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Essays on water and economic growth: A long term perspective

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ESSAYS ON WATER AND ECONOMIC GROWTH: A LONG TERM PERSPECTIVE

PhD Dissertation

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A Angelines González, mi tía.

Siempre entre nosotros.

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Contents

Agradecimientos 5

Acknowledgements 7

List of figures 13

List of tables 15

INTRODUCCIÓN 17

INTRODUCTION 29

CHAPTER 1. LOOKING BACKWARD TO LOOK FORWARD: WATER USE AND ECONOMIC GROWTH FROM A LONG-TERM PERSPECTIVE 41

1. Introduction 43

2. Material and methods 45

3. Results and Discussion 49

3.1. Historical water use 49

3.2. Looking behind the data 51

3.3. Perspectives on water use in 2050. Results from a scenario analysis 59

4. Conclusions 63

5. References 64

Appendix 1.1 70

CHAPTER 2. IS THERE AN ENVIRONMENTAL KUZNETS CURVE FOR WATER USE? A PANEL SMOOTH TRANSITION REGRESSION APPROACH 73

1. Introduction 75

2. Methodology 79

2.1. The PSTR model 79

2.2.Estimation and linearity tests 80

3. Data and Empirical results 84

4. Discussion 95

5. Conclusion 98

6. References 99

CHAPTER 3. THE WATER INEQUALITIES: THE ROLE OF INCOME AND INDUSTRIAL SPECIALIZATION 105

1. Introduction 107

2. Methodology 109

3. Data 116
4. Results 117
4.1. Water consumption trends: 1995-2009 117
4.2. Factors contributing to water consumption changes 121
5. Conclusion 129
6. References 130
CHAPTER 4. THE WATER FOOTPRINT OF THE SPANISH AGRICULTURAL SECTOR: 1860-2010 135
1. Introduction 137
2. Methodology and data 141
2.1. Methodology 141
2.2. Data 144
3. Results 145
3.1. Trends and patterns of embodied water in production 145
3.2. Factors explaining changes in embodied water in production 149
4. Discussion 150
5. Conclusions 158
6. References 159
Appendix 4.1: Uncertainty 169
Appendix 4.2: Production estimates 174
CHAPTER 5. THE EFFECT OF GLOBALISATION ON WATER CONSUMPTION: A CASE STUDY OF THE SPANISH VIRTUAL WATER TRADE, 1849-1935 179
1. Introduction 181
2. Spain's position in the international markets for agricultural products: some stylised facts 184
3. Methodology and data 186
3.1. Methodological aspects 186
3.2. Data 191
4. Results 192
4.1. Analysis of virtual water trade flows 192
4.2. Decomposition analysis of virtual water trade flows 197
5. Understanding the virtual water trade 200
6. Conclusions 202

7. References 203
Appendix 5.1: Alternative results assuming constant water intensity 209
CHAPTER 6. GLOBALISATION AND NATURAL RESOURCES: THE EXPANSION OF SPANISH AGRIFOOD TRADE AND ITS IMPACT ON WATER CONSUMPTION, 1965-2010 211
1. Introduction 213
2. Some stylized facts: the Spanish agri-food trade between 1965 and 2010.......... 216
3. Methodology and Data 217
3.1. Methodological aspects 217
3.2. Data 222
4. Results 223
4.1. Analysis of virtual water trade flows 223
4.2. Decomposition analysis of virtual water trade of flows 230
5. Discussion 233
6. Conclusions 236
7. References 237
CHAPTER 7. GLOBAL WATER IN A GLOBAL WORLD: A LONG TERM STUDY ON VIRTUAL WATER FLOWS IN THE WORLD 245
1. Introduction 247
2. Methodology and Data 249
2.1. Methodological aspects 249
2.2. Data 254
3. Results 255
3.1. Global virtual water flows assessment 255
3.2. Factors driving global virtual water flows in the long term 265
4. Conclusions 268
5. References 270
Appendix 7.1 274
CONCLUSIONS 279
CONCLUSIONES 287

List of figures

Figure 1.1: Worldwide water withdrawal (km^3), 1900-2000
Figure 1.2: Europe water withdrawal (km^3), 1900-1995
Figure 1.3: North America water withdrawal (km^3), 1900-1995
Figure 1.4: Oceania water withdrawal (km^3), 1900-1995
Figure 1.5: Asia water withdrawal (km^3), 1900-1995
Figure 1.6: Africa water withdrawal (km^3), 1900-1995
Figure 1.7: Latin America water withdrawal (km^3), 1900-1995
Figure 2.1: Per capita income vs. fitted per capita water use from the PSTR model
Figure 2.2: PSTR transition function
Figure 2.3: PSTR water use elasticity displayed for all the values of per capita income
Figure 2.4: Global time-variant elasticities
Figure 2.5: Global average EKC
Figure 3.1: Global absolute increase in water consumption: 1995-2009
Figure 3.2: Embodied water change by countries: 1995-2009
Figure 3.3: Factors contributing to global water consumption increase from 1995 to 2009
Figure 4.1: Water embodied in Spanish production (1860-2008)
Figure 4.2: Accumulated reservoir capacity in Spain, 1900-1990
Figure 4.3: Irrigated area, 1916-1996
Figure 4.4: Average annual precipitations in Spain (mm)
Figure 4.5: Adjusted annual variations (1850–2003) of daily maximum and minimum temperature
Figure 4.6: Real evapotranspiration in Spain (mm)
Figure 4.7: ETR correlogram
Figure 5.1: Total virtual water flows (1849-1935) hm^3/year
Figure 5.2: Blue virtual water flows (1849-1935) hm^3/year
Figure 5.3: Green virtual water flows (1849-1935) hm^3/year
Figure 6.1: Total virtual water exports and imports (1965-2010)
Figure 6.2: Green virtual water exports and imports (1965-2010)
Figure 6.3: Blue virtual water exports and imports (1965-2010)
Figure 6.4: Origin of green water embodied in products imported by Spain, 1965 (thousand m^3)
Figure 6.5: Origin of green water embodied in products imported by Spain, 2010 (thousand m^3)
Figure 6.6: Origin of blue water embodied in products imported by Spain, 1965 (thousand m^3)
Figure 6.7: Origin of blue water embodied in products imported by Spain, 2010 (thousand m^3)
Figure 7.1: Global virtual water flows, 1965-2010 (km^3)
Figure 7.2: Country net exports of green water and top five net flows in the world, 1965
Figure 7.3: Country net exports of green water and top five net flows in the world, 2010
Figure 7.4: Country net exports of blue water and top five net flows in the world, 1965
Figure 7.5: Country net exports of blue water and top five net flows in the world, 2010
Figure 7.6: Factors explaining virtual water flows increase, 1965-2010

List of tables

Table 1.1: Cumulative annual average growth rates in water withdrawal (%)
Table 1.2: Growth rates in water use, population, per capita GDP, and water intensity (1900-2000)
Table 1.3: Contribution of the factors to water use changes (1900–2000)
Table 1.4: Scenario analysis results. Water use in 2050 (2000=1)*
Table 2.1: Summary statistics
Table 2.2: Maddala and Wu's (1999) ADF Unit Root Test
Table 2.3: Tests for cross-sectional dependence and unit roots
Table 2.4: Water use-income relationship. Panel model with time and individual fixed effects
Table 2.5: Linearity and non-remaining heterogeneity tests
Table 2.6: Parameter estimation of the PSTR
Table 2.7: Individual average of income elasticity of water use
Table 2.8: Per capita water use average annual growth rates (%)
Table 3.1: Countries classification according the level of per capita income
Table 3.2: SDA for embodied green water changes: 1995-2009
Table 3.3: SDA for embodied blue water changes: 1995-2009
Table 3.4: SDA for embodied grey water changes: 1995-2009
Table 4.1: Composition of embodied water in production and average annual growth rates
Table 4.2: Decomposition analysis of embodied water
Table 4.3: Products with no data in 1900 and crops used to estimate their production
Table 5.1: Green and blue virtual water exports, by product group (average share %)
Table 5.2: Green and blue virtual water imports by product group (average share %)
Table 5.3: Decomposition analysis of virtual water exports and imports
Table 5.4: Comparison of water embodied in exports and production
Table 5.5: Comparison of water embodied in exports and production using constant water intensities
Table 6.1: Virtual exports by group of product (average share and average annual growth rates)
Table 6.2: Virtual imports by group of product (average share and average annual growth rates)
Table 6.3: Decomposition analysis of virtual water flows
Table 6.4: Comparison of green and blue water embodied in exports and production
Table 7.1: Average contribution of world regions to virtual water exports and imports (%)
Table 7.2: Water availability, withdrawal, Gross VWM, Gross VWX and Net VWM in 1980 (km^3)
Table 7.3: Water availability, withdrawal, Gross VWM, Gross VWX and Net VWM in 2000 (km^3)
Table 7.4: Average contribution of products to virtual water exports and imports (%)
Table 7.5: Change in virtual water flows and decomposition analysis effects, 1965-2010
Table 7.6: Average virtual water exports, imports and balance (km^3)
Table 7.7: Change in virtual water exports and decomposition analysis (%) at the country level, 1965-2010
Table 7.8: Change in virtual water imports and decomposition analysis at the country level, 1965-2010

INTRODUCCIÓN

El agua es uno de los recursos naturales más valiosos del planeta, esencial para el medio ambiente y la vida humana. El volumen total de agua de la tierra es de unos 1,400 millones de km^3, de los cuales sólo el 2.5% es agua dulce. Además, teniendo en cuenta que los lagos y ríos contienen aproximadamente 105,000 km^3, sólo el 0.3% del agua dulce del mundo está disponible para uso humano, aunque irregularmente distribuida tanto en el tiempo como en el espacio (Shiklomanov, 2000). Si bien la desigual distribución de los recursos hídricos puede estar en el origen de los problemas de escasez, el aumento de la población, junto con el crecimiento económico de largo plazo han agravado la escasez de agua.

Mientras que durante el período preindustrial la capacidad para gestionar los recursos hídricos era limitada, debido principalmente a las limitaciones tecnológicas; el crecimiento demográfico y la industrialización han conllevado la intensificación del uso del agua. De hecho, debido a la creciente demanda de agua, los ecosistemas hídricos han experimentado notables cambios desde el comienzo de la revolución industrial. Así, según L'Vovich y White (1990), de 1687 a 1987 la extracción mundial de agua aumentó 35 veces y el consumo de agua se multiplicó por nueve durante el siglo veinte. A pesar de que los procesos de industrialización y urbanización han fomentado el incremento de los usos del agua, la agricultura ha sido el principal usuario en todo el mundo, especialmente debido al desarrollo del regadío que experimentó una fuerte expansión durante el siglo pasado y que representa aproximadamente el 70% del uso total de agua.

En este contexto, la limitad disponibilidad de agua dulce junto con el crecimiento exponencial de la demanda han generado una importante preocupación en las instituciones internacionales, que reclaman la necesidad de abordar y comprender la relación entre las necesidades de agua y el crecimiento económico de una forma adecuada. Desde la perspectiva de la FAO (Food and Agriculture Organization), "la escasez de agua afecta ya a casi todos los continentes y a más del 40% de las personas en nuestro planeta. En 2025 1.8 billones de personas vivirán en países o regiones con escasez absoluta de agua, y dos tercios de la población mundial podrían estar viviendo bajo condiciones de estrés hídrico”. En esta línea, el WWAP (World Water Assessment Program) afirma que "la gestión de los recursos hídricos afecta a casi todos los aspectos de la economía, en particular, a la salud, la producción y la seguridad alimentaria, al abastecimiento y saneamiento de agua, a la energía, a la industria y a la sostenibilidad ambiental".

Hoy en día, existe evidencia empírica que demuestra que las economías industriales han generado graves impactos sobre el medio natural, ya sea modificándolo o causando notables problemas de contaminación (McNeill, 2000; Krausmann et al., 2008). El efecto de los procesos de industrialización en las emisiones (Stern y Kaufmann, 1996; Stern, 2005), sobre el uso de las materias primas (Iriarte-Goñi y Ayuda, 2008 y 2012; Krausmann et al., 2009) o en el uso de la energía (Kander y Lindmark, 2004; Rubio, 2005; Gales et al., 2007) han sido ampliamente estudiados. Sin embargo, mientras que si bien es cierto que los recursos hídricos han sido analizados durante la última década, pocos trabajos han examinado el agua desde una perspectiva histórica (Vörösmarty et al., 2005; Shiklomanov, 2000). Según Schandl y Schulz (2002) "la comprensión de cómo una determinada relación natural se ha establecido en el curso de la historia y los patrones y feedbacks que funcionaron podría permitir a la sociedad intervenir conscientemente en estas relaciones naturales e incluso podría fomentar nuestra comprensión de la sostenibilidad".

Tratando de llenar el vacío existente, esta tesis profundiza en la relación entre los recursos hídricos y el crecimiento económico desde la historia ambiental. Así, en este trabajo se estudian los recursos hídricos desde tres perspectivas estrechamente vinculadas: económica, histórica y global. El punto de vista económico permite considerar la economía como un proceso físico en el que el agua puede ser vista como un input para los procesos de producción, para el medio ambiente y para el bienestar humano. El agua es un bien escaso con notables costes de oportunidad asociados que aparecen al decidir cómo usarla. La perspectiva histórica nos ayuda a determinar la importancia de los recursos hídricos en los procesos de transición socio-económicos de largo plazo. Por último, la perspectiva global es necesaria debido a la trascendencia de cuestiones que afectan directamente al agua, como el cambio climático, los conflictos del agua o la globalización. Por tanto, esta investigación se enmarca en el contexto de la economía del agua y de la historia ambiental y económica y utiliza herramientas del análisis económico como la econometría, los modelos input-output o el análisis de descomposición de los impactos ambientales.

En consecuencia, la tesis doctoral tiene como objetivo principal el estudio detallado de las relaciones a largo plazo entre los procesos de crecimiento económico y las presiones ejercidas sobre un recurso escaso pero esencial para el desarrollo de la vida y la actividad económica: el agua. De esta manera, la conexión de dos campos aparentemente separados como la economía del agua y la historia medioambiental no sólo conlleva un notable desarrollo con respecto a estudios previos de agua, esencialmente estáticos y centrados en el corto plazo, sino que también es crucial en un mundo en el que los problemas de escasez aparecen como uno de los retos a afrontar en el siglo veintiuno.

Más concretamente, este estudio trata de responder a cuatro preguntas relevantes que nos llevan a los principales temas de la investigación.

- El uso y consumo de agua mostraron una tendencia creciente a lo largo del siglo veinte, ¿cuáles han sido los principales factores que se encuentran tras esta tendencia creciente? ¿Qué regiones son los principales usuarios del agua? Dado un conjunto de supuestos económicos, demográficos y tecnológicos, ¿cuáles son las tendencias de futuro que se pueden esperar?

- Los factores económicos y tecnológicos parecen ser relevantes para explicar la trayectoria seguida por la extracción de agua, ¿existe una Curva de Kuznets Ambiental para la relación "uso de agua per cápita-renta per cápita"?

- La agricultura es el principal consumidor de agua en el mundo, ¿afectó la expansión agraria a los recursos hídricos? ¿Cuál ha sido el papel de las infraestructuras hidráulicas para el desarrollo del sector agrario?

- El agua ha sido crecientemente intercambiada incorporada en los productos que son comerciados internacionalmente, ¿cuál ha sido la senda seguida por los flujos de agua virtual? ¿Qué países y productos ejercieron la mayor contribución a los desplazamientos de agua? ¿Se mantuvieron estos patrones estables en el tiempo? ¿Cuáles han sido los principales factores que impulsaron los flujos de agua virtual? ¿En qué medida los procesos de globalización son capaces de explicar el gran aumento en el consumo de agua?

En este marco, la tesis doctoral se divide en dos partes. Los cuatro primeros capítulos estudian la relación entre el uso y consumo de agua y el crecimiento económico desde una perspectiva histórica. Las dos primeras secciones analizan el concepto de uso de agua, que se define como el volumen de agua dulce extraído de fuentes superficiales o subterráneas (Hoekstra et al., 2011). McNeill (2000) muestra que durante el siglo veinte, el crecimiento demográfico, junto con la expansión del regadío y la industrialización implicaron un aumento sin precedentes en el uso del agua, tanto en términos absolutos como per cápita. Posteriormente, en los capítulos tres y cuatro se aborda la relación entre el consumo de agua y los procesos de crecimiento económico. Tal y como definen Hoekstra et al. (2011), el consumo de agua es el volumen de agua dulce utilizada y luego evaporada o incorporada en un producto.

En esta línea, en el primer capítulo se analiza la evolución del uso del agua a nivel mundial durante el siglo pasado, así como la relación con los principales factores determinantes del crecimiento económico. Se estudian las trayectorias del uso de agua, estableciendo los principales patrones en las diferentes regiones del mundo. Además, se trata el grado en que ciertos factores demográficos, sociales y económicos han contribuido a las tendencias mostradas por la extracción de agua, tratando de evaluar cómo afectarán estos factores a las trayectorias futuras a través de un análisis de escenarios.

Una vez demostrada la importancia de los factores económicos para explicar las tendencias de uso de agua, el capítulo dos amplía el enfoque a través del estudio de la conocida Curva Ambiental de Kuznets. La relación entre el nivel del PIB por persona y el medio ambiente ha sido ampliamente estudiada en la literatura académica (Selden y Song, 1994; Grossman y Krueger, 1995; Roca et al., 2001; Barbier, 2004) y el debate sobre sus factores explicativos y sus limitaciones continúa actualmente. Básicamente, la relación entre el ingreso per cápita y el consumo de agua per cápita se evalúa mediante un modelo econométrico de datos de panel.

Posteriormente, en los capítulos tres y cuatro se examinan los vínculos entre el consumo de agua y los procesos de crecimiento económico. Según Hoekstra et al. (2011), el consumo de agua es el volumen de agua dulce utilizada y luego evaporada o incorporada en un producto. Por lo tanto, mediante un modelo multirregional de input-output en el capítulo tres se estudian las tendencias del consumo directo e indirecto de agua en el mundo entre 1995 y 2009. Este modelo permite analizar las interrelaciones sectoriales y entre países a través de toda la cadena de producción a nivel mundial. Además, se lleva a cabo un análisis de descomposición estructural para estudiar la forma en que las diferentes especializaciones productivas, no sólo en cuanto a las tecnologías de producción, sino también referentes a los patrones de demanda, han afectado a los recursos hídricos. El impacto que las transiciones socio-económicas tienen sobre los recursos naturales parece variar en función del nivel de desarrollo de las regiones. Por lo tanto, la muestra se divide en dos grupos en función del nivel de renta por habitante clasificando los países en zonas de ingresos bajos-medios y altos. Ello nos permitirá examinar la contribución de los diferentes factores y grupos regionales al consumo de agua.

La agricultura representa aproximadamente el 70 % del consumo de agua en el mundo. Llevar a cabo un estudio detallado de la relación entre la agricultura y los recursos naturales en el contexto de las transiciones de largo plazo parece esencial. A pesar de ser un sector menor en términos de actividad económica y empleo, actualmente la agricultura genera notables impactos ambientales, especialmente en las zonas áridas y semi-áridas. En consecuencia, el capítulo cuatro aborda el caso de la agricultura española, un sector que ha pasado por un proceso intensivo de desarrollo con importantes cambios estructurales, no sólo en el propio sector, sino también en cuanto a la relación del sistema agrario con los recursos hídricos. Por lo tanto, en esta sección se trata la evolución del consumo doméstico de agua asociado con los cambios producidos en la agricultura española durante los últimos 150 años. Para ello examinamos el impacto que las crecientes necesidades de agua tuvieron en la construcción de infraestructuras de regadío. En este contexto, será posible vincular los cambios históricos y las reformas de la política agraria con el desarrollo de obras hidráulicas y con el aumento en el consumo de agua.

Los procesos de crecimiento económico han implicado además una creciente integración de la economía internacional. Desde las primeras décadas del siglo diecinueve se ha producido un fuerte proceso de globalización histórica, interrumpido con la crisis de 1929, y retomado tras el final de la Segunda Guerra Mundial. Así, la segunda parte de la tesis profundiza en el impacto que la primera y la segunda globalización ejercieron sobre los recursos hídricos, estudiando los intercambios de agua entre los países a través del comercio internacional. En este marco, durante la última década han surgido dos nuevos conceptos: el agua virtual y la huella hídrica. En primer lugar tal y como define Allan (1997), el agua virtual se refiere al volumen de agua que se utiliza para producir un bien. En la misma línea, el concepto de huella hídrica también se refiere al agua que se utiliza para producir un producto, esto es, a su contenido de agua virtual. Sin embargo, según Hoekstra et al. (2011) la huella hídrica tiene una aplicación más amplia, ya que además de la huella hídrica de un producto es posible estimar la huella hídrica de un productor, consumidor o país. Por otra parte, es un indicador multidimensional que hace explícito el lugar donde se genera la huella hídrica, el tipo de agua que se utiliza, y el momento en que se usa el agua. Esta información adicional es esencial para evaluar los impactos de la producción y el consumo de un bien así como para identificar las divergencias entre las responsabilidades del consumidor y del productor. Este tipo de estudios distinguen entre la huella hídrica verde y azul que representan diferentes tipos de apropiación del agua. La disponibilidad de agua dulce en la tierra está determinada por la precipitación anual. Una parte de las precipitaciones se evapora y la otra parte discurre hacia el mar a través de los acuíferos y ríos. La parte de la precipitación que se evapora y es utilizada para fines humanos, como la agricultura, es la huella hídrica verde. El flujo de la escorrentía extraído y posteriormente evaporado, es decir, consumido, mide la huella hídrica azul (Hoekstra et al., 2011).

Por lo tanto, los capítulos cinco a siete se centran en el análisis de los flujos de agua virtual como resultado del comercio internacional de productos agroalimentarios, que representan el 80 % de la huella hídrica total. En concreto, los capítulos cinco y seis tratan el caso de España, un país semiárido que destaca como exportador de productos agroalimentarios. Estos informan del papel que la expansión del comercio internacional producida durante la primera y segunda globalización ha jugado en el aumento de las presiones sobre los recursos hídricos. De esa manera, en el capítulo cinco se estiman los flujos de agua virtual durante el periodo 1849-1935, analizando el impacto de la expansión del comercio sobre el consuno de agua durante la primera globalización. En este sentido, la demanda extranjera de productos agroalimentarios impulsó notablemente el desarrollo del regadío, así como los primeros intercambios de cargas ambientales, como es el caso del agua. Aunque la primera globalización sentó las bases de un proceso de crecimiento económico mucho más intenso y de mayor impacto ambiental como fue la segunda globalización, la expansión del sector exterior español terminó con la Guerra Civil Española y los años de autarquía durante la dictadura franquista. Sin embargo, de 1965 a 2010, España se vio inmersa en un período de modernización económica y liberalización comercial que dio lugar a cambios importantes en cuanto a la relación del sistema agrario con los recursos naturales. En este marco, el capítulo seis se refiere al efecto que la expansión del comercio, ocurrida durante la segunda globalización, tuvo en el consumo de agua de España y en la necesidad de construir obras hidráulicas, claves para el desarrollo del regadío. Finalmente en el capítulo siete se analizan los intercambios de productos agroalimentarios que han tenido lugar durante el último medio siglo en el mundo. La segunda globalización ha supuesto una importante integración económica y comercial que ha implicado a su vez, un aumento en los intercambios productivos y la divergencia entre las responsabilidades de productores y consumidores. Además, en este capítulo se cuantifica el efecto que los cambios en el volumen del comercio, en la composición, en el origen de los flujos, en la cuota de los países en el comercio mundial, así como en la mejora de los rendimientos agrarios tuvieron en el consumo global de agua.

Esta tesis realizada como compilación de artículos, recoge siete trabajos de investigación diferentes. Esta estructura, que prioriza el formato de publicación, proporciona completos capítulos que se corresponden con los siete artículos científicos. Algunos de los capítulos han sido presentados en congresos nacionales e internacionales o han sido ya publicados en revistas científicas:

- Capítulo uno: Publicado en *Applied Economics*. Presentado en 11th Biennial Conference of the International Society for Ecological Economics, Water History Conference 2010, Encuentro Desarrollo Económico y Medio Ambiente, y Seminarios de Historia Económica de la Universidad de Zaragoza.
- Capítulo dos: Publicado en *Economic Modelling*.
- Capítulo tres: Presentado en International Symposium on Water Footprint, XXXIX Reunión de Estudios Regionales, y V Jornadas de Análisis Input-Output.
- Capítulo cuatro: Presentado en Water History Conference 2013, y Seminarios de Historia Económica de la Universidad de Zaragoza.
- Capítulo cinco: Publicado en *Ecological Economics*. Presentado en Water Leeds Seminars, II Seminario Anual de la SEHA, y Lisbon Fresh Meeting.
- Capítulo seis: Presentado en XIV Congreso Internacional de Historia Agraria, y en 7th European Society for Environmental History Conference.

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INTRODUCTION

Water is one of the world’s most precious natural resources, essential for the environment and for human life. The total volume of water on Earth is about 1.4 billion km^3, of which only 2.5 % is freshwater, and considering that freshwater lakes and rivers contain an estimated 105,000 km^3, only 0.3 % of the world's freshwater is available for human use, irregularly distributed both in time and space (Shiklomanov, 2000). Although the uneven distribution of water resources is sometimes the source of water shortages, the increasing global population, together with long-term economic growth, exacerbates the problem of water scarcity.

During the pre-industrial period there was limited capacity to manage water resources, mainly due to technological constraints. In the last three centuries, population growth and industrialization have entailed an intensification of water use. In fact, water ecosystems notably changed from the beginning of the industrial revolution as a result of increasing demands for water. According to L’Vovich and White (1990), from 1687 to 1987 global water withdrawal increased 35-fold, and water consumption multiplied by nine during the twentieth century. Despite the fact that urbanization and industrialization processes involved increasing water use, global agriculture has been the primary consumer of water, particularly as a result of the massive development of irrigation systems during the past century, accounting for approximately 70% of total water use.

In this context, the limited supply of freshwater, and exponential growth in demand, have generated great concern among those international institutions that emphasise the need to address and correctly understand the nexus between water requirements and economic growth. From the perspective of the FAO (Food and Agriculture Organization), “water scarcity already affects almost every continent and more than 40% of the people on our planet”. According to the FAO, “…by 2025, 1.8 billion people will be living in countries or regions with absolute water scarcity, and two-thirds of the world’s population could be living under water-stressed conditions”. Similarly, the WWAP (World Water Assessment Programme) states that, “…water resource management impacts almost all aspects of the economy, in particular, health, food production and security, domestic water supply and sanitation, energy, industry and environmental sustainability”.

Clear evidence now exists that industrial economies have caused serious damage to their natural environments, whether by modifying them greatly or by generating serious problems of pollution (McNeill, 2000; Krausmann et al., 2008). The analysis of the impact of the processes of industrialization on emissions (Stern and Kaufmann, 1996; Stern, 2005), on the use of raw materials (Iriarte-Goñi and Ayuda, 2008 and 2012; Krausmann et al., 2009) and on the use of energy (Kander and Lindmark, 2004; Rubio 2005; Gales et al., 2007) have merited special attention. However, whereas many studies have analyzed water resources during the last decade, only a few have examined water from a historical perspective (Vörösmarty et al., 2005; Shiklomanov, 2000). According to Schandl and Schulz (2002), "…understanding how a certain natural relation has been established in the course of history and which patterns and feedbacks were at work might enable society to consciously intervene in these natural relations and might even eventually foster our understanding of sustainability".

In an endeavour to bridge this gap, this thesis delves into the relationship between water resources and economic growth from the approaches of ecological economics and environmental history. We study water resources from three closely-linked perspectives: economic, historical, and global. The economic viewpoint allows us to consider the economy as a physical process, in which water can be seen as an input for production processes, for the environment, and for human well-being. Water is a scarce good, with associated opportunity costs that appear when choosing how to use it. The historical perspective helps to determine the significance of water resources in the socio-economic system and its long-term transition processes. Finally, a global view is necessary due to the current transcendence of issues directly affecting water, such as climate change, water conflicts, and globalisation. Our goal here is to contribute to the literatures of water economics and of environmental economic history, making use of tools from economic analysis like econometrics, input-output models, and decomposition analysis of environmental impacts.

Accordingly, this PhD dissertation has as its main objective to examine the long-term relationships between processes of economic growth and the pressures exerted on a scarce but essential resource for both life development and economic activity: water. Thus, connecting two seemingly disparate fields, water economics and environmental history not only entails an outstanding development over prior water studies, essentially static and generally focused on the short term, but is crucial in a world where the problems of water scarcity are among the most pressing challenges of the twenty-first century.

More specifically, this study addresses four important aspects.

- What have been the main drivers of the increasing growth in water use and consumption throughout the twentieth century? Which regions were the main water users? Given a set of economic, demographic, and technological assumptions, what are the expected future trends?
- Given that economic and technological factors are key in explaining the trends in water withdrawal, does there exist an Environmental Kuznets Curve for the relationship between per capita water withdrawal and per capita income?
- How has agricultural expansion affected global water resources, and what role has been played by hydraulic infrastructure in the development of the agricultural sector?
- Water has been increasingly transferred embodied in commodities exchanged through international trade. What has been the path followed by virtual water flows? Which countries and products have made the largest contribution to embodied water displacements? Have these patterns remained stable over time? What have been the main factors boosting virtual water flows? To what extent are the factors of globalisation accountable for the great increase in water consumption?

Within this framework, this PhD dissertation is divided into two parts. Chapters one to four study the relationship between water and economic growth from a historical perspective. The first two chapters analyse the concept of water withdrawal, defined as the volume of freshwater abstraction from surface- or ground-water (Hoekstra et al., 2011). McNeill (2000) shows that, during the twentieth century, population growth together with the expansion of irrigation and industrialization involved an unprecedented increase in water use in both absolute and per capita terms. In this line, chapter one examines global water use trends over the past century and their relationship to the main determinants of economic growth. Water use trajectories are analyzed, determining the main regional patterns in the world. Through a simple scenario analysis, we study the extent to which certain demographic, social, and economic factors have contributed to water withdrawal trajectories, with the aim of assessing their future trends.

Chapter two broadens the focus, to conduct an analysis of the well-known Environmental Kuznets Curve. The relationship between the level of per-capita GDP and environmental impacts has been widely studied in the literature (Selden and Song, 1994; Grossman and Krueger, 1995; Roca et. al., 2001; Barbier, 2004) and a debate on the explanations and limitations of this relationship is ongoing. The link between per-capita income and per-capita water use is assessed via a panel data econometric model. Working with a sample of 65 countries over the period 1962-2008, a variety of water use schemes appear, according to the level of development in each area.

Subsequently, the relationship between water consumption and the processes of economic growth is addressed in chapters three and four. Following Hoekstra et al. (2011), water consumption is the volume of freshwater used and then either evaporated or incorporated in a product. Thus, an environmentally extended multi-regional input-output model is utilized in chapter three to study direct and indirect water consumption trends in the world, from 1995 to 2009. This model allows us to study country and sectorial interrelations through the whole production and supply chain, at the global level. Furthermore, a structural decomposition analysis (SDA) is applied to examine the way that different productive specializations - not only production technologies but also demand patterns - have affected water resources. The impact of socio-economic transitions on natural resources varies, depending on the level of development of individual regions, and we therefore distinguish low-, middle- and high-income areas, examining the contribution of the various factors and regional groups to water consumption.

Agriculture accounts for approximately 70% of water consumption in the world. Hence, carrying out a detailed study of the relationship between agriculture and natural resources in the context of long-term transitions is essential. Despite being a minor sector in terms of total economic activity, agriculture generates significant environmental impacts, particularly in arid and semi-arid regions. Consequently, chapter four addresses the case study of Spanish agriculture, a sector that has undergone an intensive process of development resulting in important structural changes, not only in the sector itself, but also regarding the relationship of the agrarian system with water resources. The chapter deals with the evolution of domestic water consumption associated with the transition of the Spanish agricultural sector during the last 150 years, examining the impact that the growing demand for water had on the construction of irrigation infrastructure. In this context, it is possible to link historical changes and reforms of agrarian policy to the development of waterworks and to the increase in water consumption. To that end, a thorough analysis of agricultural production data from Spanish historical statistics has been carried out

The processes of economic growth also entailed a growing integration of the international economy. From the early decades of the nineteenth century, a historic globalisation process occurred. This was brought to a halt in 1929, but resumed with the end of the Second World War. Within this context, the second part of this thesis delves into the impact that the first and second globalisations had on water resources, addressing the inter-country exchanges of water through trade. During the last decade, two new concepts have come to the fore: virtual water, and the water footprint. First defined by Allan (1997), virtual water refers to the volume of water used to produce a particular good. Allied with this, the notion of a water footprint refers to the water used to make a product or, similarly, to its virtual water content. Following Hoekstra et al. (2011), the water footprint has a wider application, since, apart from the water footprint of a commodity, the water footprint of a producer, consumer, or nation can be also measured; it is a multi-dimensional indicator that makes explicit where the water footprint is located, what source of water is used, and when the water is used. This additional information is essential in order to assess the impacts of the water footprint of a product and to identify the divergences between consumer and producer responsibilities. Studies have distinguished between the green and the blue water footprint, accounting for different kinds of appropriation.

Freshwater availability on the planet is determined by annual precipitation over land; one part of this precipitation evaporates, and the other becomes run-off to the oceans through aquifers and rivers. That part of precipitation that evaporates from human/economic activities as crop growth is the green water footprint. The runoff flow that contributes to surface water and ground water, and is then either evaporated or consumed, measures the blue water footprint (Hoekstra et al. 2011).

Chapters five to seven focus on the analysis of virtual water flows as a result of the international trade in agricultural and food products, representing 80% of the total water footprint. Chapters five and six present a case study of a semi-arid country, Spain, that excels as an exporter of agricultural and food products. These chapters provide insights into the roles played by the expansion of international trade, and the first and second globalisations, in increasing pressure on water resources. Chapter five estimates virtual water flows from 1849 to 1935, analysing the impact on water consumption of trade expansion in the first era of globalisation. Foreign demand for agricultural products was one of the most important driving forces behind the development of irrigation, leading to increasing pressure on domestic natural resources - most crucially on water. Although the first globalisation laid the foundations, a much more intensive process of economic growth - and consequent environmental damage - occurred during the second globalisation. The expansion of the foreign trade sector of Spain’s economy ended with the onset of the Spanish Civil War and the subsequent years of autarky during Franco’s Dictatorship. However, from 1965 to 2010, Spain underwent a period of economic modernization and commercial liberalization that resulted in important changes in the relationship of the agrarian system to natural resources. Chapter six deals with the effect of that trade expansion, taking place during the second globalisation, on water consumption in Spain, and on the need for the construction of water infrastructure (a key to the development of irrigation). Finally, chapter seven analyses the agricultural and food product exchanges that took place globally during the last half century. The second globalisation involved a significant economic and commercial integration that led to growing exchanges of products that embodied large volumes of water, and to a remarkable mismatch between producer and consumer responsibilities. Furthermore, this chapter quantifies the impact that developments in the volume of trade, in product composition, in the origin of flows, in the importance of countries in global trade, as well as in crop and livestock yield improvements, exerted on global water consumption.

This thesis has been built from coherent and complementary articles, collecting seven different research papers. This structure, which prioritizes the publication format, provides full self-contained chapters that correspond to the seven scientific articles. Some of these chapters have been presented at national and international conferences, or have already been published in scientific journals:

- Chapter one: Published in *Applied Economics*. Presented at the 11th Biennial Conference of the International Society for Ecological Economics, Water History Conference 2010, Encuentro Desarrollo Económico y Medio Ambiente, and Seminar in Economic History at the University of Zaragoza.
- Chapter two: Published in *Economic Modelling*.
- Chapter three: Presented at the International Symposium on Water Footprint, XXXIX Reunión de Estudios Regionales, and V Jornadas de Análisis Input-Output.
- Chapter four: Presented at the Water History Conference 2013 and Seminars in Economic History at the University of Zaragoza.
- Chapter five: Published in *Ecological Economics*. Presented at Water Leeds Seminars, II Seminario Anual de la SEHA, and Lisbon Fresh Meeting.
- Chapter six: Presented at the XIV Congreso Internacional de Historia Agraria, and at the 7th European Society for Environmental History Conference.

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CHAPTER 1.

LOOKING BACKWARD TO LOOK FORWARD: WATER USE AND ECONOMIC GROWTH FROM A LONG-TERM PERSPECTIVE

1. Introduction

The threat of a global water crisis is one of the challenges to be faced in the twenty-first century both by society and the research community. Sustainability is becoming a central issue for all regions and sectors, international agencies are increasingly coping with water stress problems, setting water-related goals, especially since 1972 (UN Water, 2009).

Looking back, water use experienced a sharp rise. According to L'Vovich and White (1990), while global water withdrawals remained stable for centuries, these increased thirty-five-fold from 1687 to 1987. McNeill (2000) shows a forty-fold increase in freshwater consumption from 1700 to 1900 and a seven-fold rise in the twentieth century.

The expansion of agriculture and irrigation entailed an enormous rise in water use but allowed food security to be achieved for large populations. Today, agriculture accounts for 66% of freshwater withdrawals and 85% of freshwater consumption. From the onset of industrialization, when industrial water use was negligible, substantial growth has taken place. Today, industry accounts for approximately 20% of total freshwater withdrawals. During the twentieth century, urban populations experienced a huge rise. As a result, urbanization created a greater need for water; today, urban use currently accounts for 7% of the total (Shiklomanov,2000).

In this general context, our work aims to study the drivers of water use from a long-term perspective. More concretely, we analyze world and regional trends in water use during the last century and their relationships with population, economic growth and technological change. On the basis of this analysis, we anticipate possible scenarios regarding water stress in the future.

To date, a number of studies have examined environmental pressures from an economic perspective, bringing the consequences of unsustainable resource use to the forefront. This literature mainly focuses on the long term (Kander and Lindmank, 2004; Gales et al., 2007) and on the recent past (Feng et al., 2009). However these investigations basically aim to assess the evolution of energy use or pollution emissions.

To our knowledge, on the subject of water withdrawal from a global and historical perspective, little research has focused on this limited resource, given the lack of reliable regional and world data. Some studies, such as L'Vovich and White (1990) Shiklomanov (2000), Goklany (2002), Barbier (2004) and Gleick et al. (2009), have made a general assessment of water resources and only a few of them have focused on the relationship between water and income (Cole, 2004; Katz, 2008; Duarte et al., 2013). Nevertheless, the long-term perspective has often been excluded from the analysis, mainly due to the lack of reliable historical data on global water use[1].

