13 different products and 3 within the "Sugars" sector. Tables 7 and 8 in appendix C list these products in the decreasing order of their water footprint of those products, in m^3/ton and the current minimum water footprint for that product in the corresponding country.

Figure 7: Share of HS2 17 "Sugars" and HS2 12 "Oil Seeds" in total food exports, Ethiopia, 1994-2007



Our data shows that HS6 120740 "Sesame seeds" makes up for 81% of the total "Oil Seeds" exports with a water footprint of 6383 m^3/ton, in front of HS6 120799 "Other oil seeds with a share of 15% and a water footprint of 10851m^3/ton. While these two products make up for most of the share of exports in Oil Seeds, they are not Ethiopia's best bet in terms if water comparative advantage, as would Sugar Beet or Sugar Cane seem (with only twice the water footprint as the minimum reference).

Figure 8: Number of products exported according to sectors, Ethiopia, 1994-2007



We see in figure 10 that the number of products exported within Oil Seeds has almost tripled, thus showing that Ethiopia has diversified within its extensive Theil margin that is by opening new lines (and sometimes closing them, as in 2004). The products that closed in 2004 were 120400 (Linseed), 120500 (Rape or Colza seeds), 120720 (Cotton seeds), 120890 (Flours and Meal of other oil seeds), 121020 (Hop cones). Specifically Flours and Meal and linseed are among the top 4 water-intensive products for that sector and actually display very unstable trade patterns (disappear and re-appear every other year). On the other hand, cotton seeds have among the smallest water footprints for the country.

Regarding the Sugars sector, the very little number of products make up for 30% part of Ethiopia's exports in 2007 and HS6 "Cane Molass" makes up for 71% of the sector's exports. It so happens that this is the crop for which is Ethiopia is relatively more water efficient than the other two (HS6 170199 and HS170111 which are both Cane sugar crops) whose water footprint are almost 4 times as high. The product actually made up almost 100% of the sector's exports until 2000, where it was replaced as top exports by the cane sugar crops; out of those two, only the less water-intensive remained as an important export crops, "Cane Sugar" HS6 170111.

While we cannot conclude here that out of all the available crops to grow and export, countries focus on the ones for which they are most water efficient. However, we can notice that, as far as Ethiopia is concerned, it has opened up new lines of products that were among the least water intensive.

5 Conclusion

This paper addresses diversification patterns of agricultural exports in relation to water availability from a global perspective from 1994 to 2007. The objective is to fill a gap in the abundant literature on trade diversification regarding natural factor endowments and contribute to explaining the role of water resources in food production, food security and development.

Because agricultural dependence is water dependence, we study how water availability and water productivity affect agricultural exports using a water-measure of the Theil entropy index. Our study shows that, unlike previous results for the whole of exports, the traditional Theil index for agricultural products has an inverted u-shape relationship with growth, meaning that countries tend to concentrate their exports on fewer agricultural goods (extensive margin) within a limited number of sectors before diversifying beyond a high threshold of gdp per capita. Diversification of food exports thus concerns a limited number of wealthy countries. This result can be partly explained by agricultural intensification brought by capital and innovation as the country develops. Richer countries have a higher share of large farm-holders with little crop diversification. On the other hand, poorer nations feature weaker institutions to manage land and production, hence a larger number of small farm-holders. The correlation between growth and the Theil index disappears when controlling for water availability, meaning that the effect of growth on agricultural diversification is somewhat limited.The Water Theil index is not affected by the level of development, meaning that different levels of water diversification can be achieved in different nations.

On the other hand, the Theil and the Water Theil index both have a u-shape relationship with water availability per capita, meaning that countries diversify along water availability before re-concentrating. Water endowments thus offer countries a way to naturally diversify, at the intensive margin (more water increases production capacities) and at the extensive margin (more water increases diversity of crops).

We find that products which are relatively less water-intensive will be exported for a longer time, but when controlling for wealth and water endowments, low-income and/or water-scarce nations fail to export them as much as wealthy, water-abundant countries.

Our last finding is that out of their available bundle of available crops, countries do not necessarily chose to focus on those for which they are the most water-efficient. Market effects have a role to play, but it also shows that if countries are exporting to trading partners which are relatively less water-efficient (Delbourg and Dinar), water is still not a sufficient criterion for production strategies within the country.

This paper recommends that nations should focus on a small number of crops and improve their water footprints through technology and innovation in farming methods before diversifying. This will increase water efficiency, enable knowledge, capital and human acculumation and intensify production, leading those countries to develop and travel across the diversification cone.