This paper is an attempt to analyze the determinants of water use trends in the long term from a global perspective, as well as disentangling the major drivers responsible. In this regard, the IPAT model (Ehrlich and Holdren, 1971) is reformulated for and adapted to the case of water withdrawal to analyze the general twentieth century trends in water use, and to identify the major issues underlying water use dynamics. This analysis will be the baseline scheme to formulate scenarios for economic and demographic growth, in which we analyze water pressures under different hypotheses of population and economic growth. Looking back at historical water use offers certain lessons in order to manage current and future water scarcity in the world.

Therefore, the contribution of this paper is two-fold. Firstly, the IPAT model, together with our decomposition analysis, offers understanding and quantification of the drivers of water use. Secondly, the combined study of demographic, economic and water use trends from ahistorical perspective offers guidance for the future.

The results show that water withdrawal experienced a sharp rise until 1980, when a smooth leveling-off took place. On the whole, this growing trend could have been caused by the rapid upturn of population and GDP, together with the intensification of agriculture. Industrialization and the gradual increase in standards of living may also have boosted water use. The substantial decrease in intensity is probably one of the

[1] On the contrary, there exists an abundant and interesting literature studying more specific topics such as water footprints (Hoekstra et al., 2009), virtual water (Hoekstra and Hung, 2002), water quality (Dabrowski et al., 2009) or water demand (Ruijs et al., 2008), for specific areas and recent periods.

reasons behind the flattening of water use of the past twenty years. Thus, it is reasonable to expect elements such as economic or efficiency improvements to have exerted a significant influence on water use.

The rest of the article is organized as follows. Section 2 reviews the theory behind the relationship between economic growth and the environment, as well as the methodology and data we use. In section 3, we present the main results of the analysis. Section 4 closes the paper with a discussion of the results and our conclusions.

2. Material and methods

Since the 1970s, social and physical scientists have shown concern over the impact of industrial economies on the environment. The work of Georgescu-Roegen (1971) and the seminal report "The Limits to Growth" (Meadows et al., 1972) marked the beginning of a more academic concern for environmental impacts associated with growth. In this line, economists such as MartínezAlier and Schlüpmann (1991) and Nakicenovic et al. (2000) claim that economic and population growth, as well as improved living standards, involved ever-increasing requirements for energy and materials.

Alternatively, other economists maintain that higher levels of income reduce environmental degradation. They consider development essential for environmental quality and believe in a de-linking between natural resources and economic growth. From this perspective, the idea of dematerialization found support on the Environmental Kuznets Curve (EKC hereafter). Important papers (Grossman and Krueger, 1992 and 1995; Selden and Song, 1994) found empirical evidence regarding EKC and suggested three effects that explain the relationship: scale, composition and technology. In general terms, shifts towards the service sector, improvements in technology, trade, and societal changes in attitudes towards the environment have been cited as contributors to the decrease of environmental damage when countries become richer (Gales et al., 2007; Ekins, 1997).

The debate continues today, focusing on the possible explanations of environmental trends. It would appear that consensus regarding the location of different economic, technological and demographic factors behind the relationship between growth and environmental pressures exists. Thus, many studies have focused on the analysis of the contribution of these factors. In this context, the SDA has been applied to the IPAT model (Ehrlich and Holdren, 1971; Commoner et al., 1971) to synthesize the role played by economic growth, population demands and technology in explaining these environmental impacts. This combined methodology, which we call IPAT_DA is applied to examine water use factors for the first time in, this paper. Given that we are dealing with global trends, this tool appears to be useful to highlight the determinants of water use. As Turner (1996) has stated, the IPAT model is suitable for the macro-scale assessment of environmental impact drivers. However, it seems to be less appropriate when making local scale assessments, since other factors such as policy or institutions may play a larger role. The IPAT model emerged as a result of the discussion that took place between Ehrlich, Holdren and Commoner in the early seventies regarding the role of technology in environmental impact (Chertow, 2000). Subsequently, there was an intense debate on the different IPAT models or specifications, including those in the IPCC Special Report on Emissions Scenarios (Nakicenovic et al.,2000).

The general idea underlying the IPAT equation is that an environmental impact can be observed as the interaction result between economic growth, population trends and environmental impact per unit of GDP and this relationship can be expressed in a multiplicative way.

$$\text{Env. impact} = \text{I} = \text{P} * \text{A} * \text{T} = \text{Population} * \frac{\text{GDP}}{\text{Population}} * \frac{\text{Env. impact}}{\text{GDP}} \quad (1.1)$$

Thus, in the expression above, I summarizes the environmental impact, P stands for population (Nakicenovic et al., 2000) and A (usually measured by GDP per capita) refers to affluence. Variable T generally means I/GPD, that is, environmental impact per unit of GDP, or environmental intensity. This latter factor is the most difficult to define and quantify, since other important elements, apart from technology, are also captured (economic structure, factor endowments, geography, infrastructure, cultural history and/or climate)[2]. Dietz et al. (2007) use a comparative study to demonstrate that population and affluence are the main determinants of environmental change, while “other widely postulated drivers (e.g. urbanization, economic structure, age distribution) have little effect”. Methodologically, a similar expression can be derived in terms of the forces driving water use:

$$W_t = N_t * \frac{Y_t}{N_t} * \frac{W_t}{Y_t} = N_t * y_t * w_t \qquad (1.2)$$

In this case, water consumption in a period t can be expressed as a result of the interaction between population (N), per capita income (y) and an index of water intensity (w).

Analytically, in order to study trends in water use and disentangle the forces contributing to such trends, a decomposition analysis is applied.

It tries to separate a time trend of an aggregated variable into a group of driving forces that can act as accelerators or retardants (Dietzenbacher and Los, 1998; Hoekstra and van den Bergh, 2002; Lenzen et. al., 2001).

Generally speaking, considering a variable y depending on n explicative factors $y=f(x_1,\ldots x_n)$, an additive decomposition can be obtained through its total differential.

$$\mathrm{dy} = \frac{\partial \mathrm{y}}{\partial \mathrm{x}_1}\partial \mathrm{x}_1 + \frac{\partial \mathrm{y}}{\partial \mathrm{x}_2}\partial \mathrm{x}_2 + \cdots + \frac{\partial \mathrm{y}}{\partial \mathrm{x}_\mathrm{n}}\partial \mathrm{x}_\mathrm{n} \qquad (1.3)$$

On the basis of a multiplicative relationship, that is $y=x_1....x_n$, expression (1.4) states:

$$dy = (x_2 x_3 \ldots x_n)dx_1 + \cdots + (x_1 x_2 x_3 \ldots x_{n-1})dx_n = \sum_{i=1}^{n} \left(\prod_{j \neq i} x_j \, dx_i\right) \qquad (1.4)$$

In a discrete schema, when we try to measure the changes in the dependent variable between two periods, t-1 and t, there are different ways of solving this expression by way of exact decompositions, which lead to the well-known problem of non-uniqueness of the decomposition analysis (DA) solution. In our case, if decomposition is based on three factors, we can obtain the following 3! exact decompositions. In practice, as a “commitment solution”, the average of all possible solutions is

[2] For a thorough review of this methodology, rationale, applications, extensions and criticisms, see Chertow (2000).

considered. Nevertheless, as Dietzenbacher and Los (1998) demonstrate, the simple average of the two polar decompositions is a good approximation of the average of the 3! exact forms[3].

Thus, based on (1.2), the two polar decompositions can be written as follows:

$$\Delta W_t = W_t - W_{t-1} = N_t y_t w_t - N_{t-1} y_{t-1} w_{t-1} = \qquad (1.5)$$

$$= \Delta N y_t w_t + N_{t-1} \Delta y w_t + N_{t-1} y_{t-1} \Delta w = A_{1t} + A_{2t} + A_{3t}$$

$$\Delta W_t = W_t - W_{t-1} = N_t y_t w_t - N_{t-1} y_{t-1} w_{t-1} =$$

$$= \Delta N y_{t-1} w_{t-1} + N_t \Delta y w_{t-1} + N_t y_t \Delta w = B_{1t} + B_{2t} + B_{3t} \qquad (1.6)$$

and taking the average we obtain (1.7),

$$\Delta W_t = \frac{1}{2}(A_{1t} + A_{2t} + A_{3t}) + \frac{1}{2}(B_{1t} + B_{2t} + B_{3t})$$
$$= \frac{A_{1t} + B_{1t}}{2} + \frac{A_{2t} + B_{2t}}{2} + \frac{A_{3t} + B_{3t}}{2} = PE_t + INE_t + IE_t \quad (1.7)$$

In this way, water use evolution can be obtained as a result of the contribution of population, income and intensity effects.

$$PE_t = \Delta N_t \left(\frac{y_t w_t + y_{t-1} w_{t-1}}{2}\right) \qquad (1.8)$$

$$INE_t = \Delta w_t \left(\frac{N_t y_t + N_{t-1} y_{t-1}}{2}\right) \qquad (1.9)$$

$$IE_t = \Delta y_t \left(\frac{N_t w_t + N_{t-1} w_{t-1}}{2}\right) \qquad (1.10)$$

On these bases, we apply this methodology to a regional world water withdrawal dataset over the period 1900-2000 (UNESCO, 2011). This dataset, prepared for the Comprehensive Assessment of the Freshwater Resources of the World in the framework of the International Hydrological Programme (IHP) of UNESCO by the

[3]The identification of the different factors underlying the growth in an economic or environmental variable has been performed in the literature by way of different decomposition forms. The term Structural Decomposition Analysis has been most commonly used when decomposition analysis is developed on the basis of an input-output model, which captures direct and indirect effects, which is not our case. However, the referred problems and solutions of SDA techniques, also apply to our analysis.

Russian IHP National Committee contains data on global freshwater resources from 1900 to 1995 as well as forecasts for 2000, 2010 and 2025 and covers all economic regions and continents in the world. Since our main goal is to examine aggregate trends from a long term perspective, we use regional and world historical data. For a more specific study on local facts, country or basin data should be used. To carry out the analysis, we need income and population data series. Income is measured by GDP (in 1990$ on a Purchasing Power Parity basis) and comes from Maddison (2010). Population information is also provided by Maddison (2010).

3. Results and Discussion

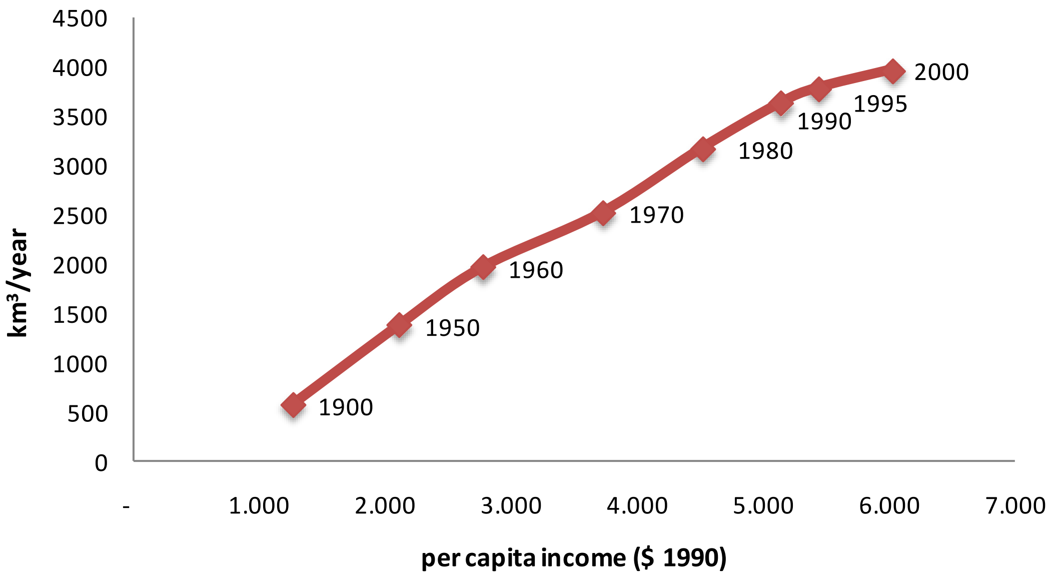
In order to organize the results and discussion, this section is divided into three subsections: an initial description of global and regional water withdrawal features (section 3.1), the quantification of the factors that entail changes in water use and the explanation of these determinants (section 3.2) in the light of the applied IPAT_DA decomposition and finally, the results obtained from the scenario analysis (section 3.3).

3.1. Historical water use

Figure 1.1 and Table 1.1 show the main features in water use from 1900 to 2000, both in global terms and for the seven regional areas in which the world has been divided.

A first look at the data shows that water withdrawal increased approximately seven-fold, from 539 cubic kilometers in 1900, to 4,000 cubic kilometers in 2000. As shown in Figure 1.1, throughout the twentieth century there was a continued growth in per capita income, and global freshwater withdrawal also experienced a continuous climb, with a weak leveling-off from the 1980s. This expansion was slightly faster in the second half of the twentieth century and especially in the 1950s, when the highest annual growth rates were reached (3.6%). Since that time, freshwater use continued to expand, although much less rapidly than in the past. In fact, from 1990 to 2000, the average annual growth rate decreased to 0.9% (Table 1.1).

Figure 1.1: Worldwide water withdrawal (km^3), 1900-2000



Source: Authors' elaboration, from UNESCO (2011).

From a regional perspective (Table 1.1 and appendix 1.1), a general trend can also be observed; both developed and developing areas displayed an upward trajectory through the twentieth century. Nonetheless, this strong growth became weaker, mainly from the 1980s onwards. This was particularly true in the developed areas, where water use deceleration was sharper.

Table 1.1: Cumulative annual average growth rates in water withdrawal (%)

	1900-2000	1950-2000	1900-1950	1950-1960	1960-1970	1970-1980	1980-1990	1990-2000
Africa	1.8	2.9	0.6	4.8	3.3	3.0	2.0	1.5
Latin America	2.5	2.9	2.0	3.9	2.9	3.9	2.0	2.0
North America	2.3	1.6	3.1	3.4	3.1	1.6	-0.6	0.5
Oceania	3.1	2.3	3.8	3.4	3.2	1.7	1.9	1.3
Europe	2.5	2.3	2.7	5.1	2.8	2.2	0.8	1.0
Asia	1.8	2.1	1.4	3.3	1.9	1.8	2.1	1.3
Ex-USSR	2.0	2.3	1.7	3.1	5.0	5.5	0.9	-2.7
World	1.9	2.1	1.8	3.6	2.5	2.3	1.4	0.9

Source: Authors' elaboration, from UNESCO (2011)

North America and the ex-USSR show a growing trend that reverses from 1980. However, the reasons for this decline in water withdrawal seem to be completely different. While in the former, this change could be due to wide range of factors that will be examined in section 3.2., in the latter it may be closely related to the economic transition to a market economy.

While in developed areas water withdrawal growth is higher during the first half of the century, developing regions exhibit sharper growth from 1950 onwards. As observed in the global pattern, every region except the ex-USSR and Oceania reached their peak annual growth rates through the 1950s and '60s (Table 1.1). North America and Europe show the largest annual growth rates.

In short, there can be observed a long-term increase in water use that seems to have steadied somewhat. However, we must ask, what forces have driven the increase in water use in the long term?

3.2. Looking behind the data

On the basis of the IPAT model, water use trends are decomposed into three components, showing the effects of population growth, economic growth, and other factors underlying water intensity changes. The results are presented in Tables 1.2 and 1.3[4].

If we look at water use growth rates we can clearly distinguish three stages. The first half of the twentieth century shows moderate annual growth rates, with water use accelerating from 1950 to 1980 and growth rates ranging between 2.3% and 3.6%. Finally the pace of water use slows down from 1980 on. Consequently, and to represent possible changes in long-term trajectories, we have divided the twentieth century into three periods: 1900-1950, 1950-1980 and 1980-2000.

To begin with, let us consider the world as a whole. For 100 years, global water withdrawal described a significant upward trend (Table 1.2). Basically, Table 1.3 shows how population and especially income growth, that is, demand for freshwater, boosted aggregate withdrawal. In turn, the constant drop in intensity prevented a greater increase.

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[4]In Table 1.3, if $\Delta W>0$, positive signs on the different effects indicate that they contribute to the increase in water withdrawal. If $\Delta W<0$, a negative sign on a component entails that it plays a part in the increase in water withdrawal. An effect promotes water withdrawal stabilization or decline if, and only if, it exhibits a positive sign. Furthermore, if changes in water use are insignificant, percentages will shoot up due to simple calculations.

The income effect stands out, particularly until 1980, given that from this time on intensity becomes stronger. During the first half of the century, the contribution of GDP growth to the increase in water use was 60%, and this increased notably during the three following decades. Taking growth rates into account (Table 1.2) we can see the vast growth in income between 1950 and 1980. The ratio of water use to GDP steadily decreased throughout the twentieth century. It is in the last two decades that the intensity effect appears to be the most prominent. From 1980 to 2000, this effect fell about 1.8% every year.

Table 1.2: Growth rates in water use, population, per capita GDP, and water intensity (1900-2000)

		W (%)	N (%)	y (%)	w (%)
Africa	1900-1950	0.63	1.47	0.79	-1.6
	1950-1980	3.7	2.5	1.79	-0.61
	1980-2000	1.75	2.68	-0.23	-0.68
Latin America	1900-1950	1.99	1.9	1.64	-1.52
	1950-1980	3.57	2.53	2.71	-1.65
	1980-2000	1.97	2	0.26	-0.28
North America	1900-1950	3.1	1.43	1.71	-0.06
	1950-1980	2.69	1.4	2.26	-0.97
	1980-2000	-0.08	1.09	2.11	-3.2
Oceania	1900-1950	3.81	1.62	1.26	0.88
	1950-1980	2.75	1.88	2.06	-1.18
	1980-2000	1.63	1.26	1.99	-1.59
Europe	1900-1950	2.71	0.51	0.91	1.26
	1950-1980	3.34	0.7	3.53	-0.88
	1980-2000	0.85	0.28	1.74	-1.15
Asia	1900-1950	1.42	0.93	0.23	0.26
	1950-1980	2.35	2.09	3.54	-3.18
	1980-2000	1.69	1.69	3.17	-3.07
Ex-USSR	1900-1950	1.68	0.74	1.68	-0.73
	1950-1980	4.52	1.32	2.76	0.39
	1980-2000	-0.91	0.41	-1.81	0.51
World	1900-1950	1.76	0.97	1.03	-0.25
	1950-1980	2.81	1.89	2.57	-1.62
	1980-2000	1.13	1.59	1.45	-1.88

Source: Authors' elaboration, from UNESCO and Maddison dataset.

Broadly speaking, every region follows a path similar to the world as a whole. Nevertheless, it is feasible to divide the world into two different groups. On the one hand, North America, Europe and Oceania are included in the same cluster. On the other hand, developing regions differ significantly from the others.

In developed areas, the income effect has been the most important determinant of water use, mainly during the second half of the twentieth century. Moreover, the intensity effect appears to have encouraged water use moderation.

Table 1.3: Contribution of the factors to water use changes (1900–2000)

		ΔW(abs)* (km^3)	**N** (%)	**Y** (%)	**W** (%)
Africa	1900-1950	15.1	240.1	162.5	-302.6
	1950-1980	110.2	67.2	52.2	-19.4
	1980-2000	69	153.7	-13.8	-39.9
Latin America	1900-1950	46.9	95.1	112.9	-108
	1950-1980	139.7	70.4	89.6	-60.1
	1980-2000	102.5	101.4	13.5	-14.9
North America	1900-1950	204.4	46.8	55.7	-2.5
	1950-1980	318.2	52.3	89	-41.3
	1980-2000	-9	-1393.8	-2949	4442.8
Oceania	1900-1950	8.8	43.9	30	26
	1950-1980	13.1	68.1	82.2	-50.3
	1980-2000	9	77.3	126.7	-103.9
Europe	1900-1950	85	20.5	32.4	47.1
	1950-1980	194	22.1	108.9	-31
	1980-2000	57.4	33.3	205.7	-139.1
Asia	1900-1950	395.5	65.2	16	18.8
	1950-1980	785.4	89	204.9	-193.9
	1980-2000	623.8	100	210.5	-210.5
Ex-USSR	1900-1950	47.4	44.2	106.7	-50.8
	1950-1980	232.3	30.8	59.4	9.8
	1980-2000	-52.7	-45.4	201.3	-55.9
World	1900-1950	803	55.2	60.5	-15.6
	1950-1980	1793	67	104.1	-71.2
	1980-2000	798	141.6	136.6	-178.2

* ΔW (abs) shows water use absolute variation in km^3
Source: Authors' elaboration, from UNESCO and Maddison dataset.

North America is the only case in the world where, between 1980 and 2000, intensity outbalances the sum of population and income, involving an imprecise but essential fall in water withdrawal levels. The decrease in water use levels took place during the eighties, mainly due to the vast improvement in intensity, which decreased annually by

3.7%. Per capita levels of water use show enormous differences between regions[5]. Although developed areas display higher figures, per capita water use attains astonishingly different values at very similar income levels, depending on the prevailing urban approach and other land-use related issues. These diverse land-use patterns clearly distinguish European cities from typical North American conurbations. The high per capita water use seen for North America could have led to efficiency improvements once the turning point was reached.

On the other hand, the less developed areas of the world describe a different evolution from the other regions. Nonetheless, in this case they are more heterogeneous.

Although, throughout the developing world, per capita GDP and population growth trigger water withdrawal, the relative importance of both has not been the same. On the whole, population has been a more important driver than income. In developing countries, the reduction in intensity has not offset the impulse of income and population on water use, but has reduced it, except for Asia between 1900 and 1950 and the ex-USSR from 1950 to 1980.

The decline in per capita GDP between 1980 and 2000 caused a reduction in water demand for economic purposes in both Africa and the ex-USSR. In the latter, contrary to what happened in Africa, this decline was so intense that it allowed the smooth drive caused by population and intensity to be offset.

In what follows, we try to delve deeper into the discussion of the historical facts underlying the different effects driving the evolution of world water demands.

3.2.1. Income effect

Increase in per capita income has been one of the most important economic facts during the two last centuries. This increase has meant not only a greater demand for traditionally consumed goods, but also a change in the structure of demand itself. In line with the increase per capita, demand has increased principally for manufactured products, while that for food has increased at a notably lower rhythm. Consequently,

[5]Data on per capita water use for all regions are available on request.

the production and trade in industrial goods has increased proportionately much less than that of agricultural products (Serrano and Pinilla, 2012). Furthermore, urbanization, parallel to industrialization, has also modified the patterns of demand. Despite these changes, agriculture continues today to be the principal consumer of water.

Growing per capita income not only increased the demand for food, but also modified food consumption patterns. Consumption of water-intensive goods has increased sharply, resulting in a significant increase in water use. However, the most serious strain on freshwater resources comes from the mounting weight of meat in the consumption package. To cope with the increase in demand, agriculture has substantially increased its production throughout the past century. The expansion of irrigation has contributed significantly to this increase in production; the global irrigated area jumped from approximately 48 million hectares in 1900 to 235 million in 1989 (Gleick et al., 1993). The development of modern irrigation systems has been also identified as a necessary condition for the efficient use of the agricultural technologies that emerged in the second half of the twentieth century (Hayami and Ruttan, 1985). In the case of the Green Revolution, the new high-yield varieties worked best where irrigation infrastructure was already available and chemical fertilizers were widely used (Federico, 2005). Huge investment in dams and irrigation canals became necessary and, accordingly, food supply more than doubled and water withdrawal grew by 2.81% annually. Consequently it was the intensification of agriculture which caused water withdrawal figures to soar, as agricultural water use is the most voluminous of all uses.

In parallel, water has been increasingly used in production processes for purposes such as cooling, transportation, solvents and so on, hand in hand with industrialization and urbanization processes. Accordingly, the development of the industrial sector meant an increase in water demand. On the other hand, growing urbanization increased the facilities and amenities that people enjoy. Furthermore, the gradual provision of water for urban needs also increased water use.

Geographical and temporal differences in economic growth may help us to see the different relevance of income as a determinant of water use. The importance of per capita income improvement as the driving force behind water withdrawal in developed countries, such as Europe during the first half of the twentieth century, can be understood perfectly if we take into account its pioneering character regarding industrialization and economic growth. On the contrary, the late entry of developing areas, such as Asia, in the process of development explains that it is not until the second half of the twentieth century when per capita income shows a higher share than population growth.

3.2.2. Population effect

Undoubtedly, one of the most impressive changes of the past century has been population growth. A greater number of inhabitants on the planet involves, *ceteris paribus*, an increase in the use of water proportional to that of population increase. Data from Madison (2010) give evidence of the sharp rise taking place during the last 100 years, from approximately one billion to six billion people. The global population grew by approximately 1.3% annually during the twentieth century. The demographic transition was not only a key phenomenon concerning the socioeconomic changes in developed countries from the second half of the ninetieth century, but also affected developing areas from 1950 onwards (Reher, 2004). From Table 1.2, we can clearly see how population exerted a considerable impact on water use throughout the century. However it was not until the period 1980-2000 that population and income gave a similar boost to worldwide water use.

3.2.3. Intensity effect

Intensity is, without doubt, the most difficult component to quantify and explain. We will try to disentangle the intensity effect by examining some of the factors which, in our view, could lie behind the intensity effect through the twentieth century.

From the beginning of the twentieth century to the late 1970s, efficiency improvements were limited. Water users paid a negligible price, supply side approaches relied on the construction of highly-subsidized hydrological infrastructure, and wastewater discharges were rarely penalized. This involved a great disincentive for the implementation of water conservation practices in every region and economic sector. From the mid-1970s things began to change, especially in developed countries. Water was no longer considered an unlimited and cheap resource and a broad array of technical, managerial and institutional instruments were introduced. These changes have generally affected both the efficiency with which current needs are met and the efficiency with which water is allocated among its users (Gleick, 2000).

Important advances have recently been implemented in agriculture. In this regard, some of the most effective methods for saving agricultural water are micro-irrigation techniques, such as drip or micro-sprinkler irrigation. According to Reinders (2006), the area under microirrigation experienced a seven-fold increase during the last two decades of the twentieth century, from 436,590 hectares in 1981 to 3,201,300 hectares in 2000. However, land under drip or sprinkler irrigation, today globally only constitutes about 1% of total irrigation. That is to say, developing regions appear to be a long way behind developed areas. Nonetheless, a growing use of these methods has taken place in both developed and developing countries during the 1990s. Recently micro-irrigation has become more affordable, allowing these innovations to be implemented in developing countries and for low value crops (Postel et al., 2001).

During the 1990s, income growth allowed some industrial processes to undergo a period of transition from inflow to circulating water supply systems. This shift was especially acute in developed countries (Shiklomanov, 2000).

When dealing with other resources, some authors (Collard et al., 1988; Jänicke et al., 1997) have suggested that the composition of an economy could be an important factor in accounting for the historical pattern followed by energy use, contaminating emissions, etc. From this historical perspective, one of the main features of modern economic growth has been structural change. This consists of the industrial and service sectors growing more quickly than agriculture. This fact led to an increased weight of the apparently less water-intensive economic sectors; that is why structural change implies a decline of water withdrawal figures relative to GDP, that is to say of intensity. In our case, the re-allocations of water appear to be negligible, due to the relatively greater weight that agricultural water withdrawal contributes. Furthermore, the character of basic products for the human feeding of agricultural products makes it difficult to transfer water from this use to others. Industrial development and urbanization meant a substantial increase in water use. However, in general, this increase was not at the expense of agricultural use, given that agriculture was and still is the primary water user in the world. Structural change, would not therefore play a significant role in water saving, but instead would add new uses and necessities by diversifying demand towards products and services from other sectors. Changes within the various economic sectors have been able to decrease the intensity of the use of water. According to Gleick (1999), one of the reasons for industrial water use decline in the USA since 1970 has been the change in the mix of industries. In this case, water shifted from water-intensive to less water-intensive activities. However, as we have already said, that is not generally the case in agriculture, since production tends to move towards highly water-intensive crops over time.

Economics may also be a determining factor in water evolution. Roughly speaking, the twentieth century could be divided into two stages.

The first covers the period 1900-1980. During this time, water was believed to be abundant and inexpensive, and no efforts were devoted to its conservation (Gleick, 2000). Governments and international institutions got involved in water management, giving financial support to water infrastructure. This process was exceptionally intense between 1950 and 1980, when the irrigation boom took place. Dams, canals, and pipelines spread at an unprecedented pace. Governments and international agencies subsidized not only the construction costs of macro projects, but also the delivery and distribution of water. As a result, water was underpriced and there was a significant degree of overspending.

From 1980 onwards, water was no longer cheap and plentiful, but had become a costly and scarce resource. Suitable locations for dams or irrigation canals had already been exploited, the rehabilitation and construction of new ones became more and more expensive and the exploitation of groundwater entailed going deeper into aquifers and thus to growing capital costs of pumping water. High financial costs, together with low crop prices, led to diminishing returns for irrigation (Postel, 1999).

Accordingly, new management directions appeared. Although public projects can still be found, especially in developing countries, there now appears to be a trend towards the reduction of public funding for hydraulic infrastructure.

Another possible explanation could be the increasing interest in environmental issues. During the first half of the twentieth century, economic growth was given priority at the expense of environmental deterioration, which led to a dramatic increase in hydrological projects. As a result, water use rose considerably, water quality was seriously damaged and many freshwater habitats were endangered.

From the early 1970s onwards, environmental awareness grew notably all over the world. The emergence of new environmental values meant a significant change in the conception of water ecosystems and the idea of a necessary balance between economic development and freshwater resources emerged. This governing belief influenced water policies and management. Opposition to large scale water constructions became stronger, water policy gradually assimilated ecological ideas and water management addressed many concerns of the environmental movement. Likewise, the reallocation of water to the environment is gradually achieving one of the main environmental goals, namely the restoration of water ecosystems. Accordingly, a new paradigm for water planning emerged (Gleick, 2000). As a result of the implementation of these new policies, efficiency gains have been possible, as in the case of urban water consumption (Tello and Ostos, 2012).

3.3. Perspectives on water use in 2050. Results from a scenario analysis

Having looked backward, it is appropriate to look forward to design a simple scenario analysis on the water use pattern that can be expected in the first half of the XXI century. The observed historical trajectories of population, economic growth and intensity help us to project the value of these three factors in 2050. To construct the scenarios regarding population, and following Reher (2007), we have considered low and medium variants of UN population prospects. Following these assumptions, global population will display a yearly growth rate of 0.53% in the low variant and 0.81% in the medium. Per capita income has been projected taking into account regional average annual growth rates obtained for the period 1995-2005[6]. We contemplate four possible scenarios for water use intensity. The degree of optimism with which we examine the reduction in the use of water per unit of GDP is the difference between them. In the most pessimistic cases (scenarios 1 and 5), we assume a 10% improvement in global water intensity; in other words, world water intensity would decrease from 0.108 hm^3/\$ in 2000 to 0.097 hm^3/\$ in 2050. Subsequently, in scenarios 2 and 6, the ratio of water use to GDP notably decreases in developing regions, being as much as twice the intensity of Europe in 2000, i.e., 0.08 hm^3/\$. Moreover, North America and Oceania water use intensity converges to European levels in 2000 (0.04 hm^3/\$) and Europe's intensity remains stable. In the third place, scenarios 3 and 7 represent a situation where water use intensity reaches European standards in 2000 all over the world, while Europe's intensity remains constant. Finally, the most optimistic situation (scenarios 4 and 8) would involve a factor 7 improvement (Harper, 2000) in intensity in developed areas, that is to say water use intensity would decrease seven-fold. Besides, in this optimistic situation developing regions' intensity would be twice the European levels of 2000.

On these assumptions, we obtain the results given in Table 1.4, which display different future situations given the year 2000 as a baseline. Worldwide water use will continue to grow under most hypotheses. Only the most optimistic scenario shows a flattening in global water withdrawal from 2000 to 2050. That is, assuming low population growth and a sharp reduction in intensity.

In all other scenarios with low population growth, the use of water would increase globally from a minimum of 14 % to a maximum of 177%.

If we now assume a medium population growth, and an economic growth that projects 1995-2005 annual rates, the results are even worse. Under these assumptions, the optimum overall result leads to a 14% global rise in water use. The most pessimistic case entails a greater than three-fold expansion in overall water use.

[6]This yearly growth rate can be considered unrealistic, given that years of economic crisis are not included in projections. At this moment, it is difficult to produce a realistic growth rate for the coming 40 years. In any case, we consider that these values (a per capita growth rate maintained equal to that corresponding to the 1995-2005 period for each region) can be interpreted as an upper limit to economic growth for the next 40 years.

It is undeniable that these results are strongly determined by the former assumptions. However, it is probably reasonable to argue that water use is expected to follow an important trend of growth during the period 2000-2050. Population and affluence appear likely to continue to expand into the future, especially in developing regions. This growing demand can only be offset by a great improvement in the ratio of water use to GDP. In our analysis, we have presented several scenarios concerning intensity. Only in the most optimistic of these, scenario 4, would water use remain steady.

From a regional perspective, the scenarios display highly diverse possible trajectories. In the developed countries only strong falls in the intensity of water used per unit of GDP could reduce hydrological necessities. In all the other scenarios the increase of consumption is difficult to sustain. In the case of developing countries sharp falls in the intensity of the use of water per unit of GDP would permit a moderate reduction in the consumption of water.

Table 1.4: Scenario analysis results. Water use in 2050 (2000=1)*

		Africa	Latin America	North America	Oceania	Europe	Asia	World
N: low variant								
y: 1995-2005								
w:10%	Scenario1	5.37	2.17	3.16	3.59	2.25	3.41	2.77
w: int.	Scenario2	2.39	1.86	2.14	2.35	2.25	1.90	1.57
w:Eu	Scenario3	1.19	0.94	2.14	2.35	2.25	0.95	1.14
w:factor7_int.	Scenario4	2.39	1.86	0.49	0.56	0.35	1.90	0.99
N:medium variant								
y: 1995-2005								
w:10%	Scenario5	6.15	2.53	3.57	4.08	2.55	2.54	3.20
w: int.	Scenario6	2.73	2.17	2.42	2.68	2.55	1.41	1.81
w:Eu	Scenario7	1.37	1.10	2.42	2.68	2.55	0.71	1.32
w:factor7_int.	Scenario8	2.73	2.17	0.55	0.64	0.40	1.41	1.14

*Values displayed in the table are W_{2050}/W_{2000} considering W_{2000}=1 and under the corresponding assumptions on N,y and w. We consider low and medium variants of UN population (N) prospects. Per capita income (A) has been projected taking into account average annual growth rates for 1995-2005. There are four scenarios for intensity. a) w: 10%, 10% improvement in global intensity. b) w: int, by 2050 the developing world's intensity will be twice Europe's figure in 2000 and reaches the 2000 European level, where it converges to European levels. c) w: Eu, by 2050 water use intensity reaches the 2000 European standards all over the world, 0.04 hm^3/$.d)w:factor7_int, by 2050 developed areas intensity decreases seven-fold, and the developing world's intensity is twice European levels in 2000.

These conclusions are in line with those made by Shiklomanov (2000) and Gleick et al. (2009), who respectively forecast a 31% increase in global water use by 2025, and an approximate 40% rise by 2020. Other studies, such as Rosegrant and Cai (2002) or

Alcamo et al. (2003), foresee stabilization in some river basins but high growth in many areas, particularly in domestic and industrial sectors.

Could these forecasts increases in water demand be sustained? Cautiously, we follow the “thirds” hypothesis proposed by Margalef (1996). He suggested that at least two thirds of total freshwater must be left to surface runoff and resource endowment, if natural systems are to be kept in a healthy state and able to provide environmental services. Therefore, those scenarios that forecast a withdrawal above 33% of freshwater resources seem rather unlikely. The most pessimistic scenarios regarding intensity seem to be unreal, especially in those regions where great population growth is expected.

The implications of these scenarios are important. History shows us that during a large part of the twentieth century, to satisfy the water needs of human societies, stimulated both by population growth and by income per inhabitant, a supply model has prevailed, that is to say principally the construction of infrastructure, to have more water available. This model has great difficulties in continuing to be the most appropriate response.

On the one hand, the scenarios proposed would require a sharp rhythm of new constructions. However, the contribution of hydraulic works to the availability of regulated water is marginally decreasing. In many countries more dams are no longer viable as the best locations have already been taken. This explains the difficulties in increasing supply and also the marginally increasing costs of infrastructure for each new unit of regulated water, which can make them financially inviable. On the other hand, the environmental impacts may also be undesirable or rejected socially.

Consequently, a new paradigm is necessary. This would be directed more at making a deceleration of demand rather than expanding supply (Gleik, 2000; Pinilla, 2008; Postel, 1999). The possibilities for action are multiple. On the one hand the low prices of water make supply lead demand. Some actions in this direction would be necessary (Anderson, 1998; Schoengold and Zilberman, 2007). On the other hand, the scenarios proposed underline that intensive efficiency gains are the surest way to achieve lower pressure upon the resource of water. The differences in water used per unit of GDP underline the broad margin existing insofar as the developing countries adopt the most modern technologies and the developed countries intensify their application and develop new ones. Here, the implementation of measures to improve efficiency in the distribution and consumption of water in the diverse productive sectors, the systems for the treatment of effluents, the encouragement of good agricultural and industrial practices with regard to the resort or the introduction of water-saving programs and integrated management of the resource in economic and environmental policies at different institutional levels (local, regional, national and international), could have important effects to mitigate the pressure on water resources in the coming years.

4. Conclusions

This paper has analyzed the evolution of water use throughout the twentieth century, and assessed the extent to which certain demographic, social and economic factors have contributed to the water withdrawal pattern, and how they will affect future trajectories.

Both global and regional evidence clearly illustrate a great expansion of water use. Population growth, economic development and the intensification of agriculture have been identified as some of the main drivers for this growing trend. On the other hand, efficiency improvements, structural change, environmental concerns, and the increasing costs of supplying water, have made population and income growth compatible with a slight leveling off in water use from 1980.

In regional terms, water withdrawal has followed a similar path, namely a rapid rise that stabilized during the last two decades of the century. Nevertheless, the three effects behave distinctly, depending on the region considered. Chiefly, the income effect has been more closely related to water use in developed areas since 1900. Likewise, the intensity impact on freshwater use has been more abrupt in the developed regions. However, the population effect has been comparativelymore important in developing areas. We find that North America stands out from other areas because of the decline in water withdrawal during the period 1980-2000, this decrease being largely driven by the intensity effect, since it offset the boost produced by income and population growth.

On the whole, as seen in our analysis of various scenarios, water use will describe a growing trend during the first half of the twenty-first century. Only in one of the eight future scenarios would global water withdrawal remain stable. Even if important improvements in efficiency took place, water use would grow, mainly in developing regions, where significant increases in population and affluence are expected. Consequently, given the enormous difficulties and problems that would be created by maintaining a rhythm of expansion of regulated water supply in accordance with the most pessimistic scenarios of the evolution of supply, it would be necessary to achieve a deceleration in the growth of the latter, whether through efficiency gains with a technological base or via pricing and demand management policies.

This study offers great scope for further research. As commented above, intensity comprises a wide variety of interdependent factors that are difficult to measure. One of the natural extensions of this research would involve opening the "black box" of long-term water intensity. Moreover, it would also be of great interest to separate aggregate water uses. In this way, chapter 3 distinguishes among the different consumptive uses of water, studying water from a local and sectorial perspective.

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Appendix 1.1

Figure 1.2: Europe water withdrawal (km^3), 1900-1995

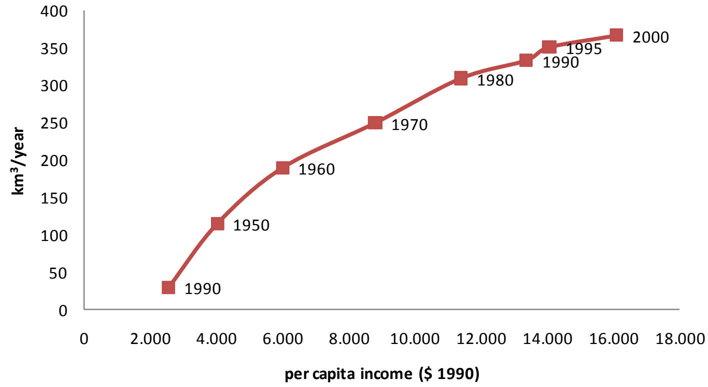


Figure 1.3: North America water withdrawal (km^3), 1900-1995

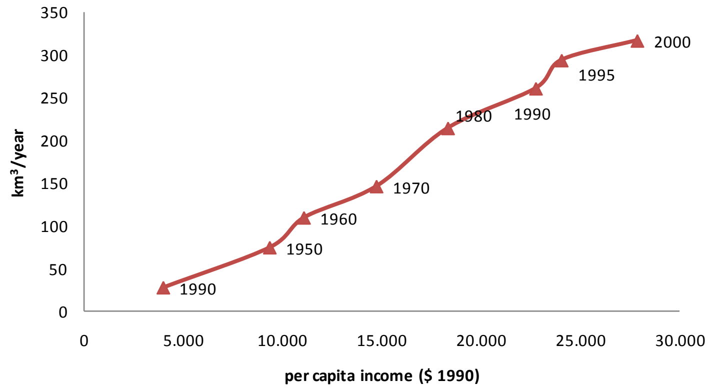


Figure 1.4: Oceania water withdrawal (km^3), 1900-1995

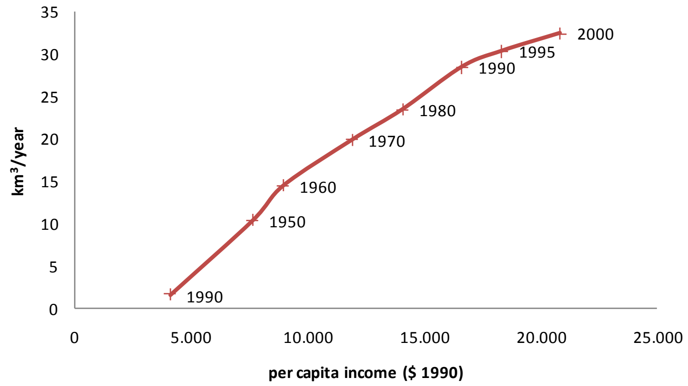


Figure 1.5: Asia water withdrawal (km³), 1900-1995

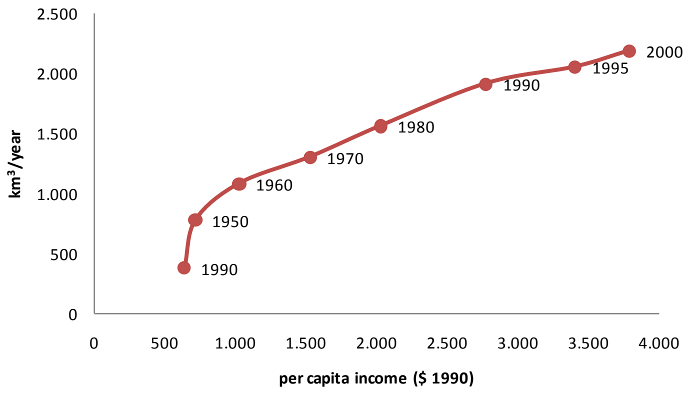


Figure 1.6: Africa water withdrawal (km³), 1900-1995

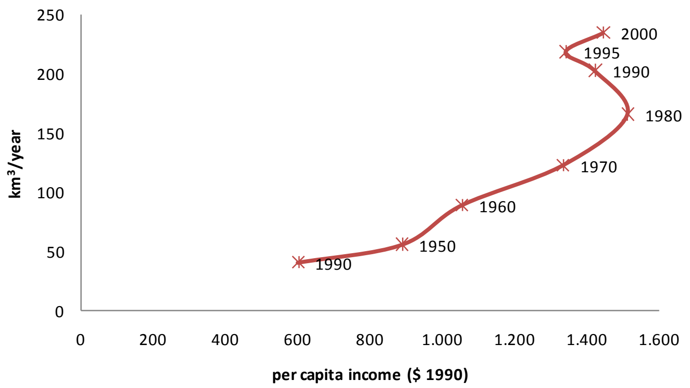
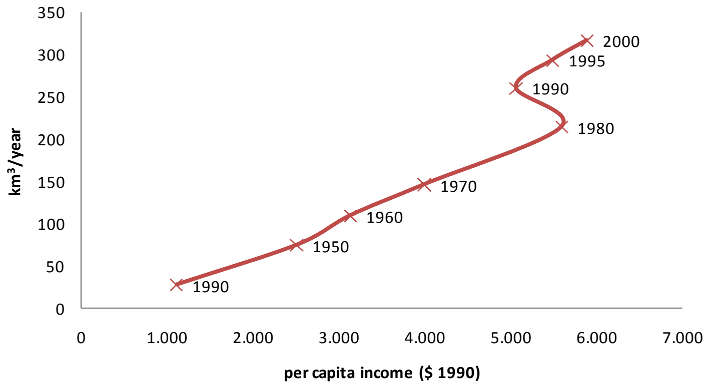


Figure 1.7: Latin America water withdrawal (km³), 1900-1995



CHAPTER 2.

IS THERE AN ENVIRONMENTAL KUZNETS CURVE FOR WATER USE? A PANEL SMOOTH TRANSITION REGRESSION APPROACH

1. Introduction

Nowadays more than 2 billion people are currently concerned with water shortages in over forty countries (WHO/UNICEF, 2000), 1,100 million people lack access to safe drinking water and about 2,600 million people lack access to basic sanitation (UNDP, 2006). Water is one of the most precious resources in the world, playing an important role in economic development. Wateris essential for human and ecosystem needs and the availability, use and management of freshwater is vital, not only for human welfare, but also for environmental conservation. The limited supply of freshwater, coupled with an exponential growth in demand, threatens the integrity of the natural world as well as the well-being of humanity. Thus, correctly understanding the nexus between water use and per capita income using global data appears to be vital in identifying current trends and forecasting future developments; especially from the perspective of international institutions like the FAO, which states that, “by 2025, 1,800 million people will be living in countries or regions with absolute water scarcity, and two-thirds of the world population could be under stress conditions”.

The relationship between economic growth and the use of natural resources or emissions has received great attention from the early 1970s and the debate continues today. To date, many studies have analyzed environmental pressures from an economic perspective, pointing to population growth, economic development, urbanization and industrialization as being among the driving forces for natural resource depletion (Nakicenovic et al., 2000; Kander and Lindmark, 2004; WWAP, 2009).

In this general context, the hypothesis of an inverted-U relationship between environmental pressures and economic growth has been in the foreground. Based on a similar association between the level of inequality and per capita income (Kuznets, 1955), this relationship has come to be known as the Environmental Kuznets Curve (EKC hereafter). The baseline idea is very simple: at a first stage, the greater the income, the greater the pressure on natural resources. After reaching an income threshold the trend reverses and the pressure on natural resources tends to decrease. Beginning with the seminal papers of Shafik and Bandyopadhyay (1992), Panayotou

(1993), Selden and Song (1994) and Grossman and Krueger (1995), a significant amount of research on this topic has been carried out. In all of these studies, the cross-country evidence pointed to an inverted-U curve between pollution indicators and income per capita; nevertheless the turning points are quite divergent. The EKC approach has not yet drawn a consistent conclusion and the debate over its shortcomings continues. On the one hand, the debate focuses on the explanations of the decreasing component (Stern et al., 1996; Ekins, 1997; Roca et al., 2001; Gales et al., 2007; Fouquau et al., 2009). On the other hand, many of the drawbacks refer to econometric issues such as heterogeneity (Mazzanti and Mussolessi, 2010; Vollebergh et al., 2009), functional form, and spatial dependence (Stern, 2004; Aslanidis, 2009).

On the whole, most research on EKC deals with pollutant emissions and energy. However, there are a few studies examining the link between water resources and per capita income. The lack of consistent data and the relative abundance of water in developed countries, among other factors, have resulted in the evaluation of water resources from a similar perspective being neglected. The few works on this topic, (Cole, 2004; Katz, 2008) study the cross-country or panel-data evidence using polynomial models and seem to be consistent with the existence of an EKC for water use. These models present, however, two major drawbacks. First, they use limited of global datasets with few observations, which could reduce the precision of the estimates reflecting variability -not only among countries, but also among time periods. Second, the use of polynomial panel data models assuming that elasticity depends indirectly on income, across N countries and T time periods of the sample, seems to be quite restrictive. In our opinion, an econometric method that allows the parameters to change smoothly appears to be more accurate in capturing the behavior of countries since a priori one would expect a slow pace behavior for water use.

Thus, the main purpose of this article is to empirically study the nexus between per capita income and water withdrawal[7]. From a theoretical point of view, the increase in

[7] Water withdrawal is the water diverted from a surface water or groundwater source whereas consumptive water use is defined as water use that permanently withdraws water from its source; water that is no longer available because it has evaporated, been transpired by plants, incorporated into products or crops, consumed by people or livestock, or otherwise removed from the immediate water environment (Vickers, 2001). Choosing water withdrawal means not falling into oblivion of efficiency issues and focusing on the most politically relevant type of water.

water use during the first stages of economic development are due to the increased consumption of high income elasticity foods that, in general, are more water intensive (for example, meat and vegetables), and also to the industrialization/urbanization processes essential to developing water delivery systems. Since agriculture has been, and still is, the main consumer of water, the expansion of irrigation that took place in many locations to enable increased production is particularly important. A possible decline in per capita water use would be related to technological developments that, particularly in agriculture, have generated more efficient irrigation systems, to structural change owing to the shared increase of activities with low water intensity, such as industry or services, and to the establishment of specific policies that seek increased efficiency in dealing with problems of scarcity (Duarte et al., 2013). It seems reasonable to consider that countries in process of development have taken advantage of technological advances that save water in recent decades, and thus could require less water per capita than pioneering countries in industrialization and modern economic growth (Dasgupta et al., 2002). Obviously, water use in any country not only depends on income but also on the climatic conditions and water management. To account for these other factors, we must add two control variables. The first, precipitation, is used as a proxy for water availability. The second, political freedom, attempts to measure the quality of institutions.

For our empirical strategy, we will use the traditional panel data models, together with the Panel Smooth Transition Regression (PSTR, hereafter) approach. PSTR models, as opposed to polynomial models, have the advantage of providing the water-income nexus with more flexibility. To this end, we use a logistic PSTR model with per capita income as a threshold variable, allowing the "income-water withdrawal" link to be influenced by a transition variable, that is, per capita income. PSTR models are quite innovative and some empirical applications have been published recently (Chang and Chiang, 2011; Lee and Chiu, 2011; Chiu, 2012).

This methodology is applied to a water use balanced panel of 65 countries, for the years 1960-2008. In our view, the contribution of this article is twofold. First, as far as we know, this kind of model is being used to explore the "water use-income" nexus for the first time, contributing to the literature on the relationship between the use of water resources and GDP per capita, and utilizing a larger dataset than in the few previous works, providing a better overview of the interactions between these two variables. Second, unlike previous studies on the same topic, the PSTR provides a quantification of the “water use-income” relationship that depends on the country and the time period, since elasticities can be obtained as a weighted average of the estimates. Thus, it is possible to examine different patterns of water use according to the level of development of each cross-section, adopting a temporal perspective which is crucial to an understanding of the historical influence of income on water use.

Although water use is found to increase for the lowest values of per capita income, our findings seem to point globally to a negative association between per capita income and per capita water withdrawal, regardless of the model used. Our results indicate that there exists a particular EKC with a decreasing limb that dominates the link between these two variables, from 1960 to today. Polynomial and PSTR models are estimated, although the latter are preferred for linearity tests, since they capture non-linearities in the dataset. The estimated elasticities show a significant variability of the data, with different patterns for different countries. The least developed countries in the sample show positive elasticities that tend to increase until 1995, when the trend reverses; emerging countries, like China, display decreasing elasticities, from positive to negative values; and, finally the richest countries in the dataset exhibit negative elasticities that seem to decrease throughout the period, although at a slower pace during recent decades. Nevertheless, it will be necessary to examine these results in a broader temporal framework.

Section 2 presents our methodology and describes the PSTR model, the specification, and the estimation procedures. Section 3 describes the data and presents the empirical results. In section 4 we discuss our results, and section 5 contains our conclusions.

2. Methodology

2.1. The PSTR model

The traditional literature on the EKC commonly uses polynomial models, which basically consist of estimating the well-known fixed effects model by ordinary least squares (Cole, 2004; Katz, 2008). Additionally, in this paper, we adopt a PSTR model: an extension of panel threshold regressions (Hansen, 1999), the PSTR was first applied by González et al. (2005) to examine the effect of capital market imperfections on investment. This methodology has been commonly used in finance (Chang and Chiang, 2011) and recently, in environmental economics (Aslanidis and Xepapadeas, 2006; Lee and Chiu, 2011; Chiu, 2012). However, water issues have not been studied from this perspective. After estimating a PSTR model of the relationship of income to energy intensity and electricity consumption, respectively, Destais et al. (2007) and Bessec and Fouquau (2008) summarize the three main advantages of this type of model. First, it allows for a smooth transition between the extreme regimes. Second, the threshold value is not given a priori, but is calculated in the model. Finally, as income is also added as an explanatory variable, its impact on water use is easy to measure. Capturing non-linearities and regime switching in this way makes the PSTR a good tool for the study of the “per capita income-water use relationship”.

The simplest model with individual-fixed effects is defined as follows:

$$W_{it} = \mu_i + \beta_1 Y_{it} + \beta_2 Y_{it} g(Y_{it}; \gamma, c) + \varepsilon_{it} \qquad (2.1)$$

$$i = 1, \dots, N t = 1, \dots, T$$

where W_{it} is the log of per capita water withdrawal in country i in year t, Y_{it} is the log of per capita income in country i in year t,μ_i represents the country-specific effects, and ε_{it} is an error term.

Following the work of González et al. (2005) and Colletaz and Hurlin (2006), who also began with the EKC hypothesis, the transition function is formulated as follows:

$$g(Y_{it}; \gamma, c) = \left(1 + \exp\left(-\gamma(Y_{it} - c)\right)\right)^{-1} \gamma > 0 \qquad (2.2)$$

where c denotes the location parameter or the threshold between the two extreme regimes and γ determines the smoothness of the transition. The transition function $g(Y_{it};\gamma,c)$ is a continuous function of Y_{it} bounded between 0 and 1, and consequently there is a continuum of states between the two extreme regimes. In order to analyse the non-linear link between GDP per capita and per capita water use, the transition variable is assumed to be the log of per capita income in country i in year t. When γ tends to infinity, the transition between the extreme regimes is sharp and the PSTR becomes a panel threshold model (Hansen, 1999). If, on the contrary, γ tends to zero, the transition function $g(Y_{it};\gamma,c)$ is constant and the model collapses into a standard linear model with country-specific effects.

In the context of the "income-water userelationship", income elasticity is obtained as a weighted average of β_1 and β_2.

$$e_{it}{}^{PSTR} = \frac{\partial W_{it}}{\partial Y_{it}} = \beta_1 + \beta_2 g(Y_{it};\gamma,c) + \beta_2 Y_{it}\frac{\partial g(Y_{it};\gamma,c)}{\partial Y_{it}} \qquad (2.3)$$

As a consequence, when examining vectors β_1 and β_2, we can only interpret the sign of the parameters,not the value itself of the elasticities, to mean an increase or a decrease in per capita water withdrawal with per capita income, with this being necessary to calculate water income elasticities in order to quantify the relative increase or decrease per unit of income.

Eventually, it is worth noting that the smooth transition regression is a more general specification of the quadratic polynomial model commonly used to study the EKC. As a result, according to Aslanidis and Xepapadeas (2006), the use of regime-switching models like the PSTR is justified by the fact that polynomial models, usually utilized to test the existence of the EKC, are particular cases of the PSTR.

2.2.Estimation and linearity tests

Before estimating the PSTR it is important to test whether the regime-switching effect is statistically significant. Testing linearity in equation 2.1 can be done by testing $H_0: \gamma = 0$ or $H_0: \beta_1 = \beta_2$. In both cases, the test will be non-standard, since under H_0 the model contains unidentified nuisance parameters. In the framework of the PSTR, the solution offered is similar to the one proposed by Luukkonen et al. (1988) for the so-called Davies problem in time series (Davies, 1977 and 1987). It consists of approximating the transition function $g(Y_{it};\gamma,c)$ using the first and second Taylor expansions around $\gamma=0$. Then, an equivalent hypothesis in an auxiliary regression is tested (see Aslanidis and Xepapadeas (2006) for more details). We then obtain:

$$W_{it}=\mu_i+\theta_1 Y_{it}+\theta_2 Y_{it}^2+\varepsilon_{it}^* \qquad (2.4)$$

$$W_{it}=\mu_i+\theta_1 Y_{it}+\theta_2 Y_{it}^2+\theta_3 Y_{it}^3+\varepsilon_{it}^* \qquad (2.5)$$

Therefore, testing linearity is equivalent to testing $H_0\colon \theta_2=0$ in equations 2.4 and $H_0\colon \theta_2=\theta_3=0$ in equation 2.5. If SSR_0 equals the sum of squared residuals under H_0 (lineal panel model with individual fixed effects), SSR_1 is the sum of squared residuals under H_1 (PSTR model with two extreme regimes), *N* is the number of cross-sections and *TN* is the number of periods multiplied by the number of cross-sections, the F statistic turns out to be:

$$LM_F=(SSR_0-SSR_1)/[SSR_0/(TN-N-1)] \qquad (2.6)$$

Once we have tested linearity, we proceed with the estimation of the PSTR in equation 2.1. It consists of two steps. First, fixed effects are eliminated by removing individual-specific means. Taking individual means in equation 2.1 yields:

$$\bar{W}=\mu_i+\beta_1\bar{Y}+\beta_2\bar{W}(\gamma,c)+\bar{\varepsilon} \qquad (2.7)$$

$\bar{W},\bar{Y},\bar{W}(\gamma,c)$ and $\bar{\varepsilon}$ are individual means with $\bar{W}(\gamma,c)=\frac{1}{T}\sum_{t=1}^{T}Y_{it}g(Y_{it};\gamma,c)$.

Subtracting equation 2.7 from equation 2.1 we obtain:

$$\tilde{W}_{it}=\beta'\tilde{Y}_{it}(\gamma,c)+\tilde{\varepsilon}_{it} \qquad (2.8)$$

Thus, the transformed element $\tilde{Y}_{it}(\gamma,c)=(Y_{it}-\bar{Y},Y_{it}g(Y_{it};\gamma,c)-\bar{W}(\gamma,c))$ depends on the parameters of the transition functions γ and c through both the levels and state means. So the vector $\tilde{Y}_{it}(\gamma,c)$ must be recomputed at each iteration. Given a couple (γ,c) obtained from a grid search, β_1 and β_2 are estimated by ordinary least squares conditioned on the values of γ and c. Then, in the second step, parameters γ and c are estimated by Non Linear Least Squares (NLS).

An important issue to take into account is the selection of starting values of γ and c, since this notably determines the convergence procedure. To select good starting values, a two-dimensional grid search of 50 values of γ and 100 values of c is carried out. Given these grids, the vector with the minimum residual sum of squares is used to estimate the corresponding β_1 and β_2.

After estimating, the next phase consists of testing the number of transition functions that must be included in the specification. Thus, we will test the null hypothesis that there is one transition function, versus the alternative that there are two.

$$W_{it} = \mu_i + \theta_1 Y_{it} + \theta_2 Y_{it} g(Y_{it}; \gamma, c) + \theta_3 Y_{it}^2 + \varepsilon_{it}^* \quad (2.9)$$

$$W_{it} = \mu_i + \theta_1 Y_{it} + \theta_2 Y_{it} g(Y_{it}; \gamma, c) + \theta_3 Y_{it}^2 + \theta_4 Y_{it}^3 + \varepsilon_{it}^* \quad (2.10)$$

In this case, the null hypothesis will be H_0: $\theta_3 = 0$ in equation 2.9 and H_0: $\theta_3 = \theta_4 = 0$ in equation 2.10. This recursive procedure continues until H_0 is not rejected.

Following Holtz-Eakin and Selden (1995), it is possible that some variables that have not been included in the regression could affect jointly per capita water use and per capita income. For instance, a compositional change towards a higher share of touristic industries could lead to a great use of water and to an increase in per capita income at the same time, generating an endogeneity problem from omitted variable bias. For that reason, we apply the instrumental variable extension of the PSTR model (IV-PSTR) proposed by Fouquau et al. (2008) and Lee and Chiu (2011). Following Lee and Chiu (2012) we take the lagged value of the explanatory variable as instrumental variable $Z_{it} = Y_{it-1}$.Then, $\tilde{Z}_{it}(\gamma, c) = (Z_{it} - \bar{Z}, g(Y_{it}; \gamma, c) - \bar{\zeta}(\gamma, c))$, where $\bar{Z} = \frac{\sum_{t=1}^{T} Z_{it}}{T}$ and $\bar{\zeta}(\gamma, c) = \frac{\sum_{t=1}^{T} Z_{it} g(Y_{it}; \gamma; c)}{T}$. As before, $\tilde{Z}_{it}(\gamma, c)$ and $\tilde{Y}_{it}(\gamma, c)$ have to be recalculated at each iteration. Consequently, given (γ, c) the parameters will be obtained by instrumental variables as follows:

$$\hat{\beta}_{IV}(\gamma, c) =$$
$$= \left[\sum_{i=1}^{N}\sum_{t=1}^{T} \tilde{Y}_{it}^{'}(\gamma, c)\tilde{Z}_{it}(\gamma, c)(\tilde{Z}_{it}^{'}(\gamma, c)\tilde{Z}_{it}(\gamma, c))^{-1}\tilde{Z}_{it}^{'}(\gamma, c)\tilde{Y}_{it}(\gamma, c)\right]$$
$$\times \left[\sum_{i=1}^{N}\sum_{t=1}^{T} \tilde{Y}_{it}^{'}(\gamma, c)\tilde{Z}_{it}(\gamma, c)(\tilde{Z}_{it}^{'}(\gamma, c)\tilde{Z}_{it}(\gamma, c))^{-1}\tilde{Z}_{it}^{'}(\gamma, c)\tilde{Y}_{it}\widetilde{W}_{it}\right] \qquad (2.11)$$

Then, during the second stage, the parameters of the transition function γ and c are estimated by Non Linear Least Squares conditionally to $\hat{\beta}_{IV}(\gamma, c)$.

So far, our model only examines the effect that per capita income exerts on the dependent variable, keeping all other factors that determine per capita water withdrawal constant. However, there are many other elements influencing per capita water use. Thus, in order to reduce the possible omission variable bias, as well as quantifying some of the factors affecting per capita water use, we add two control variables. The first, the annual average precipitation volume[8] (*Precip*) is used as a proxy for water availability. As water scarcity is usually a regional problem, we aim to capture climatic regional differences, particularly as far as water resources are concerned. The introduction of this variable is justified by the fact that those areas with greater water scarcity tend to use their resources in a more efficient way (Gleick, 2000). Thus, the variable precipitation is expected to show a positive sign. Second, some authors focus on the differences in environmental management depending on political and social conditions in different countries. Some argue that an improvement in democracy entails a development of environmental performance and consequently a lower level of natural resource use and environmental damage (Wislow, 2005; Li and Reuveny, 2006). For that reason, we try to control for institutional differences by adding a variable called political freedom (PF)[9]. On the basis of the information

[8] The same estimates have been carried out using average precipitation in depth also from AQUASTAT as a control variable. In this case, precipitation coefficient seemed to have no significant effect on per capita water withdrawal. Precipitation data from AQUASTAT are constant, i.e., they vary among countries but not on time. For future research temporal series on precipitation could be used to examine the effect that the evolution of water availability could have on the dynamics on water use.

[9] There are other index measuring the quality of institutions (The Economist Intelligence Unit's Democracy Index, Economic Freedom of the World Index by the Fraser Institute and so on). We chose Freedom house index because of its simplicity.

provided by Freedom House, we use this qualitative variable ranking from 1, representing the most politically free, to 7, the least politically free. Accordingly, PF is expected to display a positive coefficient, that is, the higher the PF index or the less politically free a country is, the more water per capita is withdrawn. Given these control variables, the model is written as:

$$W_{it} = \mu_i + \beta_1 Y_{it} + \beta_2 Y_{it} g(Y_{it}; \gamma, c) + \beta_3 Precip_{it} + \beta_4 \mathrm{PF}_{it} + \varepsilon_{it} \qquad (2.12)$$

The variable precipitation is expressed in logs, whereas PF is introduced in levels.

3. Data and Empirical results

In this study, we use a dataset of water withdrawal in 65 countries, for the years 1960, 1970, 1980, 1990, 1995, 2000 and 2008[10]. The dataset comes from UNESCO and was prepared for the Comprehensive Assessment of the Freshwater Resources of the World in the framework of the International Hydrological Programme (IHP) of UNESCO. Per capita water use is the ratio of water use to population. Per capita national income is measured by per capita GDP in Geary-Khamis 1990 U.S. $ on a Purchasing Power Parity basis. Population and per capita income data come from Maddison (2010). Table 2.1 reports some descriptive statistics. As can be seen, we have 455 observations for each variable, with per capita income (measured in constant 1990$) ranging from $217 (for Zaire in 2000) to $31,177 (for USA in 2008) and a mean of $5,232, and water use per capita between 2.41 and 205,224 thousand m^3 per person. Political Freedom is a variable that assigns a numerical rating from 1 to 7 for both political rights and civil liberties, with 1 representing the most free and 7 the least free. The average of the political rights and civil liberties ratings, known as the freedom rating, determines the overall status: Free (1.0 to 2.5), Partly Free (3.0 to 5.0), or Not Free (5.5 to 7.0) "Freedom House (n.d.)". Precipitation is measured in 10^9 m^3/year, with a mean of 1,303.3 10^9 m^3/year (AQUASTAT).

This section displays two kinds of estimations: a polynomial model with fixed effects, and the PSTR previously explained.

[10] Although the database provides information for 79 countries, as Hansen (1999) notes, it is unknown if this methodology can be extended to unbalanced panels. In this context, our option is to restrict the sample to 65 countries.

Table 2.1: Summary statistics

	Per capita GDP	Per capita water use	Precipitation	Political freedom
Mean	5,232	4,796	1,303	3.3
Standard error	5,652	20,675	2,474	1.8
Maximum	31,177	205,224	15,174	7
Minimum	217	2.4	6.1	1
Observations	455	455	455	455

Source: own calculations based on Maddison (2010), UNESCO(2011), AQUASTAT(2011)and Freedom House(2011)
Per capita water useis measured in thousand m^3 per person.
Per capita GDP in 1990 Dollars per person.
Precipitation is measured in 10^9 m^3/year.

Before estimating, it seems appropriate to determine whether our variables have unit roots or not, since to avoid spurious regressions all the variables in the model must be stationary. To this end, we utilize unit root tests for panel data. Maddala and Wu (1999)'s panel unit root tests are shown in Table 2.2, leading to the rejection of the null hypothesis of a unit root. If data present cross-sectional dependence, traditional panel data unit root tests could lead to inconsistent estimates. Pesaran and Badi (2007) proposes a one-factor model to test non-estationarity by obtaining the simple average of the t-ratios of the ordinary least squares estimates obtained from the ADF (Augmented Dickey–Fuller) regressions augmented by the cross-sectional average of lagged levels and first differences of the series. When the time dimension (T) of the panel is smaller that the number of cross sections (N), literature suggests using unit root tests with simple cross-sectional dependence as Pesaran 's unit root test (2007) (Gengenbach et al., 2009). Pesaran and Basi's test (2007) considers a single common factor, i.e., an element that evolves with time and affects all the countries. This common factor generating cross-sectional dependence is static. Regarding water use, the common factor that could produce cross-sectional dependence would be geographical or climatic conditions that seem to be static. Therefore, in Table 2.3 cross-sectional independence is tested using Pesaran's test (2004) and suggesting the existence of cross-section dependence among countries. Accordingly, Pesaran and Badi's (2007) panel unit root test is obtained in Table 2.3. Again, the results entail the rejection of the null hypothesis of a unit root. Consequently, both per capita income and per capita water use are I(0), i.e., our variables do not have a unit root.

Table 2.2: Maddala and Wu's (1999) ADF Unit Root Test

Maddala and Wu's (1999) ADF Unit Root Test		
	Per capita GDP	Per capita water use
Intercept	571.4***	583.0***
	(0.0000)	(0.0000)
Intercept and trend	190.0***	310.9***
	(0.0005)	(0.0000)

P-values in parenthesis. *** 1% significant level.
The null hypothesis is that the panel has a unit root.

Table 2.3: Tests for cross-sectional dependence and unit roots

Pesaran's (2004) cross-section dependence test

	Per capita GDP	Per capita water use
CD test	60.05***	8.31***
	(0.0000)	(0.0000)

P-values in parenthesis. *** 1% significant level.
Under the null hypothesis of cross-section independence CD~ N(0,1).

Pesaran and Badi 's (2007) CIPS Unit Root Test

	Per capita GDP	Per capita water use
Intercept	-6.972***	-7.381***
	(0.0000)	(0.0000)
Intercept and trend	-5.987***	-7.145***
	(0.0005)	(0.0000)

P-values in parenthesis. *** 1% significant level.
The null hypothesis is that the panel has a unit root.

Once the suitability of the variables is tested, we estimate the "water withdrawal-income per capita" relationship using a polynomial panel model (Table 2.4) with individual effects (μ_i) and time dummies (τ_t). It is important to note that both heteroskedasticity and autocorrelation have been detected. Therefore we have applied PCSE, that is to say, we have calculated panel-corrected standard errors (PCSE) and then estimated the following model.

$$W_{it} = \mu_i + \tau_t + \beta_1 Y_{it} + \beta_2 Y_{it}^2 + \beta_3 Precip_{it} + \beta_4 PF_{it} + u_{it} \qquad (2.13)$$

The coefficient of income appears to be positive and significant at 1%. This parameter is high and superior to 1. The parameter of income squaredis clearly negative, and again significant at 1%. In this case, its value is small, reaching -0.09. According to these results, water use seems to follow a growing trend with a steep slope for low income values. As income rises, the slope turns gentler until an income per capita of $818 is reached, from which point a continuous fall can be seen. Precipitation shows positive elasticity, indicating that the greater water endowment a country has, the more water per capita is used. Moreover, the PF coefficient is 0.723, indicating that when the political freedom index increases (that is, when political freedom falls) per capita water use tends to rise.

Table 2.4: Water use-income relationship. Panel model with time and individual fixed effects

Parameters		
β_1 Income	1.245***	(2.95)
β_2 :Income squared	-0.0928***	(-3.43)
β_3 :Precipitation	2.347 ***	(5.41)
β_4 :PF	0.7238***	(5.41)
Turning point	818.34$	

The dependent variable is log per capita water use.All variables are in logarithms, except for PF. Values in parenthesis are t-ratios. ***, **, * stand for 1%, 5% and 10% significant level.

For the PSTR model, the first step involves testing whether the regime switching is significant or not. If linearity is rejected, then we must determine the number of transition functions. In Table 2.5, we can see the F-statistics and p-values of the tests of linearity versus PSTR, as well as of the non-remaining linearity. The linearity test leads to the rejection of the linear "per capita water use – income per person" relationship. In addition, we can conclude that a model with only a transition function is sufficient to capture the non-linear behavior of the data, since the hypothesis of two regimes (one optimal transition function) is not rejected.

Table 2.5: Linearity and non-remaining heterogeneity tests

Linearity test vs. PSTR	PSTR Model(1)	PSTR-IV Model(2)	PSTR-control Model(3)
$H_0: 1\ regime\ (notransitionfunction)$	F= 12.80766	F= 12.95102	F=13.58784
$H_A: 2\ regimes\ (1\ transitionfunction)$	P-value= 3.88815e-04	P-value= 3.61036e-04	P-value= 2.59969e-04
No remaining STR-type nonlinearity			
$H_0: 2\ regimes\ (1\ transitionfunction)$	F= 0.01750	F= 4.92599e-04	F= 0.00642
$H_A: 3\ regimes\ (2\ transitionfunctions)$	P-value=0.89483	P-value= 0.98230	P-value=0.93620

Statistics are reported until the non rejection of $\mathbf{H_0}$

Table 2.6: Parameter estimation of the PSTR

Variables	PSTR Model(1)	PSTR-IV Model(2)	PSTR-control Model(3)
B_1 :Income	0.314**	0.3698**	0.346**
	(1.99)	(2.169)	(2.13)
B_2 : Income	-0.595***	-0.678***	-0.785***
Transition variable	(-3.39)	(-3.46)	(-3.50)
B_3: Precipitation			5.02***
			(3.66)
B_4 : PF			0.742***
			(5.58)
c	10.53	10.64	11.42
	(antilog 37,697.10)	(antilog 42,048.65)	(antilog 91,126.26)
γ	0.45	0.414	0.382
RSS	39.898	39.858	39.426
AIC	-2.39001	-2.39099	-2.39312
BIC	-2.29945	-2.3044	-2.28445

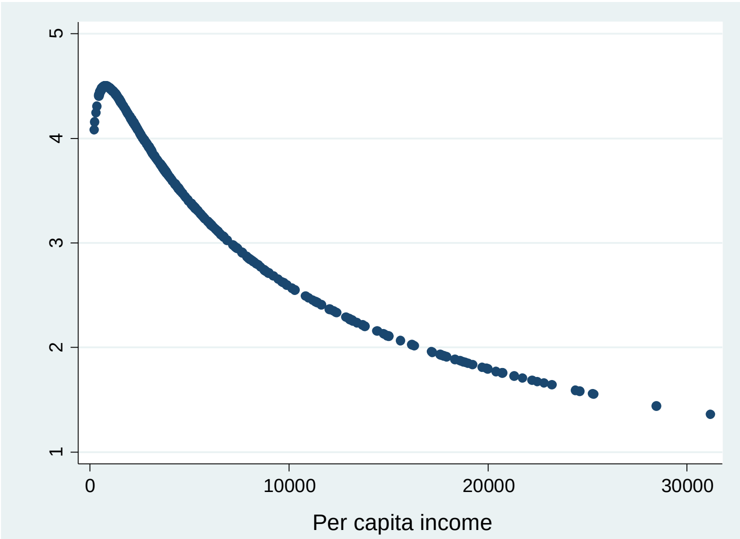
Values in parenthesis are t-ratios.
, * stand for 5% and 1% significant level.
Standard errors corrected for heteroskedasticity.

Thus, a PSTR model with one transition function seems to be appropriate. Table 2.6 shows the estimated models (model 1 to model 3) with individual fixed effects that capture country-specific features, such as climate or water endowments, and with temporal dummies to control for time-variant aspects, such as exogenous technological development, productive structure, and the rise of a consumer society[11]. Table 2.6 also includes t-ratios corrected for heteroskedasticity. Bear in mind that only the signs of the estimated parameters Income (β_1) and Income as transition variable (β_2) can be interpreted, whereas both the sign and the value of precipitation (β_3) and PF make sense (β_4). From Table 2.6, we observe that the income coefficient (β_1) is always significant and positive, whereas the parameter of the transition variable (β_2) is always negative, and higher than β_1 in absolute value. This simply means that, for low income values, when the threshold variable (per capita income) grows, the "per capita income-per capita water withdrawal" relationship although positive, tends to decrease. For medium and high incomes, the link is negative. The estimation of the

[11] Coefficients are positive and increase over time, that is, they show a trend.

slope parameter is small in all cases, indicating that the transition between the two extreme regimes is not sharp and therefore the "water use-per capita income" relationship cannot be considered as a limited number of regimes, but as a continuum of regimes. In sum, we could say that per capita water withdrawal increases with low per capita income. However, from a turning point, water withdrawal peaks and the "water use-income" link tends to be negative.

Figure 2.1: Per capita income vs. fitted per capita water use from the PSTR model

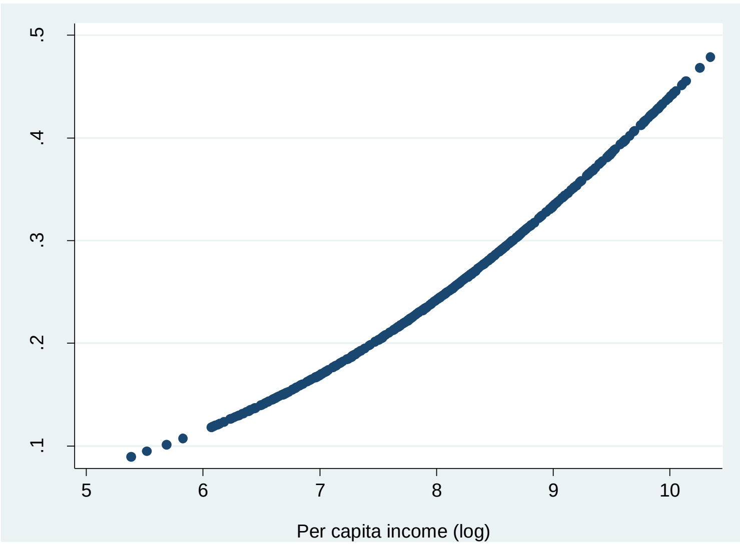


This pattern is displayed in Figure 2.1, where per capita income is plotted against the estimated per capita water use derived from the PSTR model. In this regard, it is important to say that the value of fitted per capita water withdrawal cannot be interpreted, since, as we are interested in the association between these two variables, we have omitted fixed effects. In a first step, the increase in income produces a sharp growth of water use. However, as countries develop, greater income leads to a reduction in water withdrawal per capita. Finally, there takes place a decoupling of economic growth from the level of water consumption. In this regard, it is important to note that the former does not signify that a real decrease in per capita water use takes place for medium and high GDP values, but that the relationship between per capita income and water use per inhabitant is negative when all other factors determining water withdrawal per capita remain constant. In any case, not all countries follow exactly the same trajectory, since, as stated by De Bruyn et al. (1998), the EKC is a descriptive relationship, attempting to measure the association between two variables. Some nations may not follow the estimated pattern and consequently the general turning point may not match the actuality of individual countries.

As stated above, to improve the possible omission variable bias we have estimated PSTR controlling for availability of water resources, and for the quality of institution (model 3). From Table 2.6, we can see how the estimates of income β_1 and income as transition variable β_2 are rather similar in the three models presented. Moreover, the expected sign of the parameter precipitation β_3 is positive, indicating that a 1% increase in annual average level of precipitation involves a 5.02% rise in per capita water use. Similarly, as previously indicated, the parameter β_4 associated with political freedom equals 0.74. This shows that a higher political freedom index (i.e., less political freedom) implies more per capita water use; in other words, an increase in democracy entails less use of water resources per capita.

Figure 2.2 illustrates the scattered graph of the logistic transition function against per capita income. There are few observations within the low extreme regime $g(Y_{it};\gamma,c)=0$ and none at all within the upper extreme regime $g(Y_{it};\gamma,c)=1$. Nonetheless, the transition phase contains most of the data and reminds us of the need to use the PSTR model.

Figure 2.2: PSTR transition function



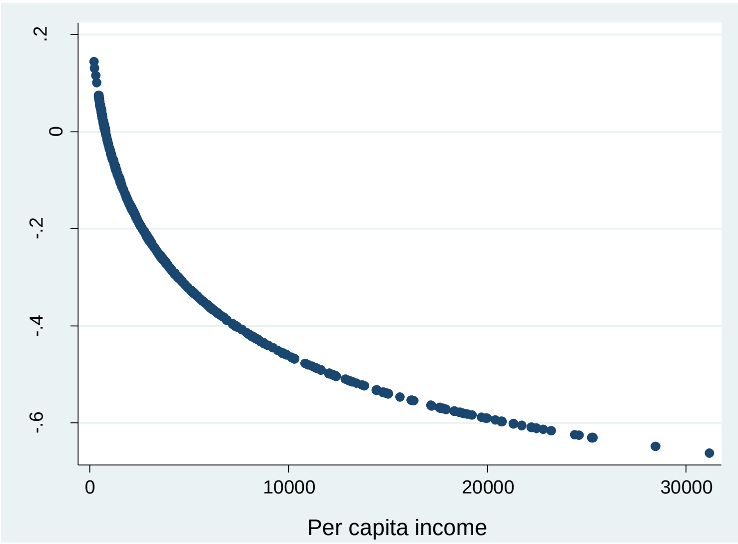
In sum, our estimates reach the same general conclusion: there exists a positive link between per capita water withdrawal and per capita income for low income levels.

From this threshold, the impact of per capita income on water use is significantly negative, that is, a rise in per capita income involves a decrease in the quantity of water used per capita, all other things being equal or held constant. Nevertheless, as we will see below (Figure 2.4), on average, the value of income elasticity is somehow divergent, depending on the model chosen (quadratic or PSTR).

Once we have estimated the parameters, it is possible to obtain the time-variant individual income elasticity of water use, for each country and period. Equation 2.3 gives the formula to calculate income elasticity of the PSTR model. The elasticity of a homogeneous quadratic polynomial model is given by the expression:

$$e_{it}{}^{quadratic} = \frac{\partial W_{it}}{\partial Y_{it}} = \beta_1 + \beta_2 Y_{it} \qquad (2.14)$$

Figure 2.3: PSTR water use elasticity displayed for all the values of per capita income



Therefore, income elasticity varies depending on both the year and the country in the PSTR model, and in the quadratic polynomial model. However, it is important to take into account that this is the case for different reasons. As we can see in equation 2.14, income elasticity in the quadratic fixed effects regression depends on the value of the parameters β_1 and β_2, as well as on the value of per capita income. That is, as the estimated β are common for all countries and periods in this model, the individual and time variability of $e_{it}{}^{quadratic}$ will be determined by per capita GDP. When we examine $e_{it}{}^{PSTR}$ (equation 2.3), apart from income, we find that the variability in elasticity stems from the transition function. Figure 2.3 reports the link between per capita income and the PSTR income elasticity. The association is clearly non-linear; more concretely, elasticity appears to be inversely correlated with per capita GDP. Nonetheless, this decreasing trend tends to steady for the highest income observations.

Income elasticity is time-variant, so Table 2.7 reports the individual average elasticities based on the historical values of per capita income for the polynomial model, the PSTR model, the instrumental variables PSTR model (IV PSTR), and the PSTR with control variables. The average standard deviations are also included. The individual average is obtained as follows:

$$\overline{e}_{i} = \frac{1}{T}\sum_{t=1}^{T} e_{it} \qquad SE = \sqrt{\frac{1}{T}\sum_{t=1}^{T}(e_{it} - \bar{e}_i)^2} \qquad (2.15)$$

Table 2.7: Individual average of income elasticity of water use

	Average GDP pc (1990$)	Quadratic $\bar{e}_{it}$	Quadratic $\bar{\sigma}$	PSTR $\bar{e}_{it}$	PSTR $\bar{\sigma}$	IV PSTR $\bar{e}_{it}$	IV PSTR $\bar{\sigma}$	PSTR control $\bar{e}_{it}$	PSTR control $\bar{\sigma}$
Afghanistan	660.5	0.03	0.03	0.02	0.02	0.03	0.03	0.02	0.02
Albania	2,366.10	-0.18	0.06	-0.18	0.06	-0.18	0.06	-0.18	0.06
Algeria	2,743.50	-0.21	0.03	-0.21	0.03	-0.21	0.03	-0.21	0.03
Argentina	7,707.90	-0.39	0.04	-0.41	0.04	-0.41	0.04	-0.41	0.05
Australia	16,042.60	-0.51	0.06	-0.55	0.07	-0.55	0.07	-0.57	0.08
Bangladesh	695.1	0.03	0.04	0.01	0.04	0.02	0.04	0.01	0.04
Bolivia	2,316.90	-0.18	0.03	-0.18	0.03	-0.18	0.04	-0.18	0.03
Brazil	4,447.10	-0.29	0.06	-0.3	0.07	-0.3	0.07	-0.3	0.07
Burkina Faso	797.9	0	0.03	0	0.02	0	0.03	-0.01	0.02
Canada	16,630.60	-0.52	0.06	-0.56	0.07	-0.56	0.07	-0.58	0.08
Colombia	4,307.00	-0.29	0.06	-0.29	0.06	-0.29	0.06	-0.3	0.06
Costa Rica	4,836.80	-0.31	0.06	-0.32	0.07	-0.32	0.07	-0.32	0.07
Cuba	2,457.70	-0.19	0.04	-0.19	0.05	-0.19	0.05	-0.19	0.05
Chad	482	0.09	0.04	0.06	0.03	0.07	0.03	0.06	0.03
Chile	7,186.80	-0.37	0.07	-0.4	0.08	-0.4	0.08	-0.4	0.09
China	1,824.40	-0.14	0.15	-0.14	0.15	-0.14	0.15	-0.15	0.15
Dominican Republic	2,445.50	-0.19	0.07	-0.19	0.08	-0.19	0.08	-0.19	0.08
Ecuador	3,442.70	-0.25	0.04	-0.25	0.04	-0.25	0.04	-0.25	0.04
Egypt	2,094.40	-0.16	0.08	-0.16	0.08	-0.16	0.08	-0.16	0.08
El Salvador	2,347.30	-0.18	0.03	-0.18	0.03	-0.18	0.03	-0.18	0.03
France	15,153.70	-0.5	0.07	-0.54	0.07	-0.54	0.07	-0.56	0.08
Guatemala	3,394.80	-0.25	0.04	-0.25	0.05	-0.25	0.05	-0.25	0.05
Haiti	900.5	-0.02	0.04	-0.02	0.03	-0.02	0.03	-0.02	0.03
Honduras	1,835.40	-0.14	0.03	-0.13	0.03	-0.13	0.03	-0.14	0.03
India	1,320.80	-0.08	0.08	-0.08	0.08	-0.08	0.08	-0.08	0.08
Indonesia	2,230.50	-0.17	0.1	-0.17	0.1	-0.17	0.1	-0.17	0.1
Israel	11,282.40	-0.45	0.08	-0.48	0.09	-0.49	0.09	-0.5	0.1
Italy	13,440.10	-0.48	0.07	-0.52	0.08	-0.52	0.09	-0.53	0.09
Jamaica	3,484.20	-0.25	0.02	-0.25	0.03	-0.25	0.03	-0.25	0.03
Japan	13,739.10	-0.49	0.11	-0.52	0.12	-0.52	0.12	-0.54	0.13
Jordan	3,684.90	-0.26	0.06	-0.26	0.06	-0.26	0.06	-0.26	0.06
Lebanon	3,029.00	-0.23	0.05	-0.23	0.05	-0.23	0.05	-0.23	0.05
Liberia	1,123.30	-0.06	0.03	-0.05	0.03	-0.05	0.03	-0.06	0.03

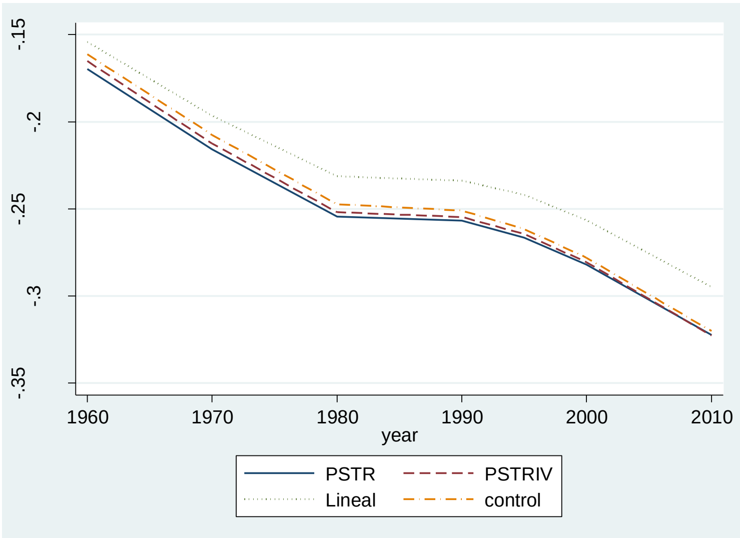
Madagascar	874.8	-0.01	0.04	-0.02	0.04	-0.01	0.04	-0.02	0.04
Malaysia	4,478.30	-0.29	0.12	-0.31	0.14	-0.3	0.14	-0.31	0.14
Mali	752.2	0.01	0.04	0	0.04	0.01	0.04	0	0.04
Mauritania	981.4	-0.03	0.04	-0.03	0.03	-0.03	0.03	-0.04	0.03
Mexico	5,642.00	-0.33	0.05	-0.35	0.06	-0.35	0.06	-0.35	0.07
Morocco	2,241.70	-0.17	0.06	-0.17	0.06	-0.17	0.06	-0.17	0.06
New Zealand	13,480.50	-0.48	0.04	-0.52	0.04	-0.52	0.04	-0.53	0.05
Nicaragua	1,784.70	-0.14	0.05	-0.13	0.05	-0.13	0.05	-0.13	0.05
Niger	614	0.05	0.04	0.03	0.03	0.04	0.04	0.03	0.03
Nigeria	1,143.70	-0.06	0.03	-0.06	0.03	-0.05	0.03	-0.06	0.03
Panama	4,564.20	-0.3	0.06	-0.31	0.07	-0.31	0.07	-0.31	0.07
Peru	3,770.60	-0.26	0.04	-0.27	0.04	-0.27	0.04	-0.27	0.04
Philippines	2,143.10	-0.17	0.04	-0.16	0.04	-0.16	0.04	-0.16	0.04
Poland	5,608.30	-0.33	0.06	-0.35	0.07	-0.35	0.07	-0.35	0.08
Portugal	8,518.50	-0.4	0.1	-0.43	0.11	-0.43	0.11	-0.44	0.12
Saudi Arabia	7,800.90	-0.39	0.06	-0.41	0.07	-0.41	0.08	-0.42	0.08
Senegal	1,328.80	-0.09	0.01	-0.08	0.01	-0.08	0.01	-0.08	0.01
South Africa	3,912.80	-0.27	0.02	-0.28	0.03	-0.28	0.03	-0.28	0.03
Spain	9,779.10	-0.43	0.11	-0.46	0.12	-0.46	0.12	-0.47	0.13
Sudan	967.8	-0.03	0.04	-0.03	0.04	-0.03	0.04	-0.03	0.03
Sweden	16,026.50	-0.51	0.06	-0.55	0.06	-0.55	0.06	-0.57	0.07
Syria	5,613.90	-0.33	0.07	-0.35	0.08	-0.35	0.08	-0.35	0.08
Tanzania	559.5	0.06	0.03	0.04	0.02	0.05	0.02	0.04	0.02
Thailand	3,608.30	-0.26	0.13	-0.27	0.15	-0.26	0.15	-0.27	0.15
Trinidad & Tobago	10,509.10	-0.44	0.07	-0.47	0.07	-0.47	0.08	-0.48	0.08
Tunisia	3,053.40	-0.23	0.09	-0.23	0.1	-0.23	0.1	-0.23	0.1
Turkey	4,623.90	-0.3	0.08	-0.31	0.09	-0.31	0.09	-0.31	0.09
Uruguay	6,727.80	-0.36	0.04	-0.38	0.05	-0.38	0.05	-0.39	0.05
USA	20,660.90	-0.56	0.06	-0.59	0.06	-0.6	0.07	-0.62	0.08
Vietnam	1,190.30	-0.07	0.09	-0.07	0.09	-0.06	0.09	-0.07	0.08
Zaire	432.2	0.11	0.09	0.07	0.06	0.08	0.06	0.07	0.06
Ex Soviet Union	5,426.20	-0.33	0.05	-0.34	0.05	-0.34	0.06	-0.34	0.06
Total	3,087.10	-0.23	0.18	-0.24	0.19	-0.24	0.19	-0.25	0.2

In general, the PSTR and quadratic elasticities tend to be quite similar in most cases (quadratic polynomial elasticities are slightly higher), which confirms that the PSTR is a good approximation of the quadratic fixed effects model. However, as linearity was rejected in Table 2.5, we find that the PSTR is the optimal model and therefore, in the following we will focus on the values of the former estimates.

On the whole, there seem to be significant differences among countries. Looking at Table 2.7, we observe that the average income elasticities of water use are rather diverse. For example, in the PSTR model, the estimated values range from -0.59 for the US, 0.07 for Zaire, clearly illustrating the range of heterogeneity of the sample. On global average, water use income elasticity is -0.24. The countries that are below average (e_{it}<-0.24) have the highest per capita income levels and belong mainly to North America (Canada and US), Oceania and Europe (Sweden and France among others), with no African country in this situation. Many of these developed areas reach elasticity values around -0.6 at the end of the period studied.

The vast majority of above-average nations are African or Asian, and mean income is less than \$3,029 (of 1990). In this heterogeneous group, it is possible to find different patterns. On the one hand, countries such as India or China that in 1960 displayed positive elasticities, have followed a decreasing trend and exhibit negative values around -0.3 today. On the other hand, we find states like Madagascar or Haiti that have adopted the opposite pattern, from negative to positive elasticities. Finally, those with the lowest income (from Bangladesh to Zaire) are outstanding, since they display positive elasticities during the whole period; in other words, from 1960 to 2008, the relationship between water withdrawal and income is direct and even growing in places like Zaire.

Figure 2.4: Global time-variant elasticities



One of the key points of the PSTR model is that it allows us to examine the temporal dynamics of the dataset. Thus, in order to analyze trends in the water use-income link, the global average of the results obtained in polynomial, PSTR, IV-PSTR and PSTR control estimates are plotted in Figure 2.4. As shown in Figure 2.4, the income elasticity of water use is, on global average, negative and decreasing. The global path is clear, there is a continuous decrease of income elasticity from 1960, that is to say, the “income-water withdrawal” relationship is negative, and tends to decrease with time. On global average, the reduction in income elasticity is particularly intense from 1960 to 1980, given that from this moment the reduction continues but at a slower pace. It is also noteworthy that, on average, PSTR, IV-PSTR and PSTR control elasticities are very close. Nevertheless, and in spite of following a similar path, the polynomial elasticity is rather divergent in value.

4. Discussion

Several recent papers (Kander et al., 2004; Gales et al., 2007) carry out the assessment of the EKC in a long-run framework, giving a historical and comprehensive overview of the relationship between economic growth and environmental impacts or energy consumption. In our case, it is not possible to obtain data prior to 1960 for a broad set of countries, although we can make a case for putting our results in the context of the trajectory of global water use, or of certain regional groupings, from 1900 on.

Figure 2.5: Global average EKC

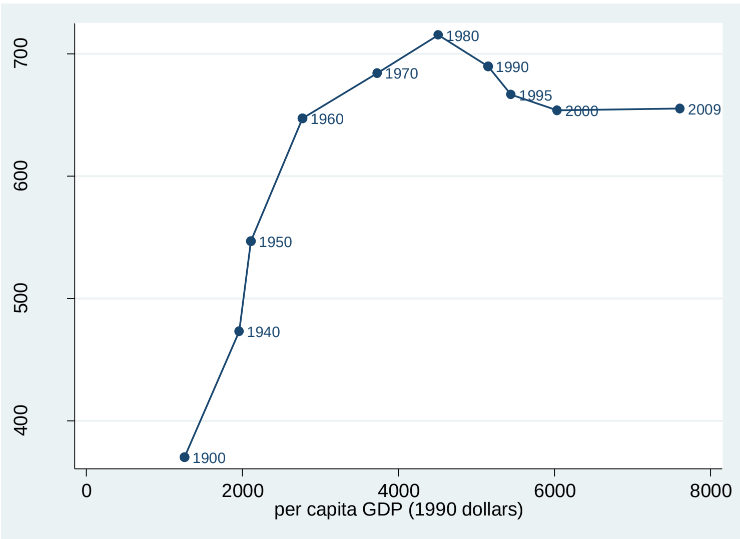


Figure 2.5 plots a curve with a sharp upward limb between 1900 and 1960, a slower growth until 1980, and a smooth fall from then. A less aggregate analysis by continents (Table 2.8), confirms, broadly speaking, this result, clearly corroborating the decrease in per capita water use from 1980 to 1990 in all of them.

Negative growth rates in the Table 2.8 for the period 1991-2000 would suggest the existence of a rising limb. For Africa positive rates could be explained by its early stage of development, whereas Europe could have reached the limits of decreasing water use with respect to economic growth. That is, if we had individual data for the whole of the twentieth century, we could analyze the link between per capita income and per capita water use graphically as seen in Figure 2.5, and it would be possible to distinguish a lengthy and steep growing trend followed by a small and smooth falling limb. Thus, the gradual growth of the first half of the twentieth century would dominate the association and we could probably assert the presence of a more complete EKC. Nevertheless, such a statement is not possible based only on our estimates from 1960.

Table 2.8: Per capita water use average annual growth rates (%)

Region	1900-1950	1951-1960	1961-1970	1971-1980	1981-1990	1991-2000
Europe	2.4	4.9	1.6	2.1	1.4	1.0
North America	1.5	0.6	1.5	0.5	-1.4	-0.3
Latin America	0.1	1.2	-0.5	0.8	-0.3	-0.2
Africa	-0.4	2.6	0.9	0.8	-0.9	1.2
Asia	0.8	1.6	-0.9	-0.3	0.1	-0.3
Oceania	2.8	1.4	1.6	0.5	1.0	-0.2
Ex Soviet Union	0.8	1.1	3.5	4.5	0.2	-2.1

Source: own calculations based on UNESCO

Accordingly, at the lowest levels of per capita income, more income seems to boost water use. As pointed out Goklany (2002), in this phase, the highest priority consists of meeting basic needs without paying attention to environmental damage. Improvements in standards of living entail changes in dietary patterns, moving towards more water-intensive goods such as meat or fruit, which is possible due to the extension of irrigation and the construction of water infrastructure. In addition, the development of the industrial sector, together with growing urbanization, implies a great and diverse increase in per capita water use (Duarte et al., 2013).

As per capita GDP increases, water use income elasticity turns out to be negative; that is, more affluence means less water withdrawal per capita. As we saw in chapter one, the combination of technical, managerial and institutional developments improves the efficiency of water use. We could point to advances in environmental regulation, the perception of health risks, improvements in irrigation systems or economic constraints, among other factors. We concur with Stern (2004) who, when talking about emissions, says that innovations are adopted in high-income countries first and with a short lag, before they are implemented in emerging countries, allowing emission drops in both developed and developing countries at the same time. Therefore, improvements like public-supply water use seem to be put in practice first in developed areas and subsequently transferred to countries with lower per capita GDP, giving place to substantial reduction or stabilization in water use per capita, in both developed and developing areas. Thus, countries such as Mexico, Malaysia or Poland, among others, show similar negative elasticities values in 2008 to those of developed countries like France, the US, or Australia in 1960. In this regard, we should consider the temporal framework we are working with; if data for the whole twentieth century were available, our results would probably change. That is, as noted above, the growing trend of the link would be steeper and developing countries could not have taken advantage of technological advances in developed areas from the 1970s on. Consequently, as the growing limb would dominate the curve, the least developed countries would reach negative elasticity at higher income levels. Finally, the areas with highest GDP per capita also show negative elasticities, but as these countries become wealthier, the decrease produced in water use due to an increase in per capita GDP tends to be smaller. Measures like the Clean Water Act in the United States or the introduction of new irrigation techniques have an important initial impact, leading to a notable decrease in water use; nonetheless their original effect appears to flatten as time goes by. Despite this fact, some authors like Gleick and Palaniappan (2010) refer to the concept of peak water, meaning that some developed countries, for instance the United States, have little leeway for the expansion of water withdrawal. Mainly, these authors refer to agriculture, responsible for around 80% of global water use, and say that a greater enlargement of agriculture in high-income countries appears difficult, particularly in arid areas, where water resources and land are no longer available, or their use appears to be ecologically and economically unsustainable. Apart from that, it is also important to take into account the growing pressure on water resources in less efficient water areas stemmed from the increasing need for food production due to agricultural and energy prices rise as well as the intensive use of water generated by biofuels what is leading to a competing use for croplands.

5. Conclusion

In this paper, we have assessed the “water use-income” relationship (in per capita terms) in 65 countries from 1960 on. To that aim, we have estimated different models; a quadratic polynomial fixed effects model, a Panel Smooth Transition Regression, the late Panel Smooth Transition Regression with lagged per capita income as an instrument, and a Panel Smooth Transition Regression with control variables. All four lead to a similar conclusion, which corroborates the robustness of the results. First, there exists a non-linear link between per capita water use and income. When plotting these two variables, they appear to represent a peculiar inverted-U shape, that is, water use tends to increase with the lowest income observations, but this trend reverses when income becomes greater, with the downward limb prevailing. As far as this relationship is concerned, it is important to highlight that a negative link between per capita income and water use per capita does not mean that the per capita use of water resources decreases, but that the more income per capita, the less use of water resources, keeping constant the other factors that influence water use. Moreover, the value of the smoothness parameter indicates that the transition is slow. Second, the variability in income elasticity of water use reflects the broad heterogeneity of the sample. Elasticity is positive when income is low and negative as income grows. Eventually, if we consider the global trajectory of income elasticity, there is no doubt that it decreases as time goes on. This decline is particularly sharp until the 1980s, but tends to be flatter for the highest income levels. The volume of water resources of a country (precipitation used as a proxy) is positively significant to explain per capita water use; thus, those countries with water scarcity tend to be more efficient and use less water per capita.Eventually, higher levels of democracy appear to trigger improved environmental institutions and thus, less water use per capita.

As a result, is there an Environmental Kuznets Curve for water use? Following Kander and Lindmark (2004), who offer an EKC examination in the long run, and taking into account the great increase seen for per capita water use during the first half of the twentieth century, together with prior estimates that show a negative water use-income link, it would be possible to distinguish an upward and a downward limb. However, the results of this study, with information from 1960, only allow us to state that there exists a peculiar EKC with a marked falling trend dominating the link. As seen in chapter one, at the same time that economic development entailed pressures on water resources, technological innovations and institutional changes were introduced in both developed and emerging nations, making up for income increases. In this respect, it is important to note that, although an increase in water use (in absolute terms) can be observed for the vast majority of regions, representing a growing pressure on the resource, our findings appear to suggest a negative link between per capita GDP and per capita water withdrawal, keeping constant all other factors. In this sense, the trajectory of variables such as population and technology, among others, could be decisive in explaining the trend followed by water withdrawal, seen in chapter one. Obviously, despite innovations adopted in developing countries with relatively short lags regarding most developed regions, there is still much to do, since there exists a wide margin of action around key issues such as water pricing and water metering, particularly in agriculture. These aspects are crucial for the continuation of the decreasing path of the "per capita water use - per capita income" nexus, since, as we have previously seen, the decline in income elasticity continues to become smoother as income grows, and pressures on the resource are increasing in many parts of the world.

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CHAPTER 3.

THE WATER INEQUALITIES: THE ROLE OF INCOME AND INDUSTRIAL SPECIALIZATION

1. Introduction

During decades, water requirements were studied from the so-called water withdrawal or water production perspective, in the sense of computing the direct requirements of water generated by economic activities. From this perspective water analysis focus on the volume of water removed from its natural source for a specific use, which includes water from primary and secondary freshwater resources and non-conventional water (direct water) (FAO, 2013). Nevertheless, in a highly globalized context, it seems quite clear that it is necessary to go beyond the domestic water withdrawal approach in the assessment of water resources trends. In this regard, the consumption perspective is being increasingly demanded in a context of shared producer-consumer responsibilities. The underlying idea is that economic activity and consumer behavior have a responsibility on the conservation or damage of the environment, with trans-boundary dimensions. The final demand of a territory generates environmental impacts beyond its own borders. Thus, in an increasingly globalized world, production chains are transnational. Besides, traded goods embody production processes and specific quantities of natural resources internationally used and degraded.

Today, it is possible to find vast literature trying to quantify the volume of water embodied in commodities as a result of production processes or exchanges through international trade (Cazcarro et. al., 2013b; Cazcarro et al., 2014; Yu et al., 2010; Galli et al., 2012; Feng et. al., 2012). In this framework, the water footprint appears as an indicator of direct and indirect freshwater that is used to produce the goods and services consumed by the inhabitants of the nation (Hoekstra et al., 2011). Studies estimating water footprint and virtual water displacements are chiefly based in two different approaches, the top-down (Lenzen and Peters, 2010;Feng et al., 2012;Steen-Olsen et al., 2012) and the bottom-up approach (Hoekstra and Mekonnen, 2012). The former, with input-output analysis as its main tool, considers the whole regional, national or global supply chains to obtain embodied water. On the contrary, the latter estimates water footprint from detailed process data, but does not distinguish between intermediate and final users (Feng et al., 2011).

Either we analyze water resources from the withdrawal or from the footprint perspective, the fact that global water use and consumption has gone through a marked growing trend in the last century seems evident (Goklany, 2002; Barbier, 2004; Gleick and Palaniappan, 2010). Many papers point at population growth, economic development, consumption patterns, technological changes or trade increase as key drivers for water use increase during the last century (Vörösmarty et al., 2005). Some of them have focused on the quantification of the effect that these driving forces have exerted on the use and consumption of water resources (Duarte et al., 2014; Cazcarro et al., 2013a; Tello and Ostos, 2012, among others).

In this context, we will try to identify and analytically obtain the impact that some of the former factors have had in the paths followed by water consumption at a global and country level. Therefore, the main objective of this paper is to deepen into water trends, trying to enumerate and measure the factors that could lie behind changes in water consumption. To that aim, we work with an Environmental Multi-Regional Input-Output (MRIO) model, being able to endogenously estimate the state and interdependencies between countries and sectors regarding direct and indirect water consumption in two different periods. Subsequently, we apply the structural decomposition analysis (SDA) that allow us to determine to what extent changes in demand, consumption patterns, technologies or intensities have involved variations in water consumption. More specifically, we want to analyze the differences in these factors between groups of countries classified depending on their level of income. We are also interested in studying the contribution of the different factors and groups to the evolution of water flows at the world level.

To go further into these issues, we will use a MRIO table based on the World Input-Output Database (WIOD, 2012). It contains detailed information of the interrelations between 41 countries with 35 sectors each one. The analysis is applied to water consumption changes between 1995 and 2009 and distinguishes among the three types of water often identified in the water footprints: green, blue and grey water. Green water is the rainwater evaporated as a result of the production of a commodity, blue water is the surface or groundwater evaporated during a production process and finally grey water is the volume of water necessary to dilute a certain amount of pollutants (Hoekstra et al., 2011). These data on water consumption are also taken from WIOD.

Our results show an increase in direct and indirect water consumption as well as in virtual water trade, chiefly due to the great boost of demand taken place during these years. More specifically, the great and global rise in the scale of demand played an essential role. Moreover, the production of inputs in low income countries notably contributed to the growth in water consumption. Only two factors, changes in water intensity and composition patterns, would be responsible for a partial moderation of water consumption increase in both high and low income countries.

The article is organized as follows. Section 2 reviews the methodology. Section 3 presents the data used. Section 4 shows the main results of our analysis and is divided into two subsections. Section 4.1 focuses on the main trends of water consumption, and section 4.2 performs the structural decomposition analysis. Finally, section 5 closes the paper with a discussion of the results and conclusions.

2. Methodology

We use the environmentally extended input-output approach to obtain the volume of water embodied in domestic production and in trade flows. The MRIO model allows us to calculate consumer and producer responsibilities of water consumption, distinguishing by regions and sectors. We use a structure of input-output table, based on the model of Isard (1951) and further explained in Miller and Blair (2009) and Cazcarro et al. (2010 and 2013b). For the 41 regions it is possible to represent the multiregional matrix of technical coefficients $\mathbf{A}^{\oplus}$ and the Leontief inverse $\mathbf{L}^{\oplus}$, respectively, as:

$$\mathbf{A}^{\oplus} = \begin{bmatrix} \mathbf{A}_{1,1} & \mathbf{A}_{1,2} & \cdots & \mathbf{A}_{1,41} \\ \mathbf{A}_{2,1} & \mathbf{A}_{2,2} & \cdots & \mathbf{A}_{2,41} \\ \cdots & \cdots & \cdots & \cdots \\ \mathbf{A}_{41,1} & \mathbf{A}_{41,2} & \cdots & \mathbf{A}_{41,41} \end{bmatrix} ; \qquad \mathbf{L}^{\oplus} = \begin{bmatrix} \mathbf{L}_{1,1} & \mathbf{L}_{1,2} & \cdots & \mathbf{L}_{1,41} \\ \mathbf{L}_{2,1} & \mathbf{L}_{2,2} & \cdots & \mathbf{L}_{2,41} \\ \cdots & \cdots & \cdots & \cdots \\ \mathbf{L}_{41,1} & \mathbf{L}_{41,2} & \cdots & \mathbf{L}_{41,41} \end{bmatrix} \qquad (3.1)$$

Each matrix $\mathbf{A}_{rr}$ ($n \times n$) which forms the main diagonal indicates the domestic technical coefficients in the region r. The off-diagonal matrices $\mathbf{A}_{rs}$ indicate the coefficients of the region of imported inputs from r. In this way, each characteristic element $a^{ij}{}_{rs}$ of the matrix $\mathbf{A}^{\oplus}$ expresses the quantity of output of sector i produced in r and consumed as input by sector j of region s, per unit of total output of sector j in s.

If we also define $\mathbf{w}_r$ (41×1) as the vector of coefficients of water consumption per output of region r, whose characteristic element $w^{i}{}_{r}$ indicates the quantity of water per unit of output of sector i in region r, we can estimate the consumption of water associated with the production of each region as follows:

$$\begin{bmatrix} \mathbf{\Omega_1} \\ \mathbf{\Omega_2} \\ \mathbf{...} \\ \mathbf{\Omega_{41}} \end{bmatrix} = \begin{bmatrix} \hat{\mathbf{w}}_{1,1} & \mathbf{0} & \dots & \mathbf{0} \\ \mathbf{0} & \hat{\mathbf{w}}_{2,2} & \dots & \mathbf{0} \\ \dots & \dots & \dots & \dots \\ \mathbf{0} & \mathbf{0} & \dots & \hat{\mathbf{w}}_{41,41} \end{bmatrix} \begin{bmatrix} \mathbf{L}_{1,1} & \mathbf{L}_{1,2} & \dots & \mathbf{L}_{1,41} \\ \mathbf{L}_{2,1} & \mathbf{L}_{2,2} & \dots & \mathbf{L}_{2,41} \\ \dots & \dots & \dots & \dots \\ \mathbf{L}_{41,1} & \mathbf{L}_{41,2} & \dots & \mathbf{L}_{41,41} \end{bmatrix} \begin{bmatrix} \mathbf{y}_{1,1} + \mathbf{y}_{1,2} + \dots + \mathbf{y}_{1,41} \\ \mathbf{y}_{2,1} + \mathbf{y}_{2,2} + \dots + \mathbf{y}_{2,41} \\ \dots \\ \mathbf{y}_{41,1} + \mathbf{y}_{41,2} + \dots + \mathbf{y}_{41,41} \end{bmatrix} \quad (3.2)$$

Where the $\mathbf{\Omega}_r$ are diagonalized, $\mathbf{y}_{rr}$ represents domestic final demand of r, and $\mathbf{y}_{rs}$ are imports from the region consumed by final demand of s. Thus, with the matrices $\mathbf{\Omega}_r$ we obtain the consumption of direct and indirect water necessary to meet the demands of each region for each sector. Finally, $\mathbf{y}_{rr}$ and $\mathbf{y}_{rs}$ can be decomposed into 5 accounts: Final consumption expenditure by households, final consumption expenditure by non-profit organisations serving households, final consumption expenditure by government, gross fixed capital formation and changes in inventories and valuables

World Input Output Database (Timmer et al., 2012) offers the MRIO table that reflects all exchanges taken place between countries and sectors. Merging it with direct water coefficients that indicate the volume of water necessary to produce a unit of product in each country, also taken from WIOD, we obtain the environmentally extended MRIO model.

$$\begin{bmatrix} \mathbf{\Omega}_{1,1} & \mathbf{\Omega}_{1,2} & \cdots & \mathbf{\Omega}_{1,41} \\ \mathbf{\Omega}_{2,1} & \mathbf{\Omega}_{2,2} & \cdots & \mathbf{\Omega}_{2,41} \\ \cdots & \cdots & \cdots & \cdots \\ \mathbf{\Omega}_{41,1} & \mathbf{\Omega}_{41,2} & \cdots & \mathbf{\Omega}_{41,41} \end{bmatrix} =$$

$$\begin{bmatrix} \hat{\mathbf{w}}_{1,1} & \mathbf{0} & \cdots & \mathbf{0} \\ \mathbf{0} & \hat{\mathbf{w}}_{2,2} & \cdots & \mathbf{0} \\ \cdots & \cdots & \cdots & \cdots \\ \mathbf{0} & \mathbf{0} & \cdots & \hat{\mathbf{w}}_{41,41} \end{bmatrix} \begin{bmatrix} \mathbf{L}_{1,1} & \mathbf{L}_{1,2} & \cdots & \mathbf{L}_{1,41} \\ \mathbf{L}_{2,1} & \mathbf{L}_{2,2} & \cdots & \mathbf{L}_{2,41} \\ \cdots & \cdots & \cdots & \cdots \\ \mathbf{L}_{41,1} & \mathbf{L}_{41,2} & \cdots & \mathbf{L}_{41,41} \end{bmatrix} \begin{bmatrix} \hat{\mathbf{y}}_{1,1} & \hat{\mathbf{y}}_{1,2} & \cdots & \hat{\mathbf{y}}_{1,41} \\ \hat{\mathbf{y}}_{2,1} & \hat{\mathbf{y}}_{2,2} & \cdots & \hat{\mathbf{y}}_{2,41} \\ \cdots & \cdots & \cdots & \cdots \\ \hat{\mathbf{y}}_{41,1} & \hat{\mathbf{y}}_{41,2} & \cdots & \hat{\mathbf{y}}_{41,41} \end{bmatrix} \quad (3.3)$$

Estimates of water consumption allow us to know the embodied water in trade flows between regions and estimate their water footprints. The pressure of countries on the global water resources (which we associate with the blue and green WF consumption), comes from the domestic water consumptive use (Wdom), plus the embodied water in imports (virtual water imports, VWM), minus embodied water in exports (virtual water export, VWX). $\mathbf{\Omega}_{rr}$ is the matrix of the amounts of water that are used in production activities in region r to support region r final demand, while $\sum_{\mathrm{r,r\neq s}} \mathbf{\Omega_{rs}}$ is the matrix of water consumed in other regions production to support region s final demand (VW imports of region s) and $\sum_{\mathrm{s,s\neq r}} \mathbf{\Omega_{rs}}$ is the matrix of water consumed in r to support the final demands of other regions (VW exports of region r). Then, $\mathbf{e}'\mathbf{\Omega_{rr}}\mathbf{e}$ is the total amount of water consumed in region r to support its own final demand, this is the domestic component of the water footprint of region r. Similarly, $\sum_{\mathbf{r,r\neq s}} \mathbf{e}'\mathbf{\Omega_{rs}}\,\mathbf{e}$ is the total VW import of region s, and $\sum_{\mathbf{s,s\neq r}} \mathbf{e}'\mathbf{\Omega_{rs}}\,\mathbf{e}$ the total VW export of region r. Moreover, $\sum_{\mathbf{r}} \mathbf{e}'\mathbf{\Omega_{rs}}\,\mathbf{e} = \mathbf{e}'\mathbf{\Omega_{ss}}\mathbf{e} + \sum_{\mathbf{r,r\neq s}} \mathbf{e}'\mathbf{\Omega_{rs}}\,\mathbf{e}$ is the water footprint of region s and $\sum_{\mathbf{s}} \mathbf{e}'\mathbf{\Omega_{rs}}\,\mathbf{e} = \mathbf{e}'\mathbf{\Omega_{rr}}\mathbf{e} + \sum_{\mathbf{s,s\neq r}} \mathbf{e}'\mathbf{\Omega_{rs}}\,\mathbf{e}$ the water due to production in region r (in other words, the direct consumption of water in region r). The difference between this water and the water footprint of the region r, $\sum_{\mathbf{s,s\neq r}} \mathbf{e}'\mathbf{\Omega_{rs}}\,\mathbf{e} - \sum_{\mathbf{r,r\neq s}} \mathbf{e}'\mathbf{\Omega_{rs}}\,\mathbf{e}$, is nothing but the net export of water, which can be positive or negative and reveals the exporter or importer character of the region.

In the basis of relationship (3.3), we can decompose $\mathbf{y}_{rs}$ into two components representing the composition (given by C) and the size (scale, given by Y) of the final demand, which yields:

$$\begin{bmatrix} \boldsymbol{\Omega}_{1,1} & \boldsymbol{\Omega}_{1,2} & \cdots & \boldsymbol{\Omega}_{1,41} \\ \boldsymbol{\Omega}_{2,1} & \boldsymbol{\Omega}_{2,2} & \cdots & \boldsymbol{\Omega}_{2,41} \\ \cdots & \cdots & \cdots & \cdots \\ \boldsymbol{\Omega}_{41,1} & \boldsymbol{\Omega}_{41,2} & \cdots & \boldsymbol{\Omega}_{41,41} \end{bmatrix} = \begin{bmatrix} \hat{\mathbf{w}}_{1,1} & \mathbf{0} & \cdots & \mathbf{0} \\ \mathbf{0} & \hat{\mathbf{w}}_{2,2} & \cdots & \mathbf{0} \\ \cdots & \cdots & \cdots & \cdots \\ \mathbf{0} & \mathbf{0} & \cdots & \hat{\mathbf{w}}_{41,41} \end{bmatrix} \begin{bmatrix} \mathbf{L}_{1,1} & \mathbf{L}_{1,2} & \cdots & \mathbf{L}_{1,41} \\ \mathbf{L}_{2,1} & \mathbf{L}_{2,2} & \cdots & \mathbf{L}_{2,41} \\ \cdots & \cdots & \cdots & \cdots \\ \mathbf{L}_{41,1} & \mathbf{L}_{41,2} & \cdots & \mathbf{L}_{41,41} \end{bmatrix}$$

$$\begin{bmatrix} \hat{\mathbf{C}}_{1,1} & \hat{\mathbf{C}}_{1,2} & \cdots & \hat{\mathbf{C}}_{1,41} \\ \hat{\mathbf{C}}_{2,1} & \hat{\mathbf{C}}_{2,2} & \cdots & \hat{\mathbf{C}}_{2,41} \\ \cdots & \cdots & \cdots & \cdots \\ \hat{\mathbf{C}}_{41,1} & \hat{\mathbf{C}}_{41,2} & \cdots & \hat{\mathbf{C}}_{41,41} \end{bmatrix} \begin{bmatrix} \hat{Y}_1 & \mathbf{0} & \cdots & \mathbf{0} \\ \mathbf{0} & \hat{Y}_2 & \cdots & \mathbf{0} \\ \cdots & \cdots & \cdots & \cdots \\ \mathbf{0} & \mathbf{0} & \cdots & \hat{Y}_{41} \end{bmatrix} \quad (3.4)$$

In this context, SDA has been applied to equation (3.4) to synthesize the driving forces underlying the changes in water embodied in regional domestic and traded production. As it is well-known, this approach tries to separate a time trend of an aggregated variable into a group of driving forces that can act as accelerators or retardants (Dietzenbacher and Los, 1998; Hoekstra and van den Bergh, 2002; Lenzen et al., 2001).

In a discrete schema, when we try to measure the changes in the dependent variable between two periods, *t-1* and *t,* there are different ways of solving this expression by way of exact decompositions, which leads to the well-known problem of the non-uniqueness of the SDA solution. In our case, if decomposition is based on four factors, we can obtain the following *4!* exact decompositions. In practice, as a "commitment solution", the average of all possible solutions is considered. Nevertheless, as Dietzenbacher and Los (1998) demonstrate, the simple average of the two polar decompositions runs as a good approximation to the average of the *4!* exact forms.

As departing point we obtain changes in matrix $\boldsymbol{\Omega}$ as difference of $\boldsymbol{\Omega_1}$ and $\boldsymbol{\Omega_0}$, i.e., $\boldsymbol{\Omega}$ in periods t_0 and t_1:

$$\Delta\boldsymbol{\Omega} = \boldsymbol{\Omega}_1 - \boldsymbol{\Omega}_0 = \widehat{\mathbf{w}}_\mathbf{1}\mathbf{L_1C_1}\widehat{\mathbf{Y}}_\mathbf{1} - \widehat{\mathbf{w}}_\mathbf{0}\mathbf{L_0C_0}\widehat{\mathbf{Y}}_\mathbf{0} \qquad (3.5)$$

Subsequently, we obtain the polar decompositions of the expression above:

$$\Delta\boldsymbol{\Omega} = \Delta\widehat{\mathbf{w}}\mathbf{L_0C_0}\widehat{\mathbf{Y}}_\mathbf{0} + \widehat{\mathbf{w}}_\mathbf{1}\Delta\mathbf{LC_0}\widehat{\mathbf{Y}}_\mathbf{0} + \widehat{\mathbf{w}}_\mathbf{1}\mathbf{L_1}\Delta\mathbf{C}\widehat{\mathbf{Y}}_\mathbf{0} + \widehat{\mathbf{w}}_\mathbf{1}\mathbf{L_1C_1}\Delta\widehat{\mathbf{Y}} \qquad (3.6)$$

$$\Delta\boldsymbol{\Omega} = \Delta\widehat{\mathbf{w}}\mathbf{L_1C_1}\widehat{\mathbf{Y}}_\mathbf{1} + \widehat{\mathbf{w}}_\mathbf{0}\Delta\mathbf{LC_1}\widehat{\mathbf{Y}}_\mathbf{1} + \widehat{\mathbf{w}}_\mathbf{0}\mathbf{L_0}\Delta\mathbf{C}\widehat{\mathbf{Y}}_\mathbf{1} + \widehat{\mathbf{w}}_\mathbf{0}\mathbf{L_0C_0}\Delta\widehat{\mathbf{Y}} \qquad (3.7)$$

Taking averages of (3.6) and (3.7) we obtain (3.8):

$$\Delta\boldsymbol{\Omega} = \frac{1}{2}\left(\Delta\widehat{\mathbf{w}}\mathbf{L_0}\mathbf{C_0}\widehat{\mathbf{Y}}_\mathbf{0} + \Delta\widehat{\mathbf{w}}\mathbf{L_1}\mathbf{C_1}\widehat{\mathbf{Y}}_\mathbf{1}\right) + \frac{1}{2}\left(\widehat{\mathbf{w}}_\mathbf{1}\Delta\mathbf{L}\mathbf{C_0}\widehat{\mathbf{Y}}_\mathbf{0} + \widehat{\mathbf{w}}_\mathbf{0}\Delta\mathbf{L}\mathbf{C_1}\widehat{\mathbf{Y}}_\mathbf{1}\right) + \frac{1}{2}\left(\widehat{\mathbf{w}}_\mathbf{1}\mathbf{L_1}\Delta\mathbf{C}\widehat{\mathbf{Y}}_\mathbf{0} + \widehat{\mathbf{w}}_\mathbf{0}\mathbf{L_0}\Delta\mathbf{C}\widehat{\mathbf{Y}}_\mathbf{1}\right) + \frac{1}{2}\left(\widehat{\mathbf{w}}_\mathbf{1}\mathbf{L_1}\mathbf{C_1}\Delta\widehat{\mathbf{Y}} + \widehat{\mathbf{w}}_\mathbf{0}\mathbf{L_0}\mathbf{C_0}\Delta\widehat{\mathbf{Y}}\right) \quad (3.8)$$

As long term effects of development on environment seem to be different regarding the economic features of regions, we have classified countries depending on their level of per capita gross domestic product, dividing the sample into high and low-middle income countries. Thus, it will possible to observe the different effects depending on countries classification. Therefore, applying this classification to water intensities, we obtain:

$$\begin{bmatrix} \hat{\mathbf{w}}_{1,1} & \mathbf{0} & \cdots & \mathbf{0} \\ \mathbf{0} & \hat{\mathbf{w}}_{2,2} & \cdots & \mathbf{0} \\ \cdots & \cdots & \cdots & \cdots \\ \mathbf{0} & \mathbf{0} & \cdots & \hat{\mathbf{w}}_{41,41} \end{bmatrix} = \begin{bmatrix} \hat{\mathbf{w}}_{\mathbf{1,1}} & \mathbf{0} & \cdots & \mathbf{0} \\ \mathbf{0} & \hat{\mathbf{w}}_{H,H} & \cdots & \mathbf{0} \\ \cdots & \cdots & \mathbf{0} & \cdots \\ \mathbf{0} & \mathbf{0} & \cdots & \mathbf{0} \end{bmatrix} + \begin{bmatrix} \mathbf{0} & \mathbf{0} & \cdots & \mathbf{0} \\ \mathbf{0} & \mathbf{0} & \cdots & \mathbf{0} \\ \cdots & \cdots & \hat{\mathbf{w}}_{H+1,H+1} & \cdots \\ \mathbf{0} & \mathbf{0} & \cdots & \hat{\mathbf{w}}_{L,L} \end{bmatrix} \quad (3.9)$$

In which *n* is the number of total countries (*n=1…41)* that comprises the two subsamples; i.e., h high income countries (h=*1,2,…,h)* and *n-h* low income countries (l=*h+1,h+2,…,l).* h consists of 29 countries and l consists of 11 countries plus ROW.

Accordingly, we obtain the intensity effect (IE) as expressed in the following equation, (3.10):

$$\mathbf{IE} = \frac{1}{2}\left(\Delta\widehat{\mathbf{w}}_\mathbf{H}\mathbf{L_1}\mathbf{C_1}\widehat{\mathbf{Y}}_\mathbf{1} + \Delta\widehat{\mathbf{w}}_\mathbf{H}\mathbf{L_0}\mathbf{C_0}\widehat{\mathbf{Y}}_\mathbf{0}\right) + \frac{1}{2}\left(\Delta\widehat{\mathbf{w}}_\mathbf{L}\mathbf{L_1}\mathbf{C_1}\widehat{\mathbf{Y}}_\mathbf{1} + \Delta\widehat{\mathbf{w}}_\mathbf{L}\mathbf{L_0}\mathbf{C_0}\widehat{\mathbf{Y}}_\mathbf{0}\right) = \mathbf{IEH} + \mathbf{IEL} \quad (3.10)$$

Thus, the intensity effect (IE) can be decomposed into:

- Intensity effect of high income countries (IEH), which quantifies the contribution of changes in high income countries water intensities to water consumption trends.

$$\mathbf{IEH} = \frac{1}{2}\left(\Delta\widehat{\mathbf{w}}_\mathbf{H}\mathbf{L_1}\mathbf{C_1}\widehat{\mathbf{Y}}_\mathbf{1} + \Delta\widehat{\mathbf{w}}_\mathbf{H}\mathbf{L_0}\mathbf{C_0}\widehat{\mathbf{Y}}_\mathbf{0}\right) \quad (3.11)$$

- Intensity effect of low income countries (IEL), which identifies the impact of changes in water intensities of low-middle income countries on water consumption trajectories.

$$\mathbf{IEL} = \frac{1}{2}\left(\Delta\widehat{\mathbf{w}}_{\mathbf{L}}\mathbf{L_1}\mathbf{C_1}\widehat{\mathbf{Y}}_{\mathbf{1}} + \Delta\widehat{\mathbf{w}}_{\mathbf{L}}\mathbf{L_0}\mathbf{C_0}\widehat{\mathbf{Y}}_{\mathbf{0}}\right) \qquad (3.12)$$

Secondly, we obtain technology effect that links variations in water consumption with changes in the technology of production.

$$\mathbf{TE} = \frac{1}{2}\left(\widehat{\mathbf{w}}_{\mathbf{1}}\Delta\mathbf{L}\mathbf{C_0}\widehat{\mathbf{Y}}_{\mathbf{0}} + \widehat{\mathbf{w}}_{\mathbf{0}}\Delta\mathbf{L}\mathbf{C_1}\widehat{\mathbf{Y}}_{\mathbf{1}}\right) \qquad (3.13)$$

Regarding this effect, note that, for each country, the technological effect can be also separated into changes in domestic technology (domestic technology effect), changes in imported technology from low income areas (backward technology effect from low) and variations in imported technology from high income countries (backward technology effect from high). The different blocks in matrix $\Delta\mathbf{L}$ approximate these effects.

As it is well known, we can describe production as a chain of processes that, departing from some primary inputs, generates intermediate inputs used in subsequent processes until the generation of final demand. This is the basis of the vertically integrated production. When this production chain is established in a multiregional input-output model, the different countries and technologies contribute to the generation of the final demand of a country, and technological changes along the entire production chain will condition the volume of water embodied in a specific final demand.

Thus, changes in $\Delta\mathbf{L}$ for a country *s,* can be decomposed into changes in inputs domestically produced (DD) (changes in the domestic technology used to produce inputs that can be used in other countries, but are eventually embodied in its domestic final demand, which will comprise the so-called internal and mixed effects) and changes in the backward effect (DB), that is, changes in technologies of other countries that produce the inputs necessary to meet the final demand of country s. This backward effect can be further decomposed identifying the contribution of high income areas (DBH) and low income countries (DBL). For the whole model, these components can be expressed as follows:

$$\Delta\mathbf{L} = \begin{bmatrix} \mathbf{D}_{1,1} & \mathbf{D}_{1,2} & \dots & \mathbf{D}_{1,41} \\ \mathbf{D}_{2,1} & \mathbf{D}_{2,2} & \dots & \mathbf{D}_{2,41} \\ \dots & \dots & \dots & \dots \\ \mathbf{D}_{41,1} & \mathbf{D}_{41,2} & \dots & \mathbf{D}_{41,41} \end{bmatrix} =$$

$$\begin{bmatrix} \mathbf{D}_{1,1} & \mathbf{0} & \dots & \mathbf{0} \\ \mathbf{0} & \mathbf{D}_{2,2} & \dots & \mathbf{0} \\ \dots & \dots & \dots & \dots \\ \mathbf{0} & \mathbf{0} & \dots & \mathbf{D}_{41,41} \end{bmatrix} + \begin{bmatrix} \mathbf{0} & \mathbf{D}_{1,2} & \dots & \mathbf{D}_{1,41} \\ \mathbf{D}_{2,1} & \mathbf{0} & \dots & \mathbf{D}_{2,41} \\ \dots & \dots & \dots & \dots \\ \mathbf{0} & \mathbf{0} & \dots & \mathbf{0} \end{bmatrix} + \begin{bmatrix} \mathbf{0} & \mathbf{0} & \dots & \mathbf{0} \\ \mathbf{0} & \mathbf{0} & \dots & \mathbf{0} \\ \dots & \dots & \dots & \dots \\ \mathbf{D}_{41,1} & \mathbf{D}_{41,2} & \dots & \mathbf{0} \end{bmatrix} =$$

$$= \mathbf{DD} + \mathbf{DBH} + \mathbf{DBL} \qquad (3.14)$$

where, as an example, we have considered country 41 as the low-income group.

Thus, we obtain technology effect:

$$\mathbf{TE} = \frac{1}{2}\left(\widehat{\mathbf{w}}_{\mathbf{0}}\mathbf{DDC}_{\mathbf{1}}\widehat{\mathbf{Y}}_{\mathbf{1}} + \widehat{\mathbf{w}}_{\mathbf{1}}\mathbf{DDC}_{\mathbf{0}}\widehat{\mathbf{Y}}_{\mathbf{0}}\right) + \frac{1}{2}\left(\widehat{\mathbf{w}}_{\mathbf{0}}\mathbf{DBHC}_{\mathbf{1}}\widehat{\mathbf{Y}}_{\mathbf{1}} + \widehat{\mathbf{w}}_{\mathbf{1}}\mathbf{DBHC}_{\mathbf{0}}\widehat{\mathbf{Y}}_{\mathbf{0}}\right) + \frac{1}{2}\left(\widehat{\mathbf{w}}_{\mathbf{0}}\mathbf{DBLC}_{\mathbf{1}}\widehat{\mathbf{Y}}_{\mathbf{1}} + \widehat{\mathbf{w}}_{\mathbf{1}}\mathbf{DBLC}_{\mathbf{0}}\widehat{\mathbf{Y}}_{\mathbf{0}}\right) = \mathbf{DTE} + \mathbf{BTEH} + \mathbf{BTEL} \qquad (3.15)$$

Accordingly, water consumption changes due to changes in technology can be explained on the basis of:

- Domestic technology effect (DTE), which quantifies the contribution of changes in inputs produced domestically to water consumption trends.

$$\mathbf{DTE} = \frac{1}{2}\left(\widehat{\mathbf{w}}_{\mathbf{0}}\mathbf{DDC}_{\mathbf{1}}\widehat{\mathbf{Y}}_{\mathbf{1}} + \widehat{\mathbf{w}}_{\mathbf{1}}\mathbf{DDC}_{\mathbf{0}}\widehat{\mathbf{Y}}_{\mathbf{0}}\right) \qquad (3.16)$$

- Backward technology effect from high income countries (BTEH), which measures to what extent changes in inputs produced in high income areas and imported by countries affect water consumption trajectories.

$$\mathbf{BTEH} = \frac{1}{2}\left(\widehat{\mathbf{w}}_{\mathbf{0}}\mathbf{DBHC}_{\mathbf{1}}\widehat{\mathbf{Y}}_{\mathbf{1}} + \widehat{\mathbf{w}}_{\mathbf{1}}\mathbf{DBHC}_{\mathbf{0}}\widehat{\mathbf{Y}}_{\mathbf{0}}\right) \qquad (3.17)$$

- Backward technology effect from low income countries (BTEL), which explains the relationship between changes in inputs produced in low income regions imported by countries and water consumption variations.

$$\mathbf{BTEL} = \frac{1}{2}\left(\widehat{\mathbf{w}}_{\mathbf{0}}\mathbf{DBLC}_{\mathbf{1}}\widehat{\mathbf{Y}}_{\mathbf{1}} + \widehat{\mathbf{w}}_{\mathbf{1}}\mathbf{DBLC}_{\mathbf{0}}\widehat{\mathbf{Y}}_{\mathbf{0}}\right) \qquad (3.18)$$

Finally, demand is decomposed into:

- Composition effect, which studies changes in water consumption as a result of variations on the composition of demand by products.

$$\mathbf{CE} = \frac{1}{2}\left(\widehat{\mathbf{w}}_{\mathbf{1}}\mathbf{L}_{\mathbf{1}}\Delta\mathbf{C}\widehat{\mathbf{Y}}_{\mathbf{0}} + \widehat{\mathbf{w}}_{\mathbf{0}}\mathbf{L}_{\mathbf{0}}\Delta\mathbf{C}\widehat{\mathbf{Y}}_{\mathbf{1}}\right) \quad (3.19)$$

- Scale effect, which quantifies how much of the change in water consumption is due to changes in the volume of final demand.

$$\mathbf{SE} = \frac{1}{2}\left(\widehat{\mathbf{w}}_{\mathbf{1}}\mathbf{L}_{\mathbf{1}}\mathbf{C}_{\mathbf{1}}\Delta\widehat{\mathbf{Y}} + \widehat{\mathbf{w}}_{\mathbf{0}}\mathbf{L}_{\mathbf{0}}\mathbf{C}_{\mathbf{0}}\Delta\widehat{\mathbf{Y}}\right) \quad (3.20)$$

All the components presented below are obtained in a matrix fully disaggregated by country and sector, aggregating the data only for the final presentation of the results. In this regard, all the components can be particularized by sector, country or group of countries, generating important information in the identification of national footprints and their evolution.

3. Data

In the empirical analysis, we use MRIO tables data from the World Input Output Database (WIOD) (see WIOD, 2012 and Dietzenbacher et al., 2013 for more information on methodology). This database offers economic information for 35 economic sectors in 40 countries and a region called Rest of the World (ROW) from 1995 to 2009. We have chosen 1995 and 2009 to be able to compare and explain trends on water resources in the largest possible time horizon. IO tables are expressed in current monetary units and in previous year prices. Thus, in order to accurately make the comparison between these two years, it was necessary to deflate 2009 data, i.e., we express 2009 MRIO table in constant 1995 prices. Since the new data does not fulfill the requirement of equal sum of totals in rows and columns, once we deflate 2009 economic data, the next step involves applying a GRAS adjustment; a generalization of RAS proposed by Junius and Oosterhaven (2003) and improved by Lenzen et al. (2007). This approach allows working with matrixes containing positive and negative values, so that adjustment it is possible despite negative values. Moreover, we use WIOD data on water consumption distinguishing its color (green, blue and grey) and sector. In the case of green water, WIOD only offers information of the direct consumption of water in one sector, agriculture[12].

As we previously said, countries are classified depending on their level of per capita income into two groups, low-middle income countries and high income countries. This has been done following the criteria of the World Bank (2013). Therefore, we consider as high income countries those who have a per capita gross national income equal or more than $12,476 (Table 3.1). On the contrary, low-middle income areas are under $12,476.

Table 3.1: Countries classification according the level of per capita income

High income countries		Low-middle income Countries
Australia	Ireland	Bulgaria
Austria	Italy	Brazil
Belgium	Japan	China
Canada	Korea	Indonesia
Cyprus	Luxembourg	India
Czech Republic	Malta	Lithuania
Germany	Netherlands	Latvia
Denmark	Poland	Mexico
Spain	Portugal	Romania
Estonia	Slovak Republic	Russian Federation
Finland	Slovenia	Turkey
France	Sweden	ROW
Great Britain	Taiwan	
Greece	United States	
Hungary		

4. Results

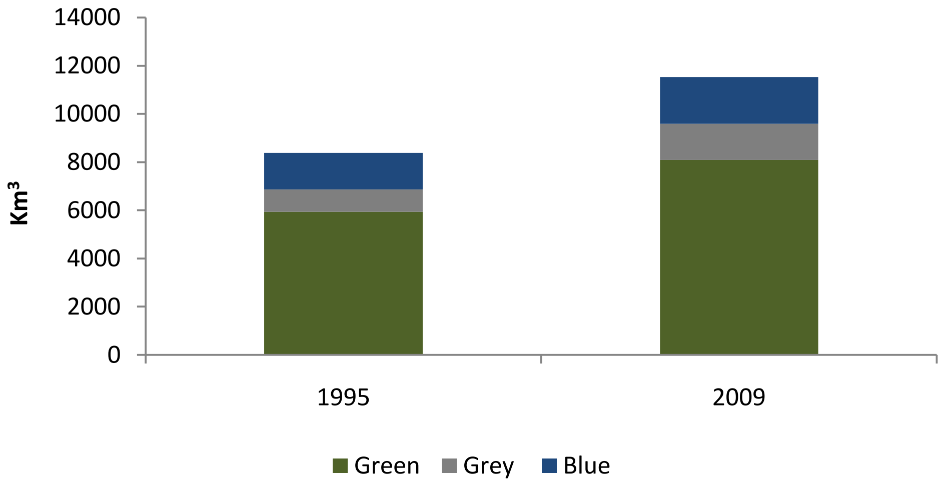
4.1. Water consumption trends: 1995-2009

From 1995 to 2009, water consumption in the world went from 8,383 km^3 to 11,536 km^3, representing a 3,152 km^3 global increase (Figure 3.1) and growing at 2.2% every year on average. Despite green water experienced the highest absolute increase,

[12] Nevertheless green water represents about 78% of global crop production water footprint (Mekonnen and Hoekstra, 2011) and 87.2% of global animal production water footprint (Mekonnen and Hoekstra, 2012).

accounting for 68% of total rise, grey water showed the most vigorous growth, rising at 3.2% yearly. In fact, whereas both green and blue water seem to slightly lose weight during these years, grey water went from being 11% of total water consumption in 1995 to 13% in 2009. Furthermore, blue water displays the smoothest rise, showing an increase of 426 km^3 and annually growing at 1.7%.

Figure 3.1: Global absolute increase in water consumption: 1995-2009

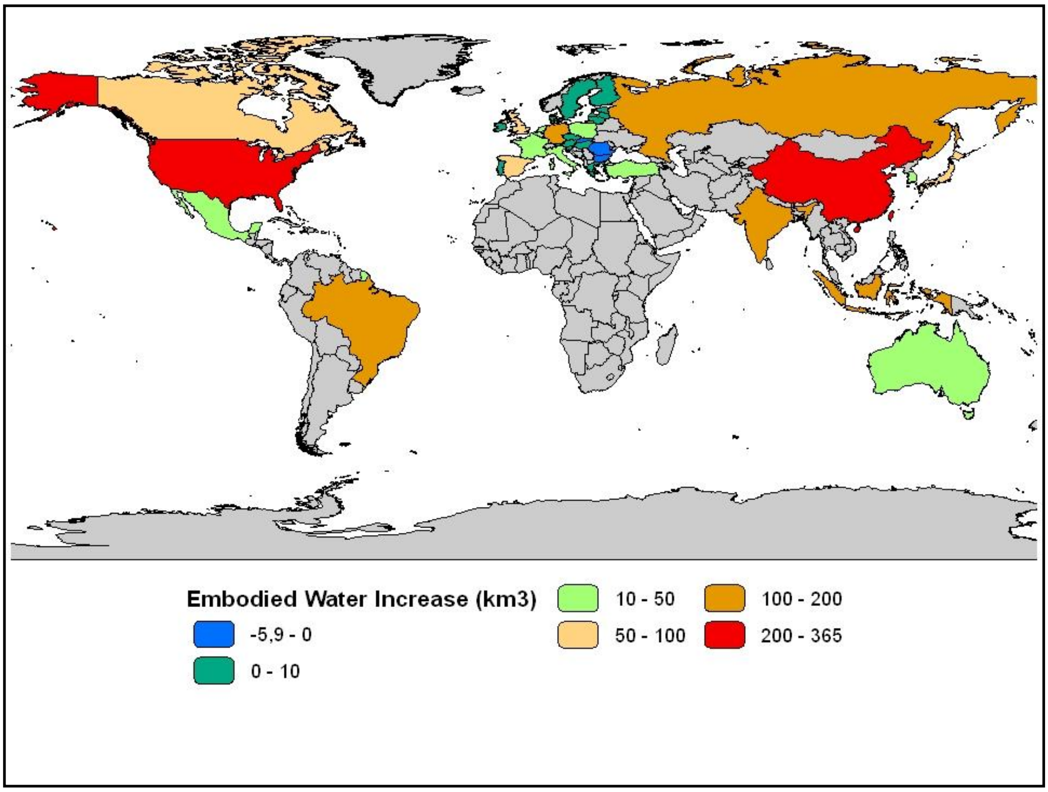


In 1995, low income areas represented 70% of embodied water consumption and 77% of direct water consumption. These countries consumed their water resources to meet domestic final demands but also to satisfy foreign needs. In fact, exports of low income areas represented about 65% on total exports, opposite to high income countries that had a share of 35%. Furthermore, low income virtual water imports only accounted for 22% over total water imports. This pattern was quite similar in 2009. Low income countries still represented 70% of embodied water consumption in world but 80% of direct water consumption. Nevertheless the share of low income countries on both global virtual water imports and exports increased, as a result of the growing integration of emerging countries in international markets. Actually, virtual water imports of developing nations reached a share of 30% over global imports. Nonetheless, the rise in the contribution of low-middle income areas exports to global exports was even higher, going from 65% in 1995 to 76% in 2009. This was mainly due to the growing participation of China in global virtual water exports.

If we proceed with the analysis of trends from the country perspective, it is possible to differentiate not only those places with the largest direct consumptive use of water, but also the water effectively embodied in their final demand, regardless where water resources come from. Moreover, it allows us to classify countries depending on their virtual water trade balance. On the whole, most countries display growing water consumption, with the exception of Bulgaria, Romania or Slovak Republic; where total water consumption tended to decline. Despite grey water displayed a growing trend during these years, blue and green water consumption were reduced.

On the other hand, large increases in embodied and direct water consumption are shown in China, USA, Brazil, India or Germany (Figure 3.2). China and USA contribute in a similar way to the rise of total embodied water; each one making an approximate 11% contribution. However the pattern is notably different. If we look at direct water consumption, China contributes about 20% to global increase whereas USA only 6%. This can be explained by the great growth of virtual water imports in USA and the huge rise of virtual water exports in China.

Figure 3.2: Embodied water change by countries: 1995-2009



Looking at the colors of water, the picture is somehow different. It is important to highlight the Chinese blue water consumption increase, but particularly the outstanding rise in grey water consumption. During these years, the Asiatic Dragon contributed by 26% to the total increase in embodied grey water in the world and by 52% to the growth of direct grey water. In fact, more than 58% of the rise of grey virtual water exports in the world was boosted by China. It is important to stress that, in China as well as in some other east European countries like Romania or Bulgaria, the increase in grey water was even greater than the increase in green water. In this respect, it would be important to identify the industries responsible for the great increase in grey water consumption. Agriculture, hunting, forestry and fishing together with basic metals and fabricated metal and chemicals and chemical products appear as the main contributors to this increase. The Chinese agricultural sector used large volumes of water to supply its own domestic sectors, but also exported water to Germany, USA and ROW. Grey water embodied in the metal sector and chemicals was used by the Chinese construction and also exported mainly to USA and ROW.

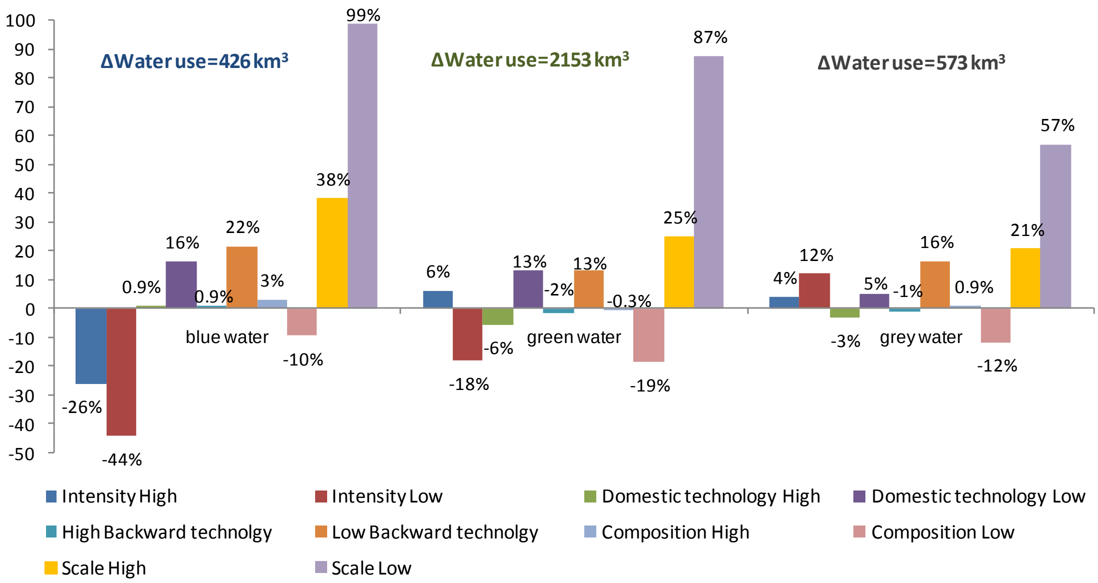
As we have seen, USA stands out as the main importer of water; it shows the highest increases for green and grey water. These growing volumes of water seem to come from China, Canada, Mexico or ROW. India, a developing country as China, depicts a similar path. Its direct consumptive use of water entails 8% of global increase and taking into account direct and indirect consumptive uses, it represented about 6% of embodied water in the world, difference mainly explained by virtual water exports. In the case of grey water India's contribution is even greater and exports went basically from agriculture in India to agriculture in European countries such as Germany or United Kingdom. The former case is quite different to the picture of Brazil, where the most important shares were due to blue water; more than 8% of the rise in blue water consumption was triggered by this American country, being the growth of domestic consumptive use of especial relevance. The sectors driving the rise of Brazilian water consumption were the electricity, gas and water supply industries. This sector was a supplier of blue water for the German's food, beverages, tobacco or electricity, gas and water supply industries in Germany. Turning to the European continent, two areas should be highlighted, Russia and Germany. The former accounted for 4.5% of the global water consumption growth. In this country green water appears to be the most dynamic, showing the highest increase. Agriculture was the most intensive sector concerning both direct and embodied water in Russia, it consumed water provided by China, Brazil and ROW, but also exported large volumes of green water embodied in agricultural, hunting, forestry and fishing sectors to China, Japan, Korea, USA or ROW. Between 1995 and 2009 about 10% of global virtual water imports rise was driven by Germany, which got water from China, ROW, India or Poland. Despite showing a lower share on global water consumption increase than other countries (3.5%), the importance of its virtual water imports was notable.

4.2. Factors contributing to water consumption changes

Once we have obtained the main patterns for water consumption, the next step involves applying the SDA to study the most important factors influencing changes in embodied water. It seems quite clear that economic growth triggered the global rise in water consumption during these years. Thus, with this approach we will obtain the weight that some of the most determinant elements associated with growth such as demand changes, technology developments or intensity of production had on these trends. Results for green, blue and grey water are shown in Tables 3.2, 3.3 and 3.4 respectively. If Δembodied water (km^3) >0, i.e., if the volume of water consumption increases, those effects with positive sign contribute to the increase seen for water consumption. On the contrary, if Δembodied water (km^3) <0, that is, if a water consumption decline happened, a negative sign on a component indicates that this factor is responsible for water consumption increase. An effect encourages water stabilization or decline if, and only if, it exhibits a positive sign. Furthermore, if changes in water consumption are insignificant, percentages will shoot up due to simple calculations.

There is a wide number of studies explaining that when a country is immerse in a process of development, the impact on natural resources shows a growing trajectory, however this trend becomes smoother or even reverses when the nation has reached a considerable level of development or per capita income (Gloklany, 2002; Gales et al., 2007; Duarte et al., 2013). For that reason, we would like to find general trends for the two groups in which we have divided the sample regarding the factors affecting water resources.

Figure 3.3: Factors contributing to global water consumption increase from 1995 to 2009



The global increase of 3,152 km^3 in total consumption was mostly driven by the rise of demand that was particularly intense in the case of low income countries. Concretely, the growth of scale of these areas below $12,476 contributed 84% to the increase in water consumption, opposite to high income countries, whose growing demands involved a share of 26%. Besides, technological changes in low income countries seem to trigger water consumption, making a contribution higher than 10%. On the other hand, two factors appear to slow down the growing trend, intensity and composition changes in low-middle income countries. That is, the volume of water consumption by unit of production experienced a reduction in low income areas throughout these years showing a value of -16%, as happens with composition effect that tends to indicate that demands in developing areas have turned to products that relatively require less water. This seems to be in line with the results obtained by Duarte et al. (2014). They identify growing demands as a result of population growth, economic development and the intensification of agriculture as the main drivers of global water use increase in the twentieth century. In addition, efficiency improvements or structural change were responsible from a slight slowdown in water withdrawal taken place in the most developed areas from 1980.

If we look at Figure 3.3 that displays the SDA results for the three colors of water, the picture is quite different. Changes in the volume of demand are the most important for all colors of water. Nevertheless, it shows the highest share for blue water, with 99% and 38% for low and high income countries respectively. The contribution of scale effect to changes in grey water consumption is less important, being 57% for low and 21% for high income areas. Scale effect was mostly associated with the demand increase in USA, China or India. Agriculture, food industry and electricity were the sectors behind the increase in water consumption. The Chinese construction industry also contributed to the scale effect. Compositional changes have less impact in high income areas, displaying negligible shares; but have a noteworthy effect in low and middle income areas, where water consumption moderation for all colors of water is trigerred. There exist remarkable differences for intensity effect. Whereas there is a clear tendency towards the reduction of intensity in blue water in both high and low income regions, the pattern is opposite for grey water. That is, the consumption of blue water per unit produced decreased from 1995 to 2009, preventing a higher increase in blue water consumption, effect of special importance in developing areas accounting for -44%. In contrast, the global production tends to be dirtier, in the sense that grey water intensity variations encourage the increase in grey water consumption, especially in low income areas with weights of 12%. For green water, intensity effect in high income areas triggers water consumption increase, while it considerably promotes deceleration of water consumption in low income areas. Finally, there is a clear path for technology effect. On the one hand, the production of inputs in low income areas contributes to the increase in water consumption, especially in the case of blue water. This can be explained by technological changes in the food, textile, electricity, construction or mining sectors of China, India or Russia. On the other hand, the inputs produced in developed regions tend to slightly moderate water consumption growth, which can be related to technological advances chiefly in the construction and food industries of countries like USA or Sweden. This means that whereas production technologies in developed regions did not experienced important developments, they notably changed in emerging areas. In fact, our results indicate that production processes in low-middle income areas tend to use more water intensive inputs. It involved not only an important growth in global water consumption but also an increase in low income areas consumptive use and in the embodied water of those countries that bought manufactured goods from developing regions.

It seems quite clear that scale effect acts as an essential factor to explain the evolution of water consumption in both high and low income areas. Only Japan and Korea behave the opposite, with an important decline of the scale effect of food, electricity and construction sectors. In most developed areas the increase in their water intensities means a growth of green and grey water consumption, but a decrease of blue water consumption. In the case of water intensities for low income regions, on the whole grey water intensities boost water consumption; but green and blue avoid a greater growth. Imported technology from low income areas is another element involving water consumption increase, meaning that the inputs coming from developing countries were not produced in a water efficient way and therefore involve a growing water consumption. This is the case of water embodied in products manufactured in the textile, food, construction or defense sectors that are exported from China to USA, Germany or Japan. On the contrary, inputs produced in high income areas tend to softly slow down green and grey water consumption. In this regard, it would be important to highlight important flows that contribute to the slowdown of water consumption as those going from USA to Ireland or from Sweden to Denmark both related to food and construction industries. Eventually, as for composition effect, demand changes towards more water consuming products can be found in high income areas for blue and grey water. The compositional change in low income regions acts in the opposite direction.

At the country level (Tables 3.2, 3.3 and 3.4), it is possible to analyze the most significant areas in terms of water consumption changes or the most outstanding effects. As we previously observed, the most important increase in embodied water took place in China. It was mainly driven by domestic growing demands. While compositional changes reduced pressures on water resources; the growth on the scale was so strong that outbalanced the negative sign of composition effect. Growing demands of agricultural goods represented more than 40% of scale effect in China. Domestic technological changes as well as imported technology from low income areas also boosted water consumption. The former effect was mostly associated with technological changes in agriculture, construction and food industry. On the contrary, although green and blue water intensities seem to decrease notably, it was not enough to counteract the great demand changes.

A developed country like USA also shows an increase in water consumption, which again was mostly driven by domestic and foreign demand growth as well as by compositional changes. Food industry and electricity, gas and water supply sectors were behind this demand boost. As an example, in the case of grey water, about 78.5% of this growth was due to scale effect and 6% to composition effect. Moreover, despite remarkable changes in domestic inputs of hotel and restaurants or real estate activities as well as variations of high income water intensities alleviated pressures on water resources, particularly on blue water; changes on imported technology from low income countries increased water consumption. USA imported water embodied in textile, construction or defense goods produced in China that made its vertically integrated water consumption to rise.

Two industrialized countries such as Japan and Korea deserve special attention. Although water consumption grew, scale effect shows negative sign. In the former, growing imports of inputs from low income areas as well as variations in demand composition and changes in low income intensities would be responsible for the growth of embodied water. On the contrary, in the latter the composition effect is also negative. These countries imported large volumes of water embodied in textile, food or construction products from China.

Finally, it is worth explaining that in those countries like Romania or Bulgaria where water consumption declined from 1995 to 2009, the contraction of the intensities of green and blue products in low income countries or compositional changes of demand were the main determinants to explain decreasing water consumption trends. This was only true for green and blue water, since grey water keeps on growing mainly because of the demands for commodities produced in agriculture, food industry or pulp, paper, paper, printing and publishing sectors that embody this kind of water.

Table 3.2: SDA for embodied green water changes: 1995-2009

	ΔEW (10^6 m^3)	IEH	IEL	DTE	BTEH	BTEL	CE	SE
				High income countries				
Australia	28	13.8	-3.3	-8.9	-1.8	9.3	-24.7	115.6
Austria	6	4.4	-2.3	-6.5	6.8	21.7	14.4	61.6
Belgium	17	7.8	1.5	-0.9	-6.4	25.7	37.2	35.2
Canada	31	1.8	-5.9	-2.0	-2.7	20.2	-32.7	121.2
Cyprus	1	-53.3	-8.8	22.8	-25.8	63.6	9.6	92.0
Czech Republic	1	-189.3	-4.9	-172.1	-44.4	-44.9	-384.5	940.0
Germany	70	20.0	-1.6	-11.1	-2.3	40.1	31.3	23.6
Denmark	4	27.4	3.6	-8.2	-3.3	23.9	-29.5	86.1
Spain	37	52.9	0.4	-25.6	-11.8	13.2	-23.2	94.2
Estonia	1	41.1	5.5	-71.0	-4.6	18.3	-134.6	245.3
Finland	5	14.7	0.3	5.1	-3.4	31.2	-12.6	64.7
France	23	98.9	0.2	-33.5	-12.7	22.2	-106.8	131.8
Great Britain	37	5.1	-5.7	-10.2	-7.7	38.4	12.6	67.5
Greece	1	-167.5	-11.8	-273.3	-32.6	132.8	-33.5	485.8
Hungary	1	841.7	-6.5	-1376.5	14.4	-54.4	-867.6	1548.9
Ireland	3	23.5	-7.2	-12.9	-7.0	22.2	-20.5	101.9
Italy	20	-50.7	-5.6	-22.4	-23.3	26.5	-37.0	212.4
Japan	29	9.0	-30.6	-0.1	-5.1	98.0	57.6	-28.8
Korea	6	82.0	-25.9	65.2	-51.8	169.0	-103.3	-35.1
Luxembourg	0	18.6	1.6	-2.7	-7.8	40.3	-33.6	83.5
Malta	0	-5.8	-2.1	0.5	-25.1	33.8	28.7	70.0
Netherlands	19	8.8	1.6	-1.7	-7.7	40.5	0.3	58.2
Poland	32	93.5	-0.1	-5.1	-0.5	3.2	-21.8	30.8
Portugal	0	-287.1	81.5	-535.8	-205.8	-164.0	-2072.7	3284.0
Slovak Republic	-1	120.1	-1.1	84.2	17.3	-4.8	320.8	-436.5
Slovenia	1	-17.4	5.3	-4.7	-34.1	8.9	5.0	137.0
Sweden	5	24.5	3.5	-3.8	-7.9	25.8	-11.9	69.9
Taiwan	8	176.1	-4.0	3.7	-18.7	46.6	-34.5	-69.3
United States	243	5.5	-5.7	-29.4	-4.0	15.7	15.3	102.6
High income countries	627	19.6	-4.9	-19.8	-6.1	26.5	-1.1	85.8
				Low income countries				
Bulgaria	-2	-5.2	29.8	177.1	-0.7	-23.8	545.7	-622.9
Brazil	140	0.1	26.6	-11.4	-0.4	2.5	-15.7	98.3
China	141	0.5	-202.9	79.5	-0.9	9.9	-48.2	262.1
Indonesia	162	0.2	0.7	21.7	0.2	3.5	-29.1	102.9
India	100	0.1	-235.2	47.9	-0.1	4.6	8.4	274.3
Lithuania	1	14.5	136.4	-197.6	-5.3	-9.4	-335.1	496.4
Latvia	2	4.3	12.4	0.0	-2.9	3.4	-99.7	182.6
Mexico	14	2.6	-225.3	-9.9	7.8	17.7	-121.9	428.9
Romania	-8	-2.8	276.2	-9.2	-1.1	-5.8	224.5	-381.9
Russian Federation	122	0.8	-13.7	0.7	-0.7	7.8	-63.2	168.2
Turkey	13	1.2	-210.7	130.4	2.2	42.7	-69.5	203.7
ROW	842	0.8	26.0	11.1	0.0	8.3	-16.3	70.2
Low income countries	1,527	0.7	-23.6	18.6	-0.1	7.6	-26.5	123.4
World	2,153	6.2	-18.2	7.4	-1.9	13.1	-19.1	112.5

EW: Embodied water, IEH: intensity effect high, IEL: intensity effect low, DTE: Domestic technology effect, BTEH: Backward technology effect from high, BTEH: Backward technology effect from low, CE: Composition effect,SE: Scale effect.

Table 3.3: SDA for embodied blue water changes: 1995-2009

	ΔEW (10^6 m^3)	IEH	IEL	DTE	BTEH	BTEL	CE	SE
				High income countries				
Australia	2.1	-216.0	-8.5	-1.1	-3.7	44.0	-1.0	286.3
Austria	1.3	-96.8	-33.6	12.3	28.5	44.9	-57.4	202.1
Belgium	4.0	-10.2	-10.1	-0.5	11.7	34.3	37.6	37.3
Canada	10.0	-168.9	-4.3	26.6	2.4	18.1	-37.5	263.5
Cyprus	0.0	887.8	127.2	-260.1	46.7	-172.7	89.3	-618.3
Czech Republic	0.5	-114.1	-37.2	-16.8	30.2	12.9	0.0	225.1
Germany	15.3	-22.5	-20.1	-0.3	18.6	53.2	45.3	25.8
Denmark	0.8	-19.7	-22.5	-2.0	12.7	49.2	-8.4	90.8
Spain	8.1	37.1	-8.6	-31.2	-5.1	16.9	-38.2	129.2
Estonia	0.1	-17.5	-81.7	-2.8	-7.2	64.5	-55.1	199.8
Finland	0.7	-169.8	-48.7	31.0	14.2	58.0	34.4	180.9
France	1.1	-394.5	-117.7	84.3	10.2	204.8	-526.1	839.0
Great Britain	8.0	-17.5	-17.0	-0.6	-1.3	52.4	15.9	68.0
Greece	0.3	-364.2	-131.6	-401.6	7.5	244.9	-75.9	821.0
Hungary	0.4	-60.6	-74.4	-24.0	39.9	27.2	3.5	188.3
Ireland	0.8	-5.8	-13.2	-7.2	12.5	28.0	8.4	77.2
Italy	9.0	-76.5	-33.0	25.7	-5.8	47.9	-1.4	143.2
Japan	8.0	-37.7	-30.8	10.5	-3.1	137.0	54.2	-30.0
Korea	2.3	3.5	-18.7	15.0	-13.9	138.1	-5.7	-18.2
Luxembourg	0.0	-1090.8	-547.9	-34.2	721.8	-727.3	-3505.9	5284.2
Malta	0.0	-45.0	-27.5	0.8	-2.2	63.8	30.4	79.7
Netherlands	3.1	-9.5	-16.8	-1.2	1.2	53.4	-1.9	74.7
Poland	1.1	-30.5	-31.1	-4.8	12.7	42.7	-21.9	132.8
Portugal	0.2	-427.2	-66.7	-300.8	-4.0	74.7	-629.7	1453.7
Slovak Republic	-0.1	3383.8	136.7	-1820.0	61.5	10.3	-497.5	-1174.9
Slovenia	0.5	-70.2	-12.5	22.4	8.8	19.4	25.9	106.2
Sweden	0.4	-1748.7	-55.3	392.1	21.4	139.5	380.4	970.6
Taiwan	0.8	208.4	-17.2	-18.1	-17.6	126.8	-62.2	-120.1
United States	34.1	-156.0	-10.9	-6.5	-3.3	38.6	37.2	201.0
High income countries	112.9	-94.3	-18.3	3.5	1.7	51.6	11.6	144.2
				Low income countries				
Bulgaria	0.4	-7.8	-133.3	-0.1	7.8	40.1	-121.3	314.6
Brazil	34.7	-0.8	-20.5	26.6	-0.2	3.7	2.6	88.7
China	73.4	-0.6	-50.1	29.6	0.2	3.2	-26.6	144.4
Indonesia	8.2	-2.5	-38.1	14.2	-0.1	18.7	-11.4	119.2
India	45.4	-0.3	-124.0	17.0	0.0	2.2	0.6	204.4
Lithuania	0.1	-15.9	-341.1	-38.0	4.7	78.8	-143.1	554.5
Latvia	0.1	-10.3	-1550.9	425.4	-14.2	8.8	254.3	986.9
Mexico	3.5	-12.2	-227.8	25.4	8.4	23.5	-58.1	340.8
Romania	-0.2	35.5	3055.7	-772.0	-41.4	-33.1	-175.8	-1969.0
Russian Federation	4.1	-4.9	-928.8	313.9	0.4	40.2	-55.7	734.9
Turkey	2.9	-4.4	-306.3	100.5	5.8	67.8	-18.1	254.6
ROW	140.9	-2.2	-1.8	8.1	1.2	16.3	-12.0	90.4
Low income countries	313.5	-1.6	-53.8	22.2	0.7	10.8	-13.1	134.7
World	426.4	-26.1	-44.4	17.3	1.0	21.6	-6.6	137.2

EW: Embodied water, IEH: intensity effect high, IEL: intensity effect low, DTE: Domestic technology effect, BTEH: Backward technology effect from high, BTEH: Backward technology effect from low, CE: Composition effect,SE: Scale effect.

Table 3.4: SDA for embodied grey water changes: 1995-2009

	ΔEW (10^6 m^3)	IEH	IEL	DTE	BTEH	BTEL	CE	SE
				High income countries				
Australia	6.1	5.8	19.3	-2.4	-2.1	22.4	-4.6	61.7
Austria	2.5	4.7	8.4	-2.4	4.2	32.0	20.4	32.7
Belgium	3.0	10.8	8.1	-1.7	-5.8	34.2	13.0	41.3
Canada	12.1	14.1	10.2	0.5	0.3	16.9	-8.7	66.7
Cyprus	0.1	-18.0	13.2	7.6	-21.6	55.4	-16.2	79.6
Czech Republic	1.0	-15.5	9.3	-35.9	-6.7	15.1	-65.8	199.6
Germany	23.5	18.0	14.5	-9.3	0.5	33.8	25.6	17.0
Denmark	1.3	21.6	18.3	-4.6	-1.8	28.1	-17.6	56.0
Spain	7.3	23.5	11.8	-17.8	-9.5	23.4	-7.8	76.5
Estonia	0.1	51.6	1.1	-29.6	-3.4	1.9	-61.3	139.7
Finland	1.1	10.7	8.6	-1.2	-3.6	31.6	10.7	43.1
France	9.7	45.0	14.6	-12.5	-4.4	23.5	-28.2	62.0
Great Britain	10.8	5.2	16.1	-7.9	-3.9	31.9	7.9	50.7
Greece	1.1	-15.2	-21.0	-33.8	-8.5	74.2	4.9	99.4
Hungary	-0.1	-223.3	-41.1	2,605.1	-47.9	-140.2	1,788.1	-3,840.7
Ireland	0.8	5.4	9.8	-3.2	-5.6	19.4	4.4	69.9
Italy	8.6	-24.1	7.4	-5.4	-8.5	34.4	-9.5	105.6
Japan	21.8	0.8	30.8	3.0	-0.2	56.8	17.7	-8.8
Korea	5.5	15.2	31.1	7.6	-7.4	66.8	-5.3	-7.9
Luxembourg	0.2	12.1	9.5	-1.5	-2.8	38.2	-7.2	51.6
Malta	0.1	-0.1	18.4	0.2	-10.3	29.5	24.1	38.2
Netherlands	4.4	8.8	20.2	-1.3	-6.0	29.5	2.7	46.1
Poland	8.1	92.3	1.6	-11.3	0.0	5.5	-21.7	33.6
Portugal	0.6	-22.3	18.8	-30.2	-16.3	38.9	-71.9	183.0
Slovak Republic	0.1	-67.5	18.8	-102.9	-28.5	38.7	-358.4	599.7
Slovenia	0.2	-38.7	12.2	-17.4	-24.4	29.0	-39.2	178.5
Sweden	1.7	18.5	17.1	-2.3	-4.6	31.9	-4.3	43.6
Taiwan	4.5	103.5	19.8	-9.2	-4.9	31.9	-15.5	-25.6
United States	79.4	-6.6	17.0	-11.7	-2.9	19.4	6.3	78.5
High income countries	215.6	9.2	16.5	-8.7	-2.8	28.4	2.5	54.9
				Low income countries				
Bulgaria	0.1	41.1	-3,991.5	1,829.7	21.6	79.7	-1,037.7	3,157.1
Brazil	11.4	0.5	7.0	2.2	-0.6	16.5	-2.9	77.3
China	148.3	0.5	15.1	8.7	-0.2	1.0	-27.0	101.8
Indonesia	18.3	0.7	7.9	13.5	-0.1	8.6	-9.3	78.7
India	37.2	0.1	-29.2	7.5	-0.1	3.6	-11.0	129.1
Lithuania	0.2	20.9	23.8	-22.4	-4.6	-8.0	-45.1	135.4
Latvia	0.3	12.2	12.6	-0.1	-0.9	-1.7	-89.9	167.7
Mexico	5.1	-1.9	-46.5	-5.6	5.8	20.8	-40.5	167.8
Romania	2.1	2.0	-30.5	-16.7	2.7	19.9	-82.1	204.8
Russian Federation	19.0	2.1	-23.3	24.0	-1.0	6.3	-54.3	146.2
Turkey	4.4	2.3	-6.8	26.7	1.7	33.6	-44.1	86.6
ROW	110.7	1.6	28.4	2.2	0.2	20.2	-3.3	50.5
Low income countries	357.1	1.0	9.3	7.8	0.0	9.2	-18.8	91.5
World	572.7	4.1	12.0	1.6	-1.0	16.4	-10.8	77.7

EW: Embodied water, IEH: intensity effect high, IEL: intensity effect low, DTE: Domestic technology effect, BTEH: Backward technology effect from high, BTEH: Backward technology effect from low, CE: Composition effect,SE: Scale effect.

5. Conclusion

Water consumption experienced a great increase in the world during the period 1995-2009. Only one factor appears as the main determinant, worldwide commodities demand. In the current international context, industrialized countries have reached high levels of development that involve strong pressures not only on their own natural resources, but also on foreign resources from those countries they have intense commercial relationships with. Furthermore, developing regions are going through rapid and profound processes of economic and demographic growth. Therefore, the growing demands of products that embody large volumes of water have lead to a growing consumption of water resources at a global level. Some developments like technological improvements that raise water efficiency together with water intensity reductions are partly making up for the upsurge of demand in the case of green and blue water. Nevertheless, grey water, one of the main indicators of ground and surface sources of pollution shows relevant growth rates, without any effect pointing at a slow down on its growing path.

It seems quite clear that during the last years the greatest pressures have mostly happened in low and middle income countries, with China being an outstanding country, particularly regarding grey water. However, the most developed areas in the world have also increased their pressure on water from 1995 to 2009. This is the case of United States, where although technological changes have exerted a notable impact to soften growing trends, both domestic demands and imports would be responsible for the great rise in water consumption.

Therefore, taking into account the consumption of water at a global level, we observe that pressures on water resources have increased all over the world, being the situation of growing concern for grey water, since there are no factors that seem to slow down the growing trend. Accordingly, our findings seem to go in line with the warnings of international agencies as United Nations that named this phenomenon as "global water scarcity". This global phenomena that tends to exacerbate in developing regions, poses a social and environmental challenge that requires urgent managerial, institutional and technological actions to alleviate water pressures in the near future.

International agreements to encourage efficiency improvements and to develop water saving programs in production and consumption would require an international and sectorial monitoring of water pressures in the origin and the final destination of products. The analysis presented is a first approximation to the evaluation of the role of countries and production processes in the growing pressures on water resources at the global level.

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CHAPTER 4.

THE WATER FOOTPRINT OF THE SPANISH AGRICULTURAL SECTOR: 1860-2010

1. Introduction

Modern economic growth and the changes associated with it (income and population growth, urbanization or structural change) profoundly modified the relationship of economies with natural resources. On the one hand, the energy transition, with the use of coal first and oil after, multiplied the productivity of economic activities. In this context, mechanization was crucial for the development of industrialization (Allen, 2009; Wrigley, 1988; Stern, 2011; Stern and Kander, 2012). But on the other hand, the intense growth has generated severe impacts on the environment. An extensive literature has addressed these impacts from a long term perspective. The main topics have been the energy transition (Gales et al., 2007; Kander and Lindmark, 2004;Rubio, 2005), the atmospheric pollution (McNeill, 2000; Krausmann et al., 2008; Stern, 2005; Stern and Kaufmann, 1996), forest resources (Iriarte-Goñi and Ayuda, 2008 and 2012), the effects of land use on ecological biomass flows (Krausmann et al., 2012; Kastner, 2009; Kohlheb and Krausmann, 2009; Krausmann, 2001; Musel, 2009; Schwarzlmüller, 2009) or materials use (Krausmann et al., 2009). This significant process of parallel economic and environmental transformations has been conceptualized as a change in the social metabolism of economies (Fischer-Kowalski and Haberl, 1993; Krausmann, 2001; Krausmann and Haberl, 2002; Krausmann et al., 2003).

Use and consumption of water, has also been seriously influenced by modern economic growth (Duarte et al., 2013 and 2014a). In fact, the scarce historical data available seem to point at huge increases in water withdrawal from the ninetieth century. McNeill (2000) indicates that in 2000 water use was sixteen times higher than in 1800 and according to L'Vovich and White (1990) while global water withdrawals remained stable for centuries, these increased thirty-five-fold from 1687 to 1987. The use of water has grown principally because of the formidable expansion of agriculture experienced in the last two centuries that allowed achieving food security for large populations but also meant the use of more land as well as the need to undertake important waterworks for the extension of irrigation in arid or semi-arid regions. Worldwide irrigation involves over 18% of cultivated land and provides between 30% and 40% of gross agricultural production; figures that tend to be higher in arid and semi-arid regions (Federico, 2005). Irrigation has been utilized, especially in arid countries, as a way to substantially increase agricultural production, to ensure its regularity and allow land use changes. Recent estimates for the case of Europe during the second half of the twentieth century show a significant influence on the increase in labour and total factor productivity (Martín-Retortillo and Pinilla, 2012 and 2013).

Spain, as a semiarid developed country that went through a long term process of industrialization, has also increased its water withdrawals affecting its landscape. Agriculture went from being the most representative sector in the Spanish economic structure in the ninetieth century and the beginning of the twentieth century to be negligible nowadays. In fact, according to Prados de la Escosura (2003) agriculture represented 39.2% of GDP and 63.5% of employment in the period 1855-1866. It slightly decreased by 1901-1913 being 31% of GDP and 58.7% of employment and fell down in the period 1992-2000 accounting for 4.5% of GDP and 7.8% of employment. However, its impact concerning the use of natural resources is notable. In this regard, Spain stands out as the second country in the ranking of harvested land (24,889,520 ha) in the EU (INE, 2009). Despite irrigation occupies only 13% of this area, it involves more than 50% of final production, producing on average six-fold greater than a rainfed hectare of land and an income four times higher. Moreover, nowadays irrigation is the main user of water entailing 68% of total water withdrawal (MAGRAMA, 2013).

The development of agricultural production between 1850 and 2000, the causes of its growth and the characteristics of its transformation have been widely studied by economic historians (GEHR, 1983; Garrabou and Sanz, 1985; Jiménez Blanco, 1986; Barciela and García, 1986; Simpson, 1995; Gallego, 2001; Clar and Pinilla, 2009; Clar, 2008). Similarly, literature has also studied the long term environmental impacts of this agricultural growth process during the last years (González de Molina, 2002; Cussó et al., 2006a and 2006b; Marull et al., 2008; Guzmán Casado and González de Molina, 2006; Infante-Amate, 2102a and 2012b; Infante-Amate and González de Molina, 2013; Infante-Amate et al., 2013; Schwarzlmüller, 2009; Tello and Ostos, 2011; González de Molina, 2010; Carpintero and Naredo, 2006).

Irrigation has also traditionally attracted attention of many researchers, although the emphasis was on the development of hydraulic works and the administration and management of water[13]. The study of irrigation agriculture in the long term has also been widely analyzed, particularly from a regional and basin perspective (Garrabou and Naredo, 1999; Pinilla, 2008).

However as far as we are concerned, so far there are no other works trying to examine the impact that the Spanish agricultural sector development had on water consumption as well as on the extension of irrigation in the long term. Hence, the objective of this article is to analyse the effect of the expansion of the agricultural sector and the consequences of the increase in water consumption. Especially, we would like to assess the impact of the growing requirements for water on the need to construct infrastructure for irrigation during the years 1860-2010. The period considered is crucial for the study of water in Spain, a semi-arid country with significant cyclical water shortages. Thus, it begins in 1860, when the agricultural production in Spain was expanding as a result of both domestic and foreign demand, which grew due to the integration process of Spanish agriculture in international markets. During the twentieth century the sector experienced important changes associated with technological development. The Civil war and the autarkic policy carried out during the first decades of Franco's dictatorship; put a halt to this process, which would be resumed by the mid-fifties. From this moment an intense modernization process associated with production and productivity growth took place, entailing the end of traditional agriculture in Spain. Moreover, technical advances from the beginning of the twentieth century allowed constructing hydraulic infrastructures that went from being paid by private investors to be mostly funded by the government. The development of irrigation was essential to set up an intensive agriculture with a marked exporting character.

To go further into these issues we will obtain the water embodied or virtual water of Spanish production, using specific water product coefficients from Mekonnen and Hoekstra (2011, 2012) and agricultural production data from "Anuario Estadístico de la

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[13]See for instance Fernández-Clemente (2000), Herranz (2004), Gil-Olcina and Morales-Gil (1992), Barciela and López (2000)

Producción Agraria" (MAGRAMA, 1904-2010). First introduced by Allan (1997), virtual water is defined as the volume of water required for the production of a commodity (Zimmer and Renault, 2003; Merrett, 2003; Hoekstra and Hung, 2005; Yang et. al, 2007). Many current studies on water resources focus on agricultural and food products since, as in the case of Spain, the production of these commodities is the main water user in many regions(Chapagain and Hoekstra, 2011; Hoekstra and Mekonnen, 2012).Thus, following the bottom-up approach proposed by Hoekstra and Hung (2005) for virtual water trade, we obtain the virtual water embodied on Spanish production, studying not only its trajectory in the long run, but also the possible changes on its composition. We analyse both green water -rainwater evaporated as a result of the production of a commodity- and blue water -surface or groundwater evaporated during a production process- (Hoekstra and Chapagain, 2008). Although they are interrelated in the hydrological system, the features and implications of using each colour of water are quite different. On the one hand, blue water is said to have higher opportunity costs than green water, given that it can be reallocated among the different users, while green water cannot be easily reallocated (Yang et. al., 2007). Furthermore, the increase in the use of blue water has great economic implications, since it demands considerable investments of capital, both public and private.

Moreover, in this paper we obtain and calculate the contribution of the factors that may lie behind the changes in the volume of water embodied in production. To that aim, a Decomposition Analysis is applied for each period, identifying and estimating the effect that changes in the volume of production (scale effect), variations in its composition (composition effect) and yield improvements (intensity effect) had in the volume of embodied water in Spanish production.

Eventually, we will try to discuss the implications that the increase in agricultural production and therefore in water consumption had on water resources, especially on the need to construct infrastructure to store and distribute water for irrigation.

Our findings point at a gradual increase in the consumption of blue and green water to produce agricultural and food goods until 1962, with a smooth deceleration from 1930 to 1962, period that comprises the Spanish Civil War and the first twenty years of

Franco's Dictatorship. This growing trend became notably marked during the period 1962-2008, when a strong growth in agri-food production and exports that significantly increased demand for water, took place. Although production patterns changed and crop and livestock yields notably improved, their effect was not enough to make up for the great increase in production taken place during these years.

In the following section we review the methodology and explain the data used. Then in section 3 the main results are explained. Section 4 presents a discussion of the findings. Finally, section 5 ends the paper with the main conclusions.

2. Methodology and data

2.1. Methodology

As a first step, we estimate the volume of water necessary for the production of Spanish agricultural and food goods, that is, virtual water or embodied water in production. Thus, following the methodology proposed by Hoekstra and Hung (2005) for virtual water trade, we obtain the volume of water embodied in Spanish agri-food production. For a country *c* (Spain in our case), in year *t,* embodied water in production (m^3/year) can be obtained as the sum of embodied water in production in each of its *p* products, what yields:

$$EWP(c,t) = \sum_{p} d_p^c(c,p,t) * P_p^c(c,p,t) \qquad (4.1)$$

Where $EWP(c,t)$ represents the volume of water necessary for the production of agricultural and food products in *c* during year t (m^3). $d_p^c(c,p,t)$ represents the water content per unit of good *p* in the producer country *c* (m^3/Ton) and $P_p^c(c,p,t)$ is the volume of production of each product *p* in country *c* and year *t* (Ton). Equation 4.1 is calculated for blue and green water.

Note that for an exact description of water embodied in agricultural and food products an estimation of all direct and indirect water requirements added through inputs would be necessary. The input-output method could help to bridge this gap; however it is impossible to obtain input-output tables for the whole period. Therefore, as agriculture is the main water consumer (about 70% of total water resources) and interdependencies with other sectors might be somehow limited, the bottom-up approach previously described is considered accurate.

Once estimated the volume of water embodied in production, we address the factors underlying the changes in water consumed for production. Firstly we get and identity in which embodied water in production equals the drivers responsible for its trajectory. After that, in order to analytically analyse trends in embodied water in production and get the forces contributing to this trend, a Decomposition Analysis (DA) is applied.

That way, departing from equation 4.1, embodied water in production can be expressed, in general terms, as dependent on three types of factors: water intensities, composition of production and scale as follows:

$$EWP(c,t) = \sum_{p} w_{cpt} \cdot \left(\frac{P_{cpt}}{p_{ct}}\right) p_{ct} \qquad (4.2)$$

This can be expressed in matrix form as:

$$EWP(c,t) = \mathbf{w}'_{\mathbf{ct}} \mathbf{v}_{\mathbf{ct}} p_{ct} \qquad (4.3)$$

Where $\mathbf{w}'_{\mathbf{ct}}$ is a row vector including the virtual water content of each product *c* per ton produced in Spain during year t (measured in m^3/peseta), i.e., the water intensity. $\mathbf{v}_{\mathbf{ct}}$ is a vector of the share of each product *c* in total Spanish production in period *t* and p_{ct} is a scalar that informs about the total value of Spanish production in year *t* (in constant pesetas of 1959).

Departing from equation 4.3, a DA is applied. This technique breaks down a time trend of an aggregated variable into a group of driving forces that can act as accelerators or retardants (Dietzenbacher and Los, 1998; Hoekstra and van den Bergh, 2002; Lenzen et al., 2001). In practice, there are different ways of solving this expression by way of exact decompositions. However, as Dietzenbacher and Los (1998) show, the simple average of the two polar decompositions can be considered as a good approximation of the average of the *n*! exact decomposition forms.

In our case, as decomposition is based on three factors we can obtain the 3! exact decompositions. Nonetheless, following Dietzenbacher and Los (1998) we obtain the simple average of the two polar decompositions.

Therefore, the two polar decompositions of (4.3) can be written as follows:

$$\Delta EWP(c) = \Delta\mathbf{w}_{\mathbf{c}}'\mathbf{v}_{\mathbf{ct-1}}p_{ct-1} + \mathbf{w}_{\mathbf{ct}}'\Delta\mathbf{v}_{\mathbf{c}}p_{ct-1} + \mathbf{w}_{\mathbf{ct}}'\mathbf{v}_{\mathbf{ct}}\Delta p_c \qquad (4.4)$$

$$\Delta EWP(c) = \Delta\mathbf{w}_{\mathbf{c}}'\mathbf{v}_{\mathbf{ct}}p_{ct} + \mathbf{w}_{\mathbf{ct-1}}'\Delta\mathbf{v}_{\mathbf{c}}p_{ct} + \mathbf{w}_{\mathbf{ct-1}}'\mathbf{v}_{\mathbf{ct-1}}\Delta p_c \qquad (4.5)$$

Taking the average of (4.4) and (4.5) we get (4.6):

$$\Delta EWP(c) = \frac{\Delta\mathbf{w}_{\mathbf{c}}'\mathbf{v}_{\mathbf{ct-1}}p_{ct-1} + \Delta\mathbf{w}_{\mathbf{c}}'\mathbf{v}_{\mathbf{ct}}p_{ct}}{2} + \frac{\mathbf{w}_{\mathbf{ct}}'\Delta\mathbf{v}_{\mathbf{c}}p_{ct-1} + \mathbf{w}_{\mathbf{ct-1}}'\Delta\mathbf{v}_{\mathbf{c}}p_{ct}}{2} + \frac{\mathbf{w}_{\mathbf{ct}}'\mathbf{v}_{\mathbf{ct}}\Delta p_c + \mathbf{w}_{\mathbf{ct-1}}'\mathbf{v}_{\mathbf{ct-1}}\Delta p_c}{2} \qquad (4.6)$$

As a result, trends in embodied water in Spanish agricultural and food products can be explained on the basis of:

- Scale effect, which links changes in water embodied in production with changes in the volume of trade and can be expressed by:

$$SE(c) = \frac{\mathbf{w}_{\mathbf{ct}}'\mathbf{v}_{\mathbf{ct}}\Delta p_c + \mathbf{w}_{\mathbf{ct-1}}'\mathbf{v}_{\mathbf{ct-1}}\Delta p_c}{2} \qquad (4.7)$$

- Composition effect, which explains changes in water virtual in production depending on changes in the share of products in trade. It is given by:

$$CE(c) = \frac{\mathbf{w}_{\mathbf{ct}}'\Delta\mathbf{v}_{\mathbf{c}}p_{ct-1} + \mathbf{w}_{\mathbf{ct-1}}'\Delta\mathbf{v}_{\mathbf{c}}p_{ct}}{2} \qquad (4.8)$$

- Intensity effect, which quantifies the contribution of variations in water intensities to changes in the volume of water embodied in production.

$$IE(c) = \frac{\Delta\mathbf{w}_{\mathbf{c}}'\mathbf{v}_{\mathbf{ct-1}}p_{ct-1} + \Delta\mathbf{w}_{\mathbf{c}}'\mathbf{v}_{\mathbf{ct}}p_{ct}}{2} \qquad (4.9)$$

2.2. Data

Data for the volume of Spanish production in physical units (Tons) have been obtained from "Anuario Estadístico de la Producción Agraria" (MAGRAMA, 1904-2010) for the period 1900-2009. When possible we get information for three years and take a simple average, trying to soften annual deviations. Despite most data were obtained from "Anuario Estadístico de la Producción Agraria" (MAGRAMA, 1904-2010), it does not contain information for 1860 and for some products in 1900. For that reason, we have added the appendix 4.2 that describes precisely the process of calculation for these data.

Regarding the quality of data used, we consider that they are reliable from 1930, i.e., from the moment in which the Ministry of Agriculture began publishing annual data for all crops and livestock products (GEHR, 1991). For 1900 we have explained in appendix 4.2 how we obtained the data of the different agricultural productions. The results from 1900 to 2010 offer a high degree of confidence and accuracy. Nonetheless, for 1860 the estimation procedures, given the total lack of data for different agricultural products, have been mixed. On the whole, these results seem to be a reasonable estimation but it is not possible to reach definitive conclusions from them.

An accurate application of the DA requires data for the volume of production in constant monetary units. Therefore, production data have been expressed in constant 1959 pesetas. These have been obtained as the multiplication of production in physical units with the price of each product in 1959. We have information for the production of 89 agricultural and food commodities in Spain (except for Canary Islands).

Water specific demand coefficients of crops or derived crop products have been taken from Mekonnen and Hoekstra (2011), whereas water coefficients for farm animals and animal products stem from Mekonnen and Hoekstra (2012). Following Hoekstra et al. (2009) crop and livestock water requirements express the volume of water necessary (green or blue) per ton of product, in other words, they are obtained as the ratio between evapotranspiration (ET) and yields (Y). As crop and climatic conditions in Spain seem to be stationary on time, it seems feasible to keep evapotranspiration constant (see appendix 4.1 for an examination of uncertainties). However, technological advances and seeds improvements happened from 1860 have caused important yield improvements. Thus, in line with Dalin et al. (2012) and Konar et al. (2013), water intensities have been modified as a function of yields Spanish series as follows:

$$w_{cpt} = w_{cp} \frac{Y_{cp}}{Y_{cpt}} \qquad (4.10)$$

With w_{cpt} being the variable water coefficient for each product in the period of analysis, or *t=1860...2010*. w_{cp} is the crop or livestock water intensity given by Mekonnen and Hoekstra (2011, 2012). Y_{cp} represents the average yield of the reference period (1996-2005) considered by the above authors. These data have been taken from FAO (FAOSTAT, 2013) and distinguish the yields of the different goods. Y_{cpt} gives information on annual product yields from 1860 to 2010. Spanish yields for the period 1860-1930 come from "Estadísticas Históricas de la Producción Agraria Española, 1859-1935" (GEHR, 1991), whereas from 1960 to 2010 they have been taken from FAOSTAT (2013).

Accordingly, the hypothesis that lies behind this approach is that technological advances have influenced historical crop and livestock yields and have notably affected water consumption per ton in the long term.

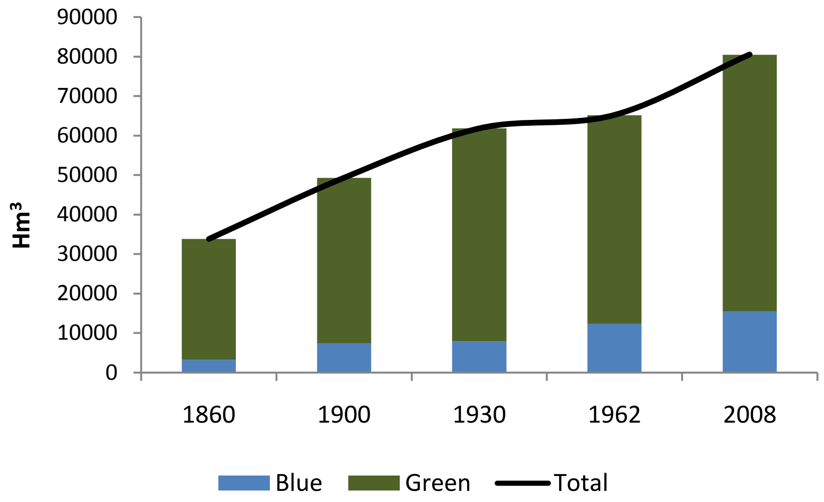
3. Results

3.1. Trends and patterns of embodied water in production

Water embodied in Spanish production tended to increase from 33,824 hm^3 in 1860 to 80,486 hm^3 in 2008, showing an average annual growth of 0.6%.

The volume of water consumed to produce agricultural and food products gradually grew until 1930, (average annual growth rates of 0.8% for green water and 1.3% for blue water), which fits well with a smooth growth of agricultural production in the same period. This increase flattened during the period that comprises the Spanish Civil war and the first years of Franco's dictatorship. It also coincides with the problems suffered by the Spanish agriculture and economy during those years. The agricultural production levels prior to the Civil War of 1936-39 did not recover until the mid-fifties, as a consequence of the isolation of the Spanish economy and the difficulties to import basic inputs for a modernizing agriculture such as fertilizers or machinery.

Figure 4.1: Water embodied in Spanish production (1860-2008)



From 1930 to 1962 the rise of embodied water in Spanish production decelerated. Whereas blue water consumption increased at 1.4% yearly, green water declined at an annual average rate of -0.06%. On the one hand, the growth of blue water embodied in production was mainly due to the increase in the production of cotton, a blue water intensive crop that was almost new and experienced an intense development with a high tariff protection. Other products as milk or sugar beet also increased its production considerably. On the other hand, the production of meat, a product with high green water content per ton produced, sank. From 1962 onwards, the volume of water for production soared from 65,186 hm^3 to 80,486 hm^3, growing at approximately 0.5% every year. During these years an abrupt growth of agricultural production happened, chiefly because of the great introduction of new technologies. Furthermore, changes in the composition of agricultural production, mainly owing to the development of the intensive stockbreeding industry, have enabled a new specialization that was not previously feasible given the scarcity of natural pastures.

As we can see in Figure 4.1, green water was the most important component of embodied water in production, representing about 85% on average of total water.

Nevertheless, blue water consumption accounted for a growing share on time and grew at a faster pace (1.1%) than green water (0.5%) during the whole period.

Table 4.1: Composition of embodied water in production and average annual growth rates

Sitc rev.1 product classif.	1860	1900	1930	1962	2008	*1860-1900*	*1900-1930*	*1930-1962*	*1962-2008*	*1860-2008*
	Green water composition (%)					*Green water growth rates (%)*				
01 Meat and preparations	25.6	20.2	21.9	9.8	32.7	0.2	1.1	-2.5	3.1	0.7
02 Dairy products and eggs	6.7	7.6	14	32.2	16.5	1.1	2.9	2.6	-1	1.1
04 Cereals	44.3	37.9	32.2	24.6	13.1	0.4	0.3	-0.9	-1	-0.3
05 Fruit and vegetables	8.5	12.9	14.8	14.8	15.7	1.9	1.3	-0.1	0.5	0.9
06 Sugar	0	0.2	0.1	0.9	0.3	n.a.	-1.9	7.8	-2	n.a.
07 Spices	0	0	0	0	0	2.9	1.6	-3.1	-13.1	-3.9
11 Beverages	11.3	17.7	12	12.3	6.1	1.9	-0.5	0.0	-1.1	0.1
1210 Tobacco, unmanuf.	0	0	0	0.1	0	0	0.9	5.3	-1.2	0.9
22 Oil seeds, nuts and kernels	0.1	0.1	0	0.2	0.5	0.8	-6.1	12.2	2	2.1
26 Textile fibres	0.5	0.1	0.1	1	0.4	-3.3	0.7	7.6	-1.2	0.4
42 Fixed vegetable oils and fats	3	3.3	4.9	4.1	14.7	1	2.2	-0.6	3.3	1.6
Total	100	100	100	100	100	0.8	0.8	-0.1	0.4	0.5
	Blue water composition (%)					*Blue water growth rates (%)*				
01 Meat and preparations	6.7	4.3	4.2	4.2	18.2	0.2	1.1	1.5	3.7	1.8
02 Dairy products and eggs	8.7	8.3	13.6	18.9	10.2	1.1	2.9	2.5	-0.9	1.2
04 Cereals	20.2	15.4	14.6	8.3	8.4	0.6	1.1	-0.3	0.5	0.5
05 Fruit and vegetables	26.3	29.9	34.6	26.8	30.0	1.6	1.7	0.7	0.7	1.2
06 Sugar	0.0	2.0	0.8	5.2	1.6	n.a.	-1.9	7.8	-2.0	n.a.
07 Spices	0.1	0.1	0.1	0.0	0.0	2.9	1.6	-3.1	-13.1	-3.9
11 Beverages	19.4	25.1	15.0	9.4	4.5	1.9	-0.5	0.0	-1.1	0.1
1210 Tobacco, unmanuf.	0.0	0.0	0.0	0.1	0.0	0.0	0.9	5.3	-1.2	0.9
22 Oil seeds, nuts and kernels	0.4	0.3	0.0	1.0	2.2	0.8	-6.1	13.3	2.1	2.3
26 Textile fibres	2.4	0.4	1.7	21.9	10.0	-3.2	6.3	9.9	-1.2	2.0
42 Fixed vegetable oils and fats	15.8	14.2	15.4	4.2	14.7	1.0	1.5	-2.5	3.3	1.0
Total	100.0	100.0	100.0	100.0	100.0	1.3	1.3	1.5	0.5	1.1

Table 4.1 displays the composition of production in terms of the volume of water consumed as well as the average annual growth rates for each group of products. If we look first at the volume of green water necessary to meet production demands, it is observed that cereals were the most important group for all the periods, accounting for 30% of total green water on average. Nevertheless, they were gradually reducing their shares until 2008. Cereals were the main source of calories, at least until Spain reached a high level of per capita income. From that moment onwards, its diet converged towards the most developed countries, with an important weight of calories of animal origin. Wheat was the main cereal consuming green water. Meat

had also a significant impact on embodied green water in production. As we previously said, it dropped in 1962 but the trend reversed by 2008, when it represented 32.7% of total green water. This fact can be explained by the great increase happened from 1962 to 2008, when meat grew at 3.2% every year.

The group formed by fruits and vegetables was also noteworthy, with increasing shares and significant positive growth rates. Nuts and citrus fruits stand out in this group. Dairy products (milk) depict a notable growth of share from 1900 until 1962. In 2008 it represented 16.5% of total green water consumption. The expansion of dairy products in Spain, very late compared to other countries, explains this trend (Hernández-Adell, 2012; Collantes, 2014). Vegetable oils, with olive oil as the main good, represented about 4% until 1962. From that moment on, this group was 15% of total green water embodied in agricultural production mostly provoked by the increase in olive oil production. Eventually beverages, with wine as the most significant item, depict percentages around 12% that decreased by 2008. The importance of wine production throughout the period analyzed explains its significant share. This was particularly intense from the end of the ninetieth century when the export boom to France reached its maximum value and the weight of wine production on agricultural production also peaked (Fernández and Pinilla, 2014).

As for blue water, the picture was somehow different. Fruits and vegetables were the most representative being responsible for about 30% of blue water requirements and kept quite stable until the end of the twentieth century. Again nuts and citrus fruits were the most representative crops. The volume of blue water needed by this group grew at an annual rate of 1.2%. The importance of fruits and vegetables as consumers of blue water has been largely influenced by the strong growth of its production, mostly destined for foreign markets. From the mid-nineteenth century fruit and vegetable exports grew strongly, but especially since the late nineteenth century (Pinilla and Ayuda, 2009). Its importance was rising, accounting for approximately 40% of blue virtual water exports in 1930 (Duarte et al., 2014b). In the years after the Civil War, there was a noticeable decline in the exports of Spanish fruits, however they recovered from the early seventies and then grew at a fast pace, particularly after the Spanish accession in the European Union in 1986 (Clar et al., 2014). Cereals were also important consumers of blue water. Although this group displays positive growth rates, they increased below average, what caused a gradual loss of share from 20% in 1860 to 8.4% in 2008. In this case, rice entailed over 60% of the volume of blue water consumed by cereals. Dairy products and meat exerted a notable contribution to the blue water footprint of agriculture; although to a less extent than green water. Besides, olive oil and wine also consumed important volumes of blue water. Olive oil remained quite stable during the period considered, but fell in 1962. Wine decreased its share going from 25% in 1900 to 4.5% in 2008. Finally it is important to highlight the high share of textile fibres in 1962. It is explained by the great rise of cotton production, a high blue water intensive crop that showed intense growth rates from 1900 to 1962.

3.2. Factors explaining changes in embodied water in production

As we have seen, the volume of water necessary to produce agricultural and food goods notably increased from 1860 to 2008. It was mainly triggered by an intense increase in production that looked for meeting the growing demands of a developing society and international markets. Table 4.2 displays the contribution of these factors to changes in embodied water. On the whole, scale effect had a direct effect on green and blue water consumption from 1860 to 2010. Compositional changes as well as the growth of crop and livestock yields that resulted in decreasing water intensities, made water consumption upward trend to slow down. Whereas composition effect was more important for green water, intensity effect had a largest effect on blue water.

It is possible to find some differences depending on the sub-period chosen. During the first stage (1860-1900) only the growing agricultural production made green water consumption to rise. However, composition (27%) and scale (73%) triggered the increase in blue water. Thus, both scale effect and productive changes towards fruits, vegetables and wine made blue water to increase. From 1900 to 1930 the embodied water increased by 14 km^3. The growing production of agricultural and food products encouraged the whole increase in green and blue water. However, the introduction of new technical inputs, like fertilizers entailed important yield improvements, which partially made up for the rise of embodied water in production. Without the former effect, total water consumption would have been 4.3 km^3 higher. The period 1930-1962 is quite peculiar. If green water decreased by 1.8 km^3, blue virtual water kept on growing. The former declined as a result of the contraction on agricultural production taken place during the Spanish Civil War and Franco's Dictatorship. On the contrary, the latter increased over 3 km^3 mainly due to changes in production patterns. As we previously commented in section 3.1., from 1930 to 1962 the production of blue water intensive products such as cotton, sugar beet or milk was promoted entailing the increase in blue water consumption.

Table 4.2: Decomposition analysis of embodied water

	Effects	1860-1900	1900-1930	1930-1962	1962-2008	1860-2008
Green virtual water	**Scale (%)**	102	153	-758	485	366
	Composition (%)	-2	-23	185	-163	-137
	Water intensity (%)	0	-30	673	-222	-129
	Δ virtual water in production (km3)	11.8	11.7	-1.8	16.4	38.1
Blue virtual water	**Scale (%)**	73	135	80	609	201
	Composition (%)	28	-1	126	-318	-31
	Water intensity (%)	0	-34	-106	-191	-70
	Δ virtual water in production (km3)	2.6	2.2	3.4	3.1	11.3

Finally during the last period (1962-2008), green and blue virtual water increased 38 km^3 and 11 km^3 respectively, as a result of the great increase in production. As it is observed in Table 4.2, composition and intensity effects display negative sign indicating that otherwise, without their negative contribution, the increase in the volume of water consumed for production would have been even greater (100 km^3 and 11 km^3 for green and blue water respectively). The notable contribution of the intensity effect to water consumption leveling off can be explained by the strong rise in yields in this period. It occurred as a result of the massive use of fertilizers, pesticides, hybrid seeds and modern inputs that significantly increased the productivity of land in agriculture in developed countries.

4. Discussion

The increase in the volume of water consumed by agricultural production was 74% due to green water on average. Although green water cannot be regulated and stored, its importance for crop and livestock production shows that it cannot be neglected. The existing data indicate that harvested land gradually expanded throughout the period considered, from 16,012,000 Ha in 1860 (Jimenez Blanco, 1986) to approximately 21,110,000 Ha in 1972 decreasing to 17,793,000 in 2005 (Martín-Retortillo and Pinilla, 2013). This growth was sometimes biased towards rainfed crops like wheat or olive oil given climatic and land conditions. Nevertheless, it involved a great increase of vegetation and consequently of green water.

The expansion of production and the substitution of certain crops also involved growing requirements of blue water. In a country in which an unlimited supply of irrigation water at zero cost could be obtained, the evolution of these needs for water would have no economic consequences. However, the obtaining of water for irrigation requires heavy capital investments and the results of these investments may on occasions be uncertain.

If we return to Figure 4.1, we can observe that the evolution of Spanish production of agricultural products involved an increasing pressure on the needs for water for irrigation. Between 1860 and 2008 it was necessary to confront an absolute increase, of some 12 km^3 of blue water. The demand for water for irrigation was linked to the needs of a developing foreign sector, but also to the self-same increase in agricultural production, destined largely to the domestic market, playing an essential role. In many areas of Spain there had been an increasing demand for irrigation water since the mid-ninetieth century, destined for traditional crops, with the objective of ensuring harvests and limiting their variations. This signifies that the production of foods intended for the internal market was an important component of the demand for water for irrigation.

Attempting to increase irrigation had been a traditional way for farmers to try to improve their production. The climatic conditions of a large part of Spain, namely scarce and irregular rainfall with seasonal drought, had resulted in a very long tradition of harnessing the river systems to irrigate arid land. Numerous small-scale hydraulic infrastructures had been built. The main aim of these efforts to expand the irrigated area was to ensure harvests rather than to raise productivity or change the use of the land. In the ninetieth century, the increase in domestic demand, due principally to population increase, in a relatively protectionist context, offered attractive possibilities to increase agricultural production. Furthermore, the increasing integration of the Spanish economy in the first globalisation meant that foreign demand for agricultural products was one of the driving forces behind the development of agricultural production (Duarte et al., 2014b).

This increase in production meant that many initiatives arose to attempt to achieve more water and thereby increase the crops benefiting from it. Under the classical liberal program, which tended to limit state intervention in the economy, it was private investors who would undertake the works necessary for irrigation. As a result, scant progress was made with irrigation throughout most of the century. This snail's pace development was a consequence of the progressively larger scale and increasing cost of the necessary infrastructure, resulting in higher initial funding requirements and longer periods to recoup investment. Perhaps the most significant exception was the drilling of wells in the Valencia region to extract water for the expansion of orange growing.

With the data available it is impossible to quantify by how much the irrigated land area increased in the ninetieth century. The scarce quantitative data and some qualitative figures permit two conclusions to be reached. Firstly, the increase in the capacity to store water and in this way ensure and increase the irrigated surface area was very small. As a result, faced with the difficulties in achieving in this way a substantial increase in the supply of water, in those places with stronger expectations of developing export-orientated crops, which required not only irrigation water but also regularity in its supply, a private effort to extract water from the subsoil in previously dry land was combined with a change in the uses of soil, dedicating land previously used for wheat or other crops to the promising export crops.

The evidence which supports the scarce increase in the capacity for water storage is the fact that in the second half of the ninetieth century the reservoirs constructed which had as sole or shared objective the supply of water for irrigation, only increased it by less than 50 hm^3. Although it is true that it doubled the capacity existing until then in Spain as a whole, it continued to offer extremely limited possibilities for storing water for irrigation. The scanty increase in storage capacity was not due to the shortage of business initiatives for the implementation of irrigation works. On the contrary, in the second half of the ninetieth century there was unleashed a fever for the constitution of companies to perform such waterworks. In some areas of Spain, especially in the Ebro valley, their results were notable. Projects which significantly increased the irrigated land area were initiated, such as the Canals of Aragon and Catalonia, the Urgel Canal or the Ebro Delta Canals in Tarragona. However, the problems with this type of canal is that as they did not have head dams to ensure the supply of water during the periods of greatest water stress they did not permit a change in the uses of land, but instead greater and more regular production of traditional crops (Ramón, 2004). The obstacle for the construction of the necessary dams was dual: technical and economic. The technical obstacle was the backwardness of the technologies capable of constructing dams which resisted the pressure of water. The economic handicap was related to the heavy investment necessary and its long amortization period.

These problems encouraged the private sector, interested in obtaining sufficient water for the expansion of crops, to look for alternatives, namely changes in the uses of land in traditional irrigated land or the drilling of wells to extract water in dry farming areas. Such types of initiatives were most highly developed in the region of Valencia.

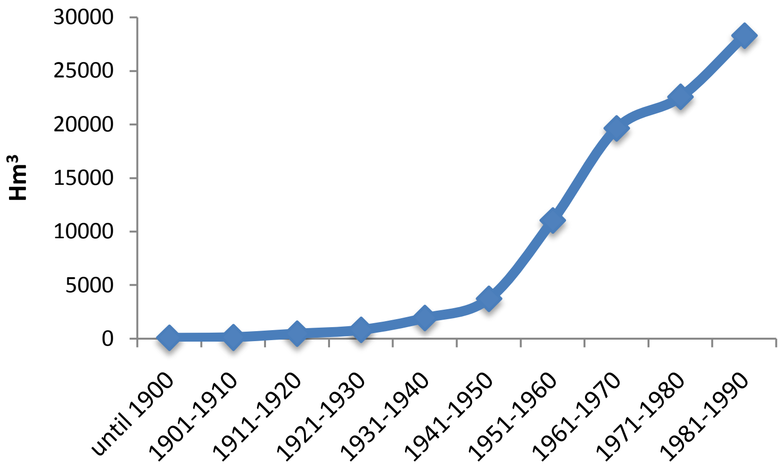
In the first third of the twentieth century, the most specialised regions in Mediterranean horticultural production went through an intensification in the substitution of irrigated traditional crops by fruit and a substantial increase in the extraction of water from the subsoil, making massive use of new technical resources such as electricity or petrol engines, which tended to replace the traditional systems of treadmills and manual pumps which had a limited capacity for elevating water. Yet even the traditional treadmills were improved by the use of iron in many of their essential parts. These new technologies were also applied to pump surface water.

With regard to the use of new technologies, these had begun to spread with the use of steam for pumping water from wells since the middle of the ninetieth century, especially for the irrigation of oranges in Valencia. Their high cost considerably limited their diffusion (Garrabou and Sanz, 1985). Together with the traditional lifting pumps, from the beginning of the twentieth century there began to be employed others driven by petrol, lean gas or electricity. In 1916 these still accounted for a small percentage of the land area irrigated with underground water (approximately 10%, while treadmills constituted over 50%), but in the lifting of surface water it already represented over 50% of the surface irrigated using this system, with a clear predominance of electric pumps. The expansion of such technologies in the following years was very rapid. The 6,000 pumps powered by fossil fuels which existed in 1916 rose to 24,000 in 1932. Almost half were electric motors and 60% were located in the Mediterranean region, the most highly specialised in horticultural export products (Calatayud and Martínez Carrión, 1998 and 2005).

However, in the first third of the twentieth century not only private enterprise played a key role through the drilling of wells and the use of modern machinery to lift water. Of substantial importance was the assumption by the state of the principal responsibility for the construction of large waterworks. The starting point was the state's decision in 1896 to complete the works of the Aragon and Catalonia Canal. This represented an acceptance of the failure of privately-sponsored great hydrological works and the beginning of state-sponsored development. This new policy implied that the state would assume responsibility for a significant part of the financing of the large-scale hydrological works (dams and main and secondary canals), while farmers would bear the cost of levelling the agricultural plots, channelling the water within them and establishing the connections between the irrigation ditches and their plots (Pinilla, 2006). This active role of the state in the development of large-scale water works was clearly influenced by the effects of the depression suffered by European agriculture at the end of the ninetieth century, as a consequence of the intense competition from agricultural products imported from the Americas or the Russian Empire and the action of the regenerationist movement in Spain. This, led by the thinker Joaquín Costa, saw irrigation as the solution to the backwardness of Spanish agriculture. From an international perspective this coincided with both the beginning of increasing state intervention in agriculture (Koning, 1994) and with the about-turn in water policy in the United States, when the federal government, during the presidency of Theodore

Roosevelt, assumed responsibility for the construction of large dams and waterworks (the National Reclamation Act of 1902). In the following 50 years the US Bureau of Reclamation constructed 173 dams and provided irrigation for 2.7 million hectares. The magnitude of the necessary investment was the principal determinant of this implication of the federal government (Pisani, 1992; Hundley, 1992). The use of new materials, such as concrete, and of new construction techniques, especially the advances in North American engineering, made this advance possible. Furthermore, the possible multiple use of dams, to produce hydroelectricity and at the same time to provide water for agriculture, facilitated the development of waterworks (Pinilla, 2008).

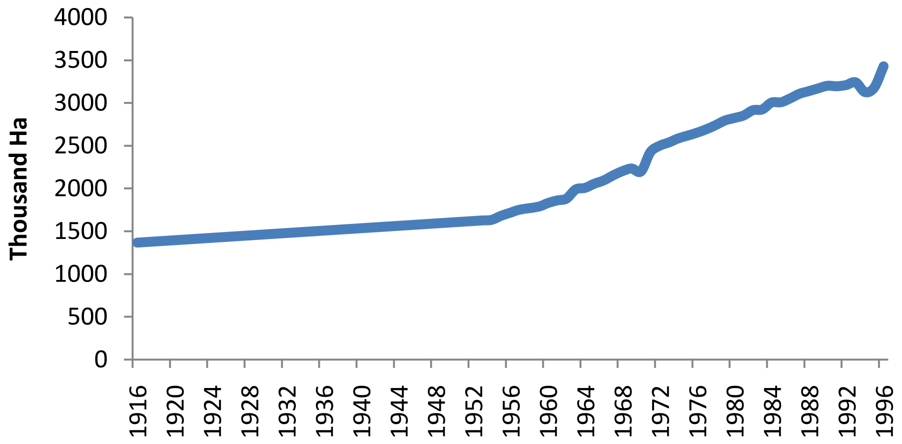
Figure 4.2: Accumulated reservoir capacity in Spain, 1900-1990



Spain also experienced, in the first third of the twentieth century, a rapid increase in the construction of dams (Figure 4.2). While in 1900 their capacity for water storage for irrigation was 82.2 hm^3, between that date and 1930 this increased by 744 hm^3, that is to say, an increase of 905%. Between 1930 and 1940 this increased by a further 1,105 hm^3, thereby more than doubling in only 10 years the existing dam capacity (Pinilla, 2006). The regional distribution of these constructions was strongly focused on the Ebro basin, which in 1930 represented 50% of the capacity of water stored in dams for irrigation. This strong concentration in the Ebro valley was partly linked to the supply of water to traditional crops, but also to new crops such as fodder for cattle and, above all, sugar beet. Furthermore, the character of the Pyrenees as a region strongly specialised in the production of electricity was key in this development.

In summary, whether through the drilling of wells and the use of modern machinery for the lifting of water or through an intensive programme of large waterworks, the capacity to supply water for irrigation increased at an unprecedented rhythm and quantity during the first third of the twentieth century.

Figure 4.3: Irrigated area, 1916-1996



Data from 1917 to 1953 were not available. We linearly interpolated information between 1916 and 1954

But the boost to the completion of waterworks was spectacular during the Franco's dictatorship. The abolition of the Republican agrarian reform, the repression of trade unions and any social protest, and the adoption of a set of laws designed to weaken the farmers bargaining power, annoyed small and medium peasants. They supported Franco's side during the war in parts of Spain and as a result, hydraulic policy became an important ideological element of Franco's agricultural policy. In this context, a biased program of the thinker Joaquin Costa and of the large waterworks plans designed by republican governments was recovered. The construction of reservoirs and channels thus became one of the central pillars of Franco's agricultural policy. The picture of Franco inaugurating dams and reservoirs was typical of the dictatorship. The result was a dramatic increase in reservoirs capacity, which dwarfs previous achievements. As Figure 4.2 depicts, between 1950 and 1970 dams had a control capacity of nearly 16,000 hm3, representing about half of the current capacity and more than five times the pre-1950.

The irrigation policy was at its best with the founding of new towns (villages of colonization) in former dryland areas, where landless peasants or small landowners that lived in rainfed areas settled. The large irrigation schemes developed lead to a very strong increase in agricultural irrigated area (see Figure 4.3). The new regulation capacity of dams that ensured a regular supply of water resulted in important land use changes. Thus, crops that in Spain could only grow under irrigation conditions were gradually replacing traditional crops.

In the democratic period that started in 1977, water, water policy and the extension of irrigation were still import topics in the Spanish economy and in the social and political debate. Dam construction went on until the late twentieth century. It allowed carrying on with the expansion of the irrigated area at a slower pace than in the previous two decades, but still high. The result has been a clear trend towards the concentration of production in the irrigated area, which despite being smaller that rainfed land, represents more than half of agricultural production nowadays. Irrigation has become essential for the Spanish agricultural production. In a context of high agri-food trade opening, a great part of the expansion of irrigation has been allocated towards export products (Clar et al., 2014).

However, the new democratic framework allowed an intense debate on water policy, which had became one of the important issues in the Spanish political debate. The construction of costly infrastructure to transfer water from the Ebro River, Spain's largest river system, to the Mediterranean coast has been the most hotly debated issue. This debate was strongly influenced by clashes between the territorial interests of the Autonomous Communities (political regions) that opposed the Ebro transfer (Aragon and Catalonia) and those that were in favor (Valencia, Murcia and Andalusia).

From a social point of view, it is also important to acknowledge the popular opposition which has emerged since the beginning of the 1990s to the execution of further large-scale water regulation projects in the mountain areas. This has taken the form of a new unwillingness of people living in the affected areas to having their land or houses expropriated. As a result, there has been a clash between their interests and those of the farmers, who have anticipated that such regulatory works would result in a further expansion of the irrigated area or in an improvement in the supply to those already in existence. It is the view of those who oppose these large-scale projects that the mountain areas paid a very high price throughout the twentieth century in terms of the flooding of population centers and cultivated lands, and the enforced movement of whole populations as a consequence of reservoir construction

From an academic point of view, the most interesting aspect is the growing questioning of the 'classical' policies aimed at increasing the supply of cheap water, and the emergence of a 'new water culture', which places stress on demand management, water saving measures, and higher prices to act as an incentive for efficiency. When viewed from this perspective, it is assumed that policies aimed at increasing supply made sense throughout the majority of the twentieth century, to the extent that they solved either simultaneously or in parallel three key problems faced by underdeveloped, predominantly agricultural, countries, with un-regulated rivers and limited deposits of fossil fuel, namely the provision of drinking water, the development of irrigation and the expansion of hydro-electric production. The change in the socio-economic context and the significant increase in the supply of water that had been made possible by the very high levels of hydrological regulation have resulted in a new paradigm being proposed, whose key elements are concern for sustainable development, the integrated management of water and territory and the management of water demand.

5. Conclusions

The strong expansion of agricultural production taken place in Spain between 1860 and 2010 lead to growing needs of water resources. Actually, water consumption more than doubled during these years. Although the sub-periods chosen differ depending on economic, social or institutional circumstances, on the whole, it was the scale of production the main factor driving water consumption. Products substitution as well as crop and livestock yield increases prevented a higher growth of embodied water in production. On the one hand, green water was essential for the development of the agricultural sector and its consumption rose associated with the upward trend followed by harvested land. On the other hand, crops substitution would have not been possible without the key role of irrigation. Irrigated area gradually increased during these years, and with it, the consumption of blue water.

Accordingly, the development of the Spanish agricultural sector was closely linked with technological developments that allowed obtaining and storing water in an easier and cheaper way. However, it was essential to overcome important economic obstacles to build water infrastructure. In this respect, the role of the government as the main funder of large waterworks was determinant.

Nevertheless, it seems quite clear that the Spanish agricultural expansion was carried out neglecting its environmental impacts, considering water resources only as a productive input. In addition, the fact that most water infrastructure was funded mainly by the government for a long time, even using hydraulic policy as a political instrument, could have separated the Spanish society from the actual cost of water as well as from the impact of economic growth on the environment. The excessive water consumption together with an unequal and unbalanced agricultural policy has resulted in an alarming water scarcity in many Spanish regions today. Therefore, the Spanish case in which a long term agricultural transition happened neglecting its environmental consequences should be taken as an illustration of an unsustainable water resources management. In this context, it seems essential that economic development and environmental protection go together to avoid unintended effects in the near future.

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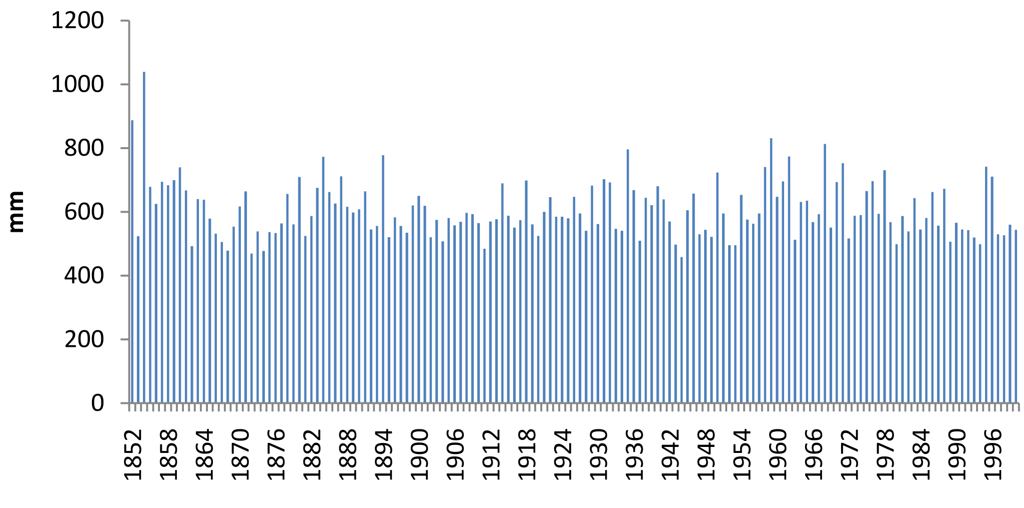
Appendix 4.1: Uncertainty

The data, taken from Mekonnen and Hoekstra (2011, 2012), provide information concerning the average volume of water required per crop, from 1996 to 2005. Although the main focus of this paper is to examine long-term trends in virtual water, an analysis of the impact of the assumption that evapotranspiration at the end of the twentieth century can be applicable to the ninetieth century, is now in order.

As stated earlier, Mekonnen and Hoekstra (2011, 2012) obtain water demand coefficients following Allen et al. (1998), who consider that evapotranspiration (crop water use) under non-optimal conditions depends on climatic parameters, crop characteristics, and management and environmental conditions. Whereas crop parameters are assumed to be static (Allen et al., 1998), climatic variables may have changed over time. Consequently, we have proceeded to examine time series for some of the variables for which long-term data are available.

Firstly, if we observe Figure 4.4, which offers data on average precipitation in Spain, and following Carreras (2005), it is possible to say that precipitation generally appears to be fairly stable from 1852 to the present day. However, due to the marked variability of these data, there is currently no clear evidence regarding trends in precipitation (Rodrigo and Barriendos, 2005; Pauling et al., 2006).

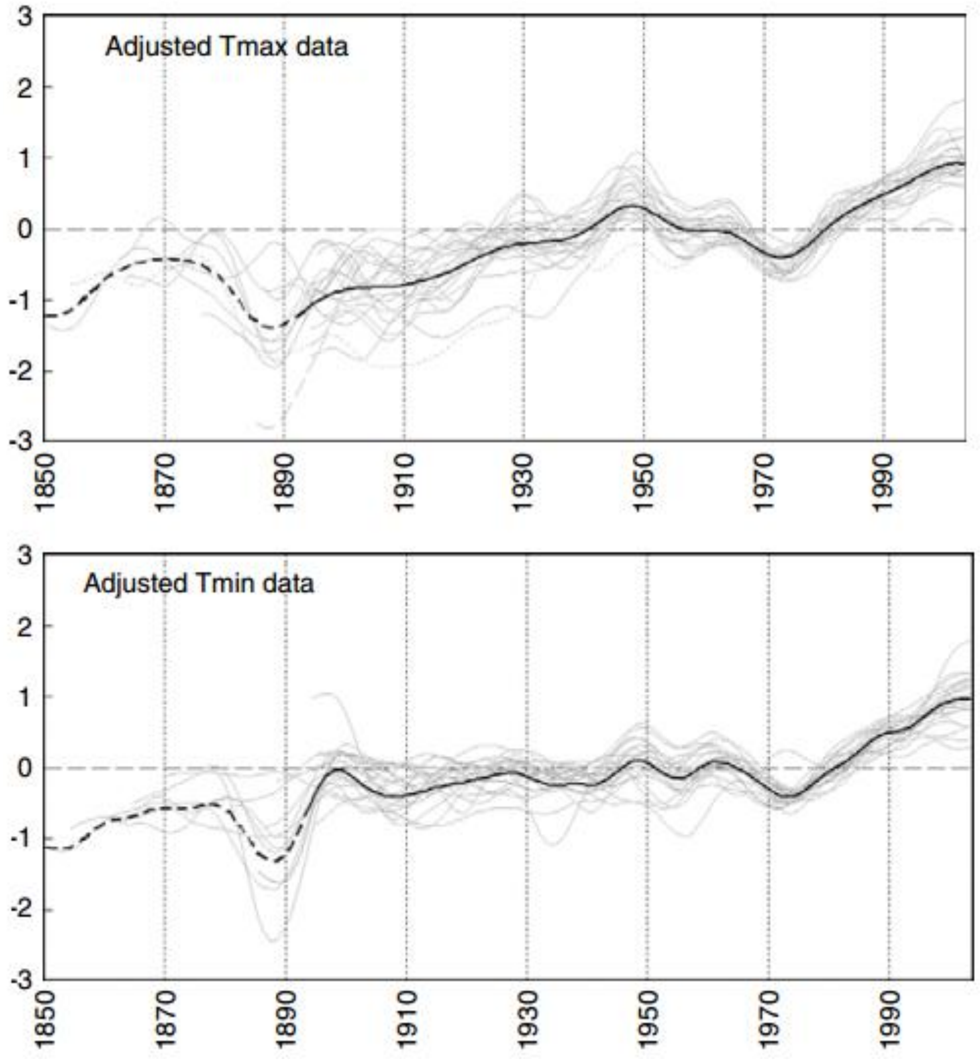
Figure 4.4: Average annual precipitations in Spain (mm)



Source: Authors' elaboration, from Carreras (2005).

By contrast, most researchers into climatic history are apparently in agreement concerning the rise in global temperatures (Guiotet al., 2010; Brunet et al., 2006), as illustrated in Figure 4.5, which displays the trajectory of adjusted annual variations (1850–2003) in daily maximum and minimum temperature records.

Figure 4.5: Adjusted annual variations (1850–2003) of daily maximum and minimum temperature

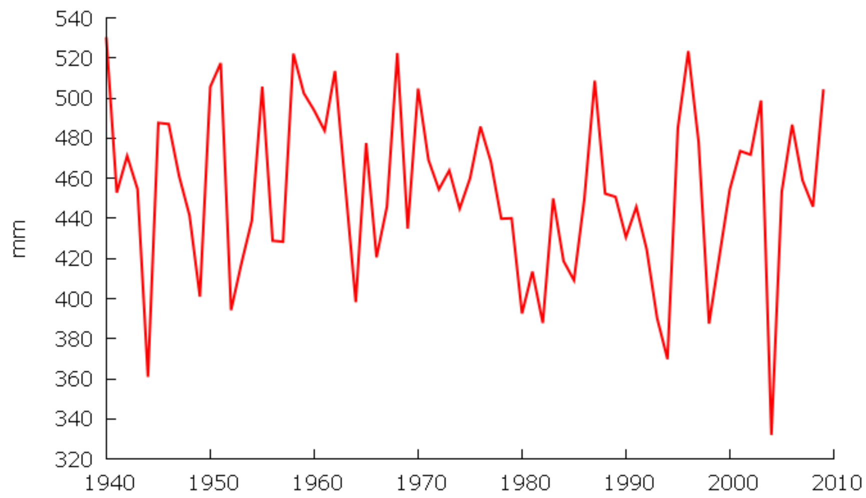


Source: Brunet et al. (2006)

While it is possible to discover many variables affecting crop water use in different ways, it is impossible to find a long-term series that helps us to determine their overall effect on evapotranspiration throughout the study period.

As a result, faced with the impossibility of exploiting an accurate reconstruction of crop water requirements, we sought an alternative time series dataset for long-term evapotranspiration in Spain. For the twentieth century, we discovered historical data for real and potential evapotranspiration for the period 1940-2010. According to MAGRAMA (2013), potential evapotranspiration (ETP), which is highly dependent on temperature, is that evapotranspiration produced with soil moisture and vegetation under optimal conditions. Its mean reaches 1,041 mm, showing its highest values in the south of Spain, the Ebro Valley, and the Canary Islands. In turn, real evapotranspiration (ETR) is that which actually takes place under existing conditions. In Spain, this reaches an average of 453.65 mm, notably below ETP because optimal soil humidity conditions are not fulfilled. Since ETR is the actual volume of water required by crops, we performed an econometric analysis of this time series to determine whether keeping its magnitude constant over time is justifiable. As a first step, we shall observe the time series graph, which appears to have no definite tendency and fluctuates around its mean. In other words, it appears to be stationary in the mean at first sight.

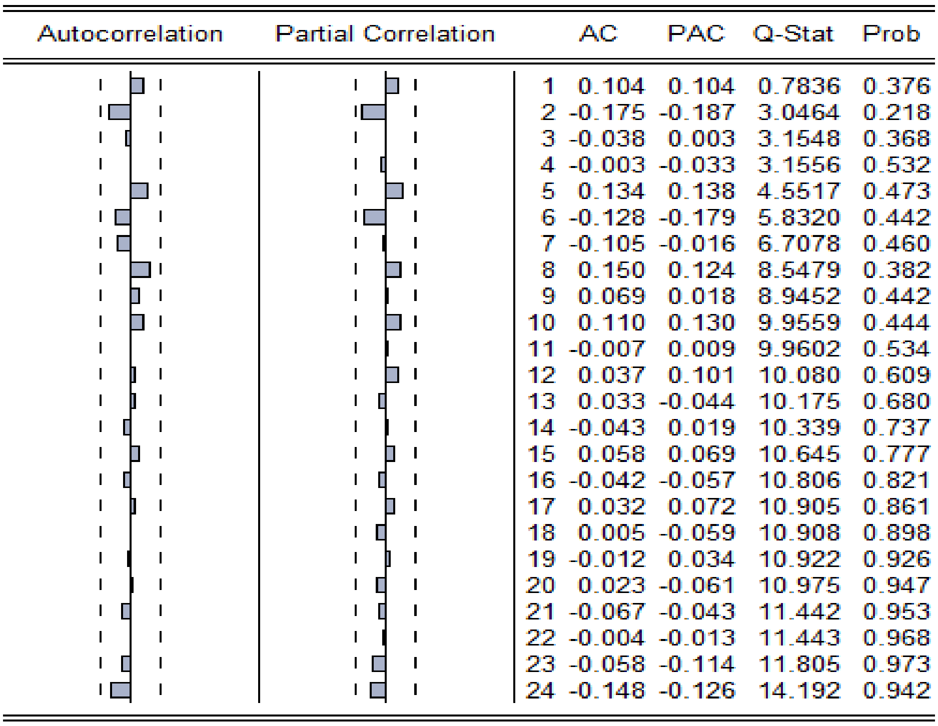
Figure 4.6: Real evapotranspiration in Spain (mm)



Source: MAGRAMA (2013)

It is also necessary to undertake a range-mean analysis to check whether the series is variance-stationary. We find that the slope of the range with respect to the mean equals -0.27, with a p-value of the test of p=0.77; this leads to the non-rejection of the null hypothesis of the slope=0, and the conclusion that the series is also variance-stationary. Moreover, if we observe the correlogram of real evapotranspiration, this also points to a stationary series. Finally, to gather hard evidence regarding the stationary character of real evapotranspiration we perform the KPSS test (Kwiatkowski-Phillips-Schmidt-Shin), which yields a statistic of 0.074, and thus the null hypothesis of stationarity at the 1% significance level is not rejected.

Figure 4.7: ETR correlogram



	AC	PAC	Q-Stat	Prob
1	0.104	0.104	0.7836	0.376
2	-0.175	-0.187	3.0464	0.218
3	-0.038	0.003	3.1548	0.368
4	-0.003	-0.033	3.1556	0.532
5	0.134	0.138	4.5517	0.473
6	-0.128	-0.179	5.8320	0.442
7	-0.105	-0.016	6.7078	0.460
8	0.150	0.124	8.5479	0.382
9	0.069	0.018	8.9452	0.442
10	0.110	0.130	9.9559	0.444
11	-0.007	0.009	9.9602	0.534
12	0.037	0.101	10.080	0.609
13	0.033	-0.044	10.175	0.680
14	-0.043	0.019	10.339	0.737
15	0.058	0.069	10.645	0.777
16	-0.042	-0.057	10.806	0.821
17	0.032	0.072	10.905	0.861
18	0.005	-0.059	10.908	0.898
19	-0.012	0.034	10.922	0.926
20	0.023	-0.061	10.975	0.947
21	-0.067	-0.043	11.442	0.953
22	-0.004	-0.013	11.443	0.968
23	-0.058	-0.114	11.805	0.973
24	-0.148	-0.126	14.192	0.942

Source: Authors' elaboration

In short, real evapotranspiration appears to be stationary in the long term, providing us with a certain degree of confidence in the hypothesis of constant water evapotranspiration during the period studied.

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Appendix 4.2: Production estimates

To estimate the volume of water for Spanish production it was necessary to get Spanish agrarian production for 1860, 1900, 1930, 1962 and 2008. On the whole, for the period 1860-1930 Spanish agrarian production data come from "Estadísticas Históricas de la Producción Agraria Española, 1859-1935" (GEHR, 1991). To reduce data volatility, we employed triennial production averages whenever possible. Crops for livestock feed are not considered, to avoid double counting.

Since "Estadísticas Históricas de la Producción Agraria Española", 1859-1935 do not provide data for most products in 1860, we used alternative sources. Specifically, data for physical production of wheat, rye, barley, oats, corn, rice, chickpeas, broad beans, beans, potatoes, sweet potatoes, wine, olive oil, flax, hemp, almonds, chestnuts, oranges, lemons, raisins, figs and olives have been taken from Bringas (2013), whose information is based on Navarro Faulo (1882). Data on sugar cane and sugar beet production were taken from Martín Rodriguez (1994). The remaining agricultural products were obtained by assuming that per capita production in 1860 and 1900 were the same. Thus, Spanish production minus exports in 1900 was divided by population in that year, obtaining the non-exported per capita production. Subsequently, we multiplied the former coefficient by the number of inhabitants in 1860 and, where information is available; we added exports in 1860 from foreign trade statistics for Spain. The next step involved estimating livestock production. Data on animal numbers were taken from GEHR (1991), which collects data from the "Censo de Ganadería" (Livestock Census) of 1865. We used these to estimate meat production, keeping in mind the age and sex of different livestock species, the average life of animals before slaughter, and the meat obtained from each animal, adult and young. To calculate the coefficients of conversion we used the livestock census of 1932 and the data for animals in the slaughterhouse of Zaragoza between 1870 and 1935 (Pinilla, 1995b). We took the data for milk from Hernández Adell (2012). The problem with production data for crops in 1860 stems from a serious underestimation, as Bringas (2013) points out. Nevertheless the livestock production data appear to be correct or, at worst, somewhat overestimated. In order to verify the quality of the data, we compared the differences in the monetary value of production in our calculations for 1860 and 1900. The result is disproportionate growth if compared with the growth of gross agricultural value added between 1860 and 1900, supplied by Prados de la Escosura (2003). To correct our estimate from 1860, and following the principal analyses (GEHR, 1978 and 1979; Bringas, 2013), we assumed that there exists a serious problem of the underestimation of crop production for 1860, while the data for animal production were correct. To resolve this problem, we have re-scaled crop production to its corresponding value assuming that the data from Prados de la Escosura are reliable.

For those goods for which we have no information for 1900, we assumed that their production followed a similar pattern to the nearest similar crop for which data were available. The following table provides information about the crops for which we have no data, the coefficients used, and the reference product or group of products used to obtain them. The main source is also given.

Table 4.3: Products with no data in 1900 and crops used to estimate their production

Data unavailable for	Similar crop
Grapes	production of wine
Raisins	production of wine
Olives	production of olive oil
Source: GEHR (1987)	
Sweet potatoes	potatoes
Walnuts	almonds
Dates	figs
Source: GEHR (1991)	
Tomatoes	horticultural products
Peppers	horticultural products
Artichokes	horticultural products
Asparagus	horticultural products
Green beans	horticultural products
Melons	horticultural products
Water melons	horticultural products
Aniseed	horticultural products
Source: GEHR (1983), Gallego (1986), Pinilla (1992)	

For livestock production data in 1900 we obtained the number of animals of each species from the livestock census for 1910. We then proceeded in a similar way for

1860 to estimate meat production. Data for milk are from Hernández Adell (2012), and the numbers for eggs come from the official data for 1908.

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CHAPTER 5.

THE EFFECT OF GLOBALISATION ON WATER CONSUMPTION: A CASE STUDY OF THE SPANISH VIRTUAL WATER TRADE, 1849-1935

1. Introduction

Those countries which experienced intensive economic growth during the Industrial Revolution profoundly modified their relationship to the environment. Such economies have, throughout the last two hundred years, caused serious damage to their natural environments, whether by modifying them extensively or by generating serious problems of pollution (McNeill, 2000; Krausmann et al., 2008; Stern and Kaufmann, 1996; Stern, 2005). Water ecosystems have been gravely affected by these long-term changes, the global water crisis being one of the challenges to be faced in the twenty-first century. Whereas the changing uses of energy and of raw materials have been closely studied from a long-term perspective (Iriarte and Ayuda, 2008 and 2012; Krausmann et al., 2009), water, another key resource for human subsistence and economic development, has traditionally received less attention from environmental history.

The seminal work of Shiklomanov (1998) was one of the first to perform estimates of long-term global water use trajectories by sectors and world regions, demonstrating their massive growth and the predominance of the agricultural use of water. As seen in chapters one and two, this growth was basically driven by population growth but also, and very significantly, by rising per capita income (Duarte et al., 2013 and 2014). The consumption of water has increased principally as a consequence of the formidable growth of agricultural production, leading to not only the use of more land but also the need to undertake significant water projects for the extension of irrigation in arid or semi-arid regions (Federico, 2005). Next to population growth and rising domestic demand for food and other biomass products, trade has been a major driving force. In this field, new studies presenting concepts such as virtual water or the water footprint have appeared over the last decade. First conceived by Allan (1997, 1999), virtual water has been defined as the volume of water required for the production of a commodity (Zimmer and Renault, 2003; Hoekstra and Hung, 2005; Yang et al., 2007). Thus, virtual water trade is the volume of water embodied in products exchanged internationally. While water itself is a not a significant commodity in international trade, exchanges of agricultural commodities are related to large volumes of upstream water use (Hoekstra et al., 2011; Mekonnen and Hoekstra, 2011 and 2012). In fact, Hoekstra and Hung (2005) have shown that international virtual water flows related to trade in crops amounted to 695 billion cubic metres (Gm^3), on average, in the period 1995-1999, equivalent to 13% of all the water used for crop production. Currently, many studies of water resources tend to distinguish between green and blue water, since although they are interrelated in the hydrological system they present different characteristics. Green water refers to the volume of rainwater (stored in soil as moisture) evaporating during a production process and blue water is the volume of surface or groundwater evaporating as a result of the production of a commodity (Hoekstra and Chapagain, 2008). Blue water can be reallocated to agricultural, industrial, or urban use; by contrast, green water cannot be easily reallocated (Yang et al., 2007). Accordingly, blue water has greater opportunity costs (Hoekstra, 2010). Green water is particularly important for agricultural and forestry products; it consists of total rainwater evapotranspiration plus the water incorporated into the harvested crop or wood (Hoekstra et al., 2011).

Using this general framework, our paper aims to study the roles that international trade expansion and the process of economic globalisation have played in increasing global pressures on water resources. This historical analysis is relevant to the wider context of ecological economics. In fact, as Schandl and Schulz (2002) have stated, “understanding how a certain natural relation has been established in the course of history and which patterns and feedbacks were at work might enable society to consciously intervene in these natural relations and might even eventually foster our understanding of sustainability”. Addressing virtual water flows from a long-term perspective allows us to qualitatively and quantitatively study shifts in water sustainability in a period of important institutional and structural changes regarding trade and irrigation infrastructure. The increasing integration of Spain into the first globalisation meant that foreign demand for agricultural products was one of the most important driving forces behind the development of irrigation, and therefore behind early displacements of environmental burdens, particularly of water. Furthermore, the first globalisation laid the foundations for a much more intensive process of economic growth and environmental damage which occurred during the second globalisation.

Against this background, our study examines agri-food virtual water trade flows over time, their composition and their underlying economic factors. The period chosen coincides with the first globalisation, which occurred between 1850 and 1929 and collapsed following the crash in 1929. From 1849 to 1935, the exchange of agricultural raw materials and food was of enormous importance in world trade (Lewis, 1952). Trade in agricultural products and food increased worldwide between 1850 and 1902 at an average annual rate of 3.7%, and between 1903 and 1938 at a much slower pace, 1.4%. This deceleration was mainly due to the impact of the First World War, the collapse of the first globalisation produced by the crisis of 1929 and the measures adopted by various countries in its wake (Aparicio et al., 2009).

As a case study, we have chosen Spain, which was an important exporter of agricultural products in the period analysed. The period chosen is quite meaningful for Spain. It commences with Spanish integration into international markets, producing intensive growth in agricultural exports, taking advantage of demand from the more developed European countries. This period ended in 1936 with the beginning of the Spanish Civil War. Beginning in 1939, Franco's dictatorship meant approximately 20 years of isolation. The first and second globalisation periods must be studied separately since they differ, among other elements, in their scale and in the share of agriculture in GDP. During the period under analysis, the Spanish economy embarked upon the long-term process of industrialization which was abruptly interrupted in 1936, continued during the early years of Franco's dictatorship and ended in the 1960s. The study of the Spanish case can offer important lessons for developing countries whose integration in international markets is growing.

For this country and period, we are interested in answering the following questions. What volume of water was embodied in agricultural and food exports and imports? How did this variable evolve over time? What factors lay behind such evolution? Was virtual water trade a driving force for overall water consumption in Spain?

We relate the data to their historical context and establish the role played by trade composition, the increasing volume of trade, and water intensities in the final net balance of water. So far, no other study has analysed virtual water trade flows from a long-term perspective.

The article is organised as follows. Section 2 provides a stylised view of the evolution of Spanish foreign trade in agricultural products during the first wave of globalisation and the early years of its collapse. Section 3 reviews the methodology and the data used. Section 4 presents the main results of our analysis and is divided into two subsections: Section 4.1 focuses on the principal trends and composition of virtual water trade flows, while section 4.2 performs a decomposition analysis of virtual water exports and imports. Finally, section 5 closes the paper with a discussion of the results and our conclusions.

2. Spain's position in the international markets for agricultural products: some stylised facts

From the middle of the ninetieth century onwards, the institutional changes promoted by Liberal governments were complete, making the development of a market economy possible. The deregulation of trade from 1869 onwards and the growth in agricultural exports, taking advantage of demand from the more developed European countries, increased the degree of integration of Spain into international markets.

Between 1850 and 1935, food and other agricultural products accounted for between 60% and 75% of total Spanish exports (measured in constant prices of 1910), and only the boom in mining exports, which took place between 1890 and 1920, caused this percentage to fall to approximately 50%.

Between 1850 and 1891, Spanish agricultural exports were concentrated on Mediterranean products, in which it had a clear competitive advantage. The growing demand for wine imports in France, as a result of the phylloxera plague that devastated French vineyards, provided an authentic export boom for Spain. Between 1870 and 1890, wine represented 53% of Spanish agricultural exports (measured in constant prices of 1910); when nuts and olive oil were added, this sector's share of total exports reached two thirds (Pinilla, 1995). The growth of exports was rapid between 1850 and 1890, as agricultural and food exports by volume increased at an average annual rate of 3.2%, thereby increasing by over 300% in four decades (Gallego and Pinilla, 1996). These products were principally cultivated on rain-fed land, although they were also partly cultivated on irrigated land, creating a moderate pressure on the need for water for agricultural uses. These crops were very well adapted to their natural and climate conditions (land, hours of sunshine, temperature) whenever water was available. In the final decade of the ninetieth century, the expansion of traditional exports (wine and olive oil) was sharply halted. In the case of the most important product, table wine, the ending in 1891 of the wine trade agreement with France, and the French choice to import wine from Algeria, which had a more favourable tariff treatment, ended the golden age of Spanish wine exports (Pinilla and Ayuda, 2002). Alternative markets did not compensate for the loss of that of France, while further restrictions were due to lower levels of wine consumption, protectionist policies in Argentina and Uruguay, and Prohibition in the USA (Pinilla and Ayuda, 2008; Pinilla and Serrano, 2008). Exports of olive oil also encountered serious difficulties, due to the employment of other, cheaper oils for industrial use, and to the low level of consumption in non-Mediterranean countries (Ramón, 2000).

Consequently, the rate of growth of exports fell markedly and from 1890 to 1930 grew at an average annual rate of only 1.3%. The most important factor from the end of the ninetieth century onwards was the growth of Mediterranean horticultural products as the principal items in Spanish agricultural exports. Before 1890, these constituted no more than 15% of exports (measured in constant prices of 1910), but then became the most important element. At the turn of the century they represented 25% of Spanish agricultural exports (measured in constant prices of 1910), and by 1930 accounted for approximately 50%. The volume of exports of fresh fruit, the most important in this group, was 63 times greater in the 1930s than it had been in the 1850s (Pinilla and Ayuda, 2010). Between 1900 and 1935, Spain accounted for over one third of the world exports of Mediterranean horticultural products (Pinilla and Ayuda, 2009). For oranges alone, the share of Spain ranged between 50 and 60% of world exports (measured in constant prices of 1910).

On the imports side, Spanish trade policy evolved from a high degree of protectionism from 1820 onwards to a significant liberalisation, beginning in 1869. Subsequently, approximately half of imports were products characteristic of tropical zones, not cultivated in Spain, such as sugar, cotton, coffee, cocoa and tobacco. From 1891 onwards, and principally as a consequence of the agricultural depression at the turn of the century, a move towards protectionism occurred, which in the case of agricultural products tended to be selective. Especially protected were certain products which facilitated the development of the agro-industry in Spain, such as wheat (Gallego, 2001 and 2003).

The Spanish agri-food trade expansion described above had its counterpart in the need for water to produce the goods traded, at a time when additional potential pressures on domestic resources were curbed through imports. Accordingly, water was essential for the development of trade flows. Analysis of the consequences of this globalisation process cannot be performed by looking solely at monetary or physical trade flows, but requires a virtual water perspective. These virtual water flows can be calculated and analysed on the basis of the methodology and data described in the following section.

3. Methodology and data

3.1. Methodological aspects

Our starting point is the calculation of virtual water trade flows for agri-food products, following the approach developed by Hoekstra and Hung (2005).

For a country *c* (Spain in our case), in year *t,* the virtual water flow (m^3/year) associated with exports can be obtained as the sum of the virtual water content in each of its exported products *p*:

$$VWX(c,t) = \sum_p d_p^c(c,p,t) * x_p^c(c,p,t) \qquad (5.1)$$

Where x_p^c denotes the physical quantity of product *p* exported and d_p^c denotes the specific demand for water for each product (physical water intensity) in the exporting country. We will distinguish between green and blue virtual water flows, depending on whether d_p^c represents green or blue water content.

Similarly, the virtual water content of the imports for country *c* can be calculated as the sum of the virtual water content of the imported goods *p* emanating from the different countries *z* which are the origin of imports.

$$VWM(c,t) = \sum_{p,z} d_p^Z(z,p,t) * m_p^z(z,p,t) \qquad (5.2)$$

with d_p^Z being the physical water intensity (m^3/Tons) in country z for product *p*, and m_p^z the imports (Tons) of product *p* emanating from country *z*. Thus, the virtual water trade balance for a country can be defined as:

$$VWB(c,t) = VWX(c,t) - VWM(c,t) \qquad (5.3)$$

The expressions above are calculated for blue and green water. Having obtained the virtual water flows and balances, we proceed to analyse their underlying economic drivers. This consists of two steps. Firstly, virtual water exports and imports are expressed in terms of economic trade flows and, more specifically, a comparison is made of the contributions of size, product and country of origin to the changes observed in economic and water flows. Secondly, in order to analytically study trends in virtual water flows and disentangle the forces contributing to this trend, a form of Decomposition Analysis (DA) is applied.

From the equations above, water exports and water imports can be expressed, in general terms, as dependent on three kinds of factor: water intensity, trade composition and trade scale.

More concretely, Spanish virtual water exports can be written as:

$$VWX(c,t) = \sum_p w_{cpt} \cdot \left(\frac{e_{cpt}}{e_{ct}}\right) e_{ct} \qquad (5.4)$$

Expressing the information by products in matrix form, we can write:

$$\mathbf{VWX}'(\mathbf{c},\mathbf{t}) = \mathbf{w}'_{\mathbf{ct}}\hat{\mathbf{F}}_{\mathbf{ct}} e_{ct} \qquad (5.5)$$

where $\mathbf{w}'_{\mathrm{ct}}$ is a vector including the virtual water content of each product in Spain, measured in m^3/peseta; that is to say, water intensity. $\hat{\mathbf{F}}_{\mathrm{ct}}$ is a diagonal matrix of the share of each product in total Spanish exports in period t, and e_{ct} is a scalar containing the total value of Spanish exports in year t (in pesetas).

The decomposition of virtual water imports can be given as follows:

$$VWM(c,t) = \sum_{p,z} w_{cpzt} \cdot \frac{m_{cpzt}}{m_{cpt}} \cdot \frac{m_{cpt}}{m_{ct}} m_{ct} \qquad (5.6)$$

And expressed by products

$$\mathbf{VWM}'(\mathbf{c},\mathbf{t}) = \mathbf{w}'_{\mathbf{czt}} \mathbf{M}_{\mathbf{czt}} \widehat{\mathbf{B}}_{\mathbf{ct}} m_{ct} \qquad (5.7)$$

in which $\mathbf{w}'_{\mathrm{czt}}$ is a vector of the adequate dimension computing the virtual water content for each product in each of the country of origin *z*,measured in m^3/pesetas; in other words, the water intensity. $\mathbf{M}_{\mathrm{czt}}$ is a matrix with information concerning the share that each country *z* represents in Spanish imports of each product, $\widehat{\mathbf{B}}_{\mathrm{ct}}$ is a diagonal matrix of the share of each product in total Spanish imports, and m_{ct} is a scalar representing the total value of Spanish imports in year t (in pesetas).

As shall be explained in section 3.2 of this chapter, water intensity coefficients have been constructed on the basis of Mekonnen and Hoekstra (2011; 2012). These coefficients represent the volume of water (green or blue) necessary (in m^3) to produce a ton of crop or livestock. They differ among countries and products and, as the data section will explain, they vary as a function of historical yield series.

Changes in trade components would imply changes in the volume of virtual water exports and imports and, consequently, changes in the country's water balance. From the empirical point of view, one assumption must be introduced, due to the lack of information for the period analysed. When dealing with historical trade data, we find one or more significant commercial partners for each product. Thus, when working with imports, we have chosen the specific water coefficient of the country with the largest volume of Spanish imports; otherwise, in those cases where several countries display a significant weight in Spanish imports, we have computed a simple average of water coefficients for each of these nations.

Applying the former assumption, equation (5.7) becomes:

$$\mathbf{VWM}'(\mathbf{c},\mathbf{t}) = \mathbf{w}'_{\mathbf{cz}}\widehat{\mathbf{B}}_{\mathbf{ct}}m_{ct} \qquad (5.8)$$

Note that $VWX(c,t) = \mathbf{VWX}'(\mathbf{c},\mathbf{t})\mathbf{u}$ and $VWM(c,t) = \mathbf{VWM}'(\mathbf{c},\mathbf{t})\mathbf{u}$ being $\mathbf{u}$ a column vector of ones and the same holds for the different effects obtained below.

DA has been applied to equations (5.5) and (5.8), to synthesise the driving forces responsible for virtual water exports and virtual water imports, respectively. This approach attempts to separate a time trend of an aggregate variable into a group of driving forces that can act as accelerators or retardants (Dietzenbacher and Los, 1998; Hoekstra and van den Bergh, 2002; Lenzen et al., 2001).

Generally speaking, considering a variable *y* depending on *n* explicative factors $y=f(x_1,\ldots x_n)$, an additive structural decomposition can be obtained through its total differential.

$$dy = \frac{\partial y}{\partial x_1}dx_1 + \frac{\partial y}{\partial x_2}dx_2 + \cdots + \frac{\partial y}{\partial x_n}dx_n \qquad (5.9)$$

On the basis of a multiplicative relationship, that is to say $y=x_1\ldots.x_n$, expression (5.9) holds:

$$dy = (x_2x_3\ldots x_n)dx_1 + \cdots + (x_1x_2x_3\ldots x_{n-1})dx_n = \sum_{i=1}^{n}\left(\prod_{j\neq i} x_j\, dx_i\right) \qquad (5.10)$$

If decomposition is based on three factors, we obtain the following 3! exact decompositions. In practice, the average of two decompositions is considered to be a good approximation for the calculation of the contribution of the different factors.

Thus, the two polar decompositions of (5.5) can be written as follows:

$$\Delta\mathbf{VWX}'(\mathbf{c}) = \Delta\mathbf{w}'_{\mathbf{c}}\widehat{\mathbf{F}}_{\mathbf{ct-1}}e_{ct-1} + \mathbf{w}'_{\mathbf{ct}}\Delta\widehat{\mathbf{F}}_{\mathbf{c}}e_{ct-1} + \mathbf{w}'_{\mathbf{ct}}\widehat{\mathbf{F}}_{\mathbf{ct}}\Delta e_c \qquad (5.11)$$

$$\Delta\mathbf{VWX}'(\mathbf{c}) = \Delta\mathbf{w}'_{\mathbf{c}}\widehat{\mathbf{F}}_{\mathbf{ct}}e_{ct} + \mathbf{w}'_{\mathbf{ct-1}}\Delta\widehat{\mathbf{F}}_{\mathbf{c}}e_{ct} + \mathbf{w}'_{\mathbf{ct-1}}\widehat{\mathbf{F}}_{\mathbf{ct-1}}\Delta e_{\mathrm{c}} \qquad (5.12)$$

Furthermore, based on (5.8) we obtain its two polar decompositions, which yield:

$$\Delta\mathbf{VWM}'(\mathbf{c}) = \Delta\mathbf{w}'_{\mathbf{cz}}\widehat{\mathbf{B}}_{\mathbf{ct-1}}m_{ct-1} + \mathbf{w}'_{\mathbf{czt}}\Delta\widehat{\mathbf{B}}_{\mathbf{c}}m_{ct-1} + \mathbf{w}'_{\mathbf{czt}}\widehat{\mathbf{B}}_{\mathbf{ct}}\Delta m_c \qquad (5.13)$$

$$\Delta\mathbf{VWM}'(\mathbf{c}) = \Delta\mathbf{w}'_{\mathbf{cz}}\widehat{\mathbf{B}}_{\mathbf{ct}}m_{ct} + \mathbf{w}'_{\mathbf{czt-1}}\Delta\widehat{\mathbf{B}}_{\mathbf{c}}m_{ct} + \mathbf{w}'_{\mathbf{czt-1}}\widehat{\mathbf{B}}_{\mathbf{ct-1}}\Delta m_c \qquad (5.14)$$

Taking the average of (5.11) and (5.12) we obtain (5.15):

$$\Delta\mathbf{VWX}'(\mathbf{c}) = \frac{\Delta\mathbf{w}'_{\mathbf{c}}\widehat{\mathbf{F}}_{\mathbf{ct-1}}e_{ct-1} + \Delta\mathbf{w}'_{\mathbf{c}}\widehat{\mathbf{F}}_{\mathbf{ct}}e_{ct}}{2} + \frac{\mathbf{w}'_{\mathbf{ct}}\Delta\widehat{\mathbf{F}}_{\mathbf{c}}e_{ct-1} + \mathbf{w}'_{\mathbf{ct-1}}\Delta\widehat{\mathbf{F}}_{\mathbf{c}}e_{ct}}{2} + \frac{\mathbf{w}'_{\mathbf{ct}}\widehat{\mathbf{F}}_{\mathbf{ct}}\Delta e_c + \mathbf{w}'_{\mathbf{ct-1}}\widehat{\mathbf{F}}_{\mathbf{ct-1}}\Delta e_c}{2} \qquad (5.15)$$

Proceeding the same way with (5.13) and (5.14) gives equation (5.16):

$$\Delta\mathbf{VWM}'(\mathbf{c}) = \frac{\Delta\mathbf{w}'_{\mathbf{cz}}\widehat{\mathbf{B}}_{\mathbf{ct-1}}m_{ct-1} + \Delta\mathbf{w}'_{\mathbf{cz}}\widehat{\mathbf{B}}_{\mathbf{ct}}m_{ct}}{2} + \frac{\mathbf{w}'_{\mathbf{czt}}\Delta\widehat{\mathbf{B}}_{\mathbf{c}}m_{ct-1} + \mathbf{w}'_{\mathbf{czt-1}}\Delta\widehat{\mathbf{B}}_{\mathbf{c}}m_{ct}}{2} + \frac{\mathbf{w}'_{\mathbf{czt}}\widehat{\mathbf{B}}_{\mathbf{ct}}\Delta m_c + \mathbf{w}'_{\mathbf{czt-1}}\widehat{\mathbf{B}}_{\mathbf{ct-1}}\Delta m_c}{2} \qquad (5.16)$$

As a result, trends in virtual water flows can be explained by:

- The scale effect, which links changes in virtual water flows to changes in the volume of trade; it can be expressed by (5.17) for exports and (5.18) for imports:

$$\mathbf{SE'_e}(\mathbf{c}) = \frac{\mathbf{w}'_{\mathbf{ct}}\widehat{\mathbf{F}}_{\mathbf{ct}}\Delta e_c + \mathbf{w}'_{\mathbf{ct-1}}\widehat{\mathbf{F}}_{\mathbf{ct-1}}\Delta e_c}{2} \qquad (5.17)$$

$$\mathbf{SE'_{m=}}(\mathbf{c}) \frac{\mathbf{w}'_{\mathbf{czt}}\widehat{\mathbf{B}}_{\mathbf{ct}}\Delta m_c + \mathbf{w}'_{\mathbf{czt-1}}\widehat{\mathbf{B}}_{\mathbf{ct-1}}\Delta m_c}{2} \qquad (5.18)$$

- The composition effect, which explains changes in water virtual flows depending on changes in the share of products in trade; it is given by (5.19) for exports and (5.20) for imports:

$$\mathbf{CE'_e}(\mathbf{c}) = \frac{\mathbf{w}'_{\mathbf{ct}}\Delta\widehat{\mathbf{F}}_{\mathbf{c}}e_{ct-1} + \mathbf{w}'_{\mathbf{ct-1}}\Delta\widehat{\mathbf{F}}_{\mathbf{c}}e_{ct}}{2} \qquad (5.19)$$

$$\mathbf{CE'_m}(\mathbf{c}) = \frac{\mathbf{w}'_{\mathbf{czt}}\Delta\widehat{\mathbf{B}}_{\mathbf{c}}m_{ct-1} + \mathbf{w}'_{\mathbf{czt-1}}\Delta\widehat{\mathbf{B}}_{\mathbf{c}}m_{ct}}{2} \qquad (5.20)$$

- The water intensity effect, which measures the extent to which variations in water intensities contribute to changes in virtual water flows. It is shown in (5.21) for exports and (5.22) for imports:

$$\mathbf{IE'_e(c)} = \frac{\Delta\mathbf{w'_c}\hat{\mathbf{F}}_{\mathbf{ct-1}}e_{ct-1} + \Delta\mathbf{w'_c}\hat{\mathbf{F}}_{\mathbf{ct}}e_{ct}}{2} \quad (5.21)$$

$$\mathbf{IE'_m(c)} = \frac{\Delta\mathbf{w'_{cz}}\hat{\mathbf{B}}_{\mathbf{ct-1}}m_{ct-1} + \Delta\mathbf{w'_{cz}}\hat{\mathbf{B}}_{\mathbf{ct}}m_{ct}}{2} \quad (5.22)$$

Thus, this approach would allow us to separate the effect of trade patterns, trade volumes and water intensities on virtual water imports and export trends. It permits us to advance a hypothesis regarding the size of the increase in water flows without the key role of trade increase, without product compositional change or even without water intensity changes.

3.2. Data

Spanish data for the agri-food trade during the period 1849-1935 come from "Estadísticas del Comercio Exterior de España" (1849-1935). These data, compiled by Gallego and Pinilla (1996) present import and export flows in monetary and physical units. We work with a sample of 148 products for exports and 118 products for imports, over the years 1849 to 1935. This sample accounts, on average, for approximately 90% of total Spanish agri-food trade. When applying the decomposition analysis, data for trade values measured in constant prices are needed; therefore, monetary trade values are deflated and given in constant 1910 prices. In the discussion section we use data on the volume of agricultural and food production in Spain from "Estadísticas Históricas de la Producción Agraria Española", 1859-1935 (GEHR, 1991).

Data for specific water demand for crops, or derived crop products (by individual countries), have been taken from Mekonnen and Hoekstra (2011), while water coefficients for farm animals and animal products come from Mekonnen and Hoekstra (2012) and are average coefficients for the period 1996-2005. These coefficients compute water volumes per physical unit of production. Since water intensities depend on geographical and physical conditions which may have changed from the middle of the ninetieth century until today, the coefficients from Mekonnen and Hoekstra (2011; 2012), obtained as the ratio between evapotranspiration (ET) and yields (Y), have been modified to approximate this fact. Assuming that the main climatic and crop characteristics in Spain have remained stable over time, that is to say

ET has remained constant (see appendix 4.1 for an analysis of potential uncertainties), water coefficients have been adapted depending on the yields of national series, in line with Dalin et al. (2012) and Konar et al. (2013):

$$w_{cpt} = w_{cp}\frac{Y_{cp}}{Y_{cpt}} \qquad (5.23)$$

where w_{cpt} is the variable water coefficient for each product in the period of analysis, or *t=1849...1935*. w_{cp} is the crop or livestock water intensity given by Mekonnen and Hoekstra (2011, 2012). Y_{cp} represents the average yield of the reference period (1996-2005) considered by the above authors. These data have been taken from FAO (2013) and distinguish the yields of the different goods. Y_{cpt} gives information on annual product yields for 1849-1935. Historical Spanish yields come from "Estadísticas Históricas de la Producción Agraria Española, 1859-1935" (GEHR, 1991), whereas for trade partners past yields are provided by the International Institute of Agriculture (1910-1939). Consequently, when accounting for changes in yields we consider the significant technological developments, such as irrigation or improvements in seeds, which occurred from 1850 to the present day. The hypothesis underlying this approach is that technological advances have affected crop and livestock yields in the long term and have notably influenced water consumption per ton in the long term[14].

4. Results

In order to better organise the results, this section is divided into two subsections: the analysis of virtual water trade flows (section 4.1) and the quantification of the factors that entail changes in virtual water trade (section 4.2).

4.1. Analysis of virtual water trade flows

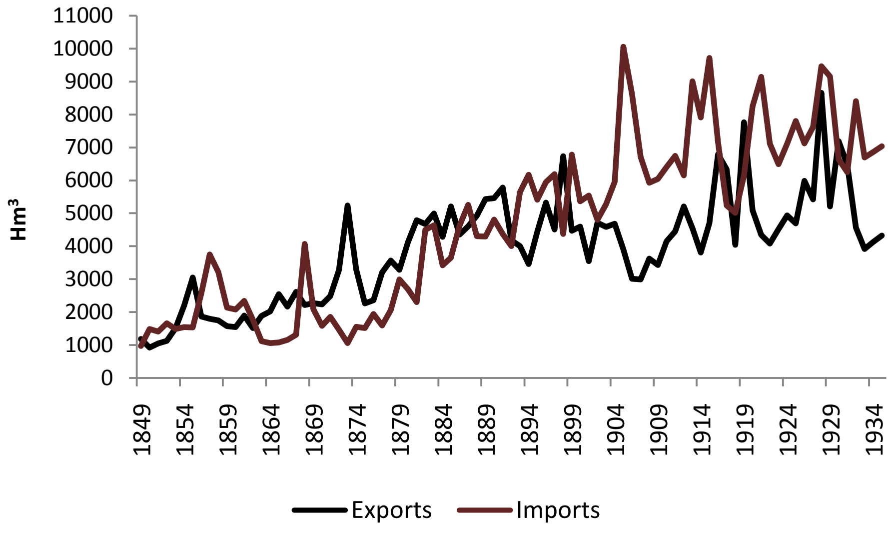
On the whole, virtual water exports and virtual water imports display a rising pattern throughout the period 1849-1935 (Figure 5.1), green water being much larger than blue water in both (80% for exports and 90% for imports, on average). Nevertheless, the importance of blue water for total virtual water trade has not remained constant.

[14]Results have also been obtained keeping water intensities constant, namely by assuming that historical yield changes do not affect water intensities. This alternative method yields lower water consumptions, but the general results and conclusions do not vary (see appendix 5.1 for more details).

Whereas blue water was less than 15% of total virtual water exports during the last years of the ninetieth century, it accounted for 23% by 1930, which could be explained by the notable expansion of irrigation occurring during these years. For imports the share of blue water also changed, but more gradually.

Virtual water exports grew at an annual average rate of 1.5%, from around 917 hm^3 in 1850 to over 4,000 hm^3 before the Spanish Civil War (Figure 5.1). Nevertheless, this growth was not homogeneous over the period considered. An upward trend in virtual water exports is apparent, with annual growth of 2.8% until 1903 and a smooth deceleration from then on, to increase at 1.4% annually. However, virtual water exports clearly plunged from 1929 onwards, decreasing by 7% per annum, as a consequence of the contraction of trade caused by the Great Depression. Virtual water imports also display an upward trend, which was nevertheless flat during the first two decades of the study period, when the Spanish economy was largely closed to the entry of goods from abroad. From 1870 onwards, this trajectory rose at an annual rate of 2.7% until 1929. From then on, virtual water imports decreased by 2.3% annually, a less dramatic fall than that observed for Spanish exports.

Figure 5.1: Total virtual water flows (1849-1935) hm^3/year

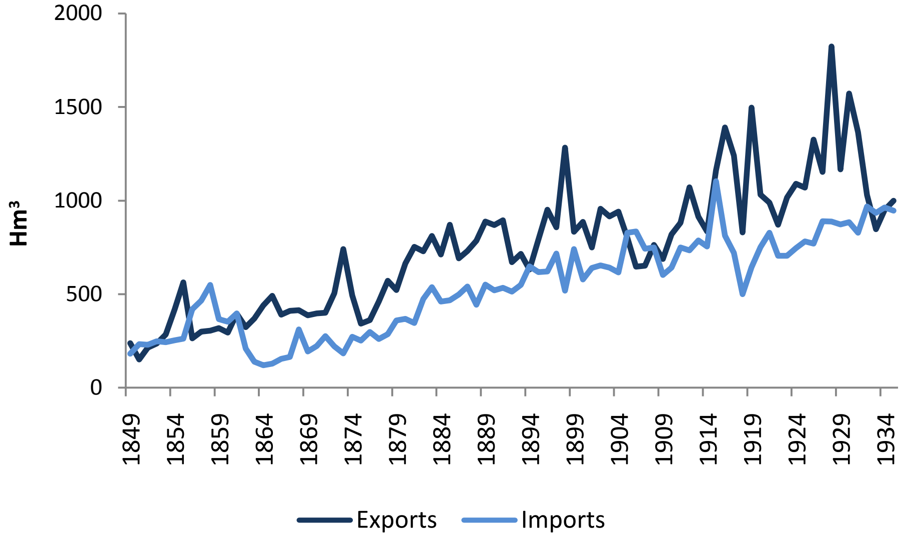


Source: Authors' elaboration based on Statistics of Spain for foreign trade, extracted by Gallego and Pinilla (1996). Sum of green and blue water flows.

Figure 5.2 shows blue virtual water flows, both exports and imports, which grew at a similar pace until 1905. However, whereas virtual water imports rose by 0.7% from

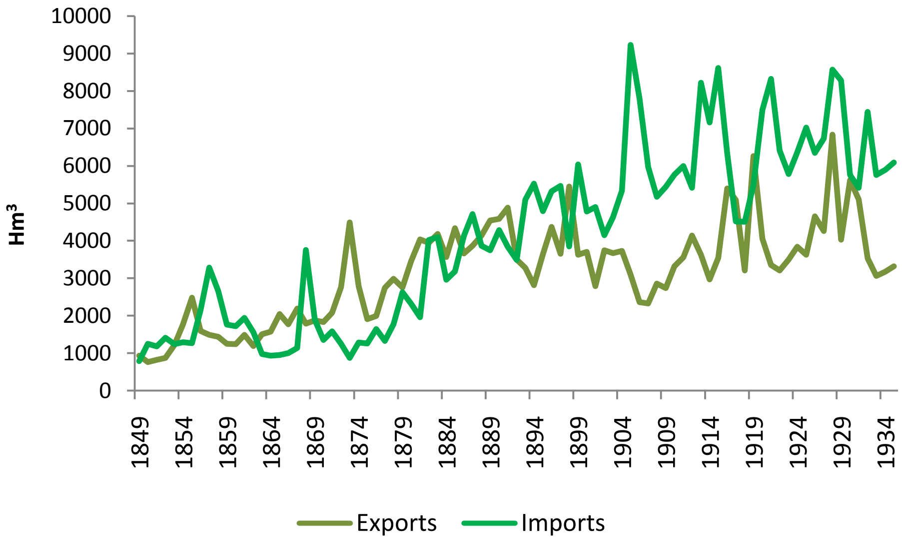
1905 to 1935, virtual water exports rose, at 2.7% annually, until 1929 onwards, when they plunged by 7% annually until 1935.

Figure 5.2: Blue virtual water flows (1849-1935) hm^3/year



Source: Authors' elaboration, based on Statistics of Spain for foreign trade and extracted by Gallego and Pinilla (1996).

Figure 5.3: Green virtual water flows (1849-1935) hm^3/year



Source: Authors' elaboration, based onStatistics of Spain for foreign trade and extracted by Gallego and Pinilla (1996).

Spain appears as a net exporter of blue water from 1862, and the largest net exports are to be found between 1916 and 1931. These data reflect the strong growth of exports of Mediterranean horticultural products taking place from the end of the ninetieth century onwards. The green water balance (Figure 5.3) followed nearly the same path as the overall figure and contributes notably to total virtual water. That is to say, net Spanish imports of green virtual water continued to expand, particularly from 1890 onwards.

An overview of the evolution of virtual water trade by agri-food products is summarised in Tables 5.1 and 5.2, which respectively present the average share of virtual green and blue water exports and imports of agricultural and food products, and their growth rates, for the 16 groups comprising such trade.

Table 5.1: Green and blue virtual water exports, by product group (average share %)

	1850-1870	*1871-1890*	*1891-1914*	*1915-1929*	*1930-1935*	*1850-1870*	*1871-1890*	*1891-1914*	*1915-1929*	*1930-1935*
Sitc rev.1 product classification	**Green VWX**					**Blue VWX**				
00. Live