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Appendices

A World Customs Organization - HS Nomenclature 2012

- HS01 - Live animals
- HS02 - Meat and edible meat offal
- HS03 - Fish and crustaceans, molluscs and other aquatic invertebrates
- HS04 - Dairy products; birds' eggs; natural honey; edible products of animal origin, not elsewhere specified or included
- HS05 - Products of animal origin, not elsewhere specified or included
- HS07 - Edible vegetables and certain roots and tubers
- HS08 - Edible fruit and nuts; peel of citrus fruit or melons
- HS09 - Coffee, tea, mat and spices
- HS10 - Cereals
- HS11 - Products of the milling industry; malt; starches; inulin; wheat gluten
- HS12 - Oil seeds and oleaginous fruits; miscellaneous grains, seeds and fruit; industrial or medicinal plants; straw and fodder
- HS13 - Lac; gums, resins and other vegetable saps and extracts
- HS14 - Vegetable plaiting materials; vegetable products not elsewhere specified or included
- HS15 - Animal or vegetable fats and oils and their cleavage products; prepared edible fats; animal or vegetable waxes
- HS16 - Preparations of meat, of fish or of crustaceans, molluscs or other aquatic invertebrates
- HS17 - Sugars and sugar confectionery
- HS18 - Cocoa and cocoa preparations

- HS20 - Preparations of vegetables, fruit, nuts or other parts of plants
- HS22 - Beverages, spirits and vinegar
- HS23 - Residues and waste from the food industries; prepared animal fodder
- HS24 - Tobacco and manufactured tobacco substitutes

B Additional regression results

Table 6: Within regression results for between and within components of the Theil index, 1994-2007

	(1) Theil Between	(2) Theil Within
GDPpc	-0.0000198***	0.0000150***
	(-5.02)	(3.42)
$GDPpc^2$	1.22e-10**	-1.69e-10***
	(2.74)	(-3.41)
_cons	1.674***	1.912***
	(68.48)	(70.42)
N	2572	2572
R^2	0.017	0.005
adj. R^2	-0.061	-0.074

t statistics in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

C The Oil Seeds and Sugars sector in Ethiopia

Figure 9: Water Theil Index for Ethiopia, 1994-2007

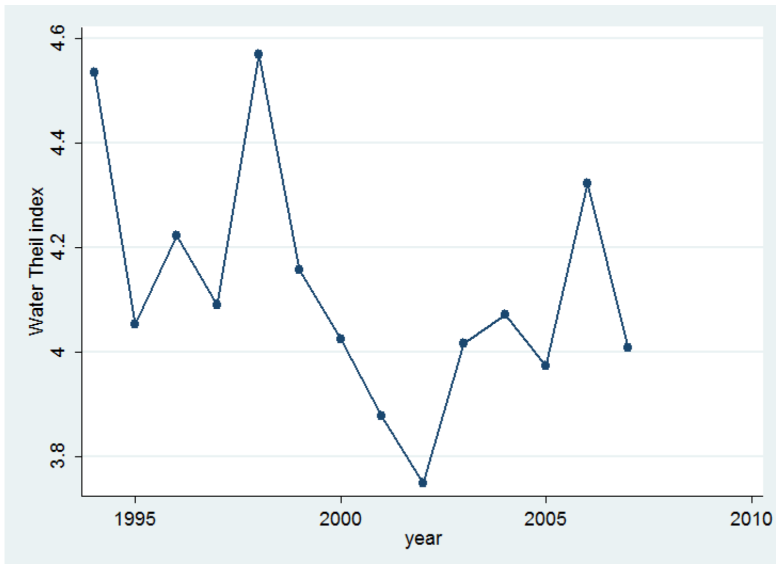

Table 7: Within regression results for between and within components of the Theil index, 1994-2007

HS6	HS2 12 - Oil Seeds	WFP (m^3/ton)	Best WFP i(m^3/ton)
120890	Flours and Meal of Other Oil Seeds	13564	2586
120799	Other Oil Seeds	10851	1229
120760	Safflower Seeds	8348	2509
120400	Linseed	8219	789
120740	Sesame Seeds	6383	429
120810	Flours and Meal of Soya Beans	5602	874
120210	Ground-nuts	5578	889
120100	Soya Beans	4762	743
120500	Rape or Colza Seeds	4284	935
121020	Hop Cones	4050	1428
120750	Mustard Seeds	3078	75
120720	Cotton Seeds	2293	568
121299	Other Vegetable Products	1153	97

Table 8: Within regression results for between and within components of the Theil index, 1994-2007

HS6	HS2 17 -Sugars	WFP (m^3/ton)	Best WFP i(m^3/ton)
170199	Other Cane or Beet Sugar	1482	560
170111	Cane Sugar	1304	478
170310	Cane Molasses	412	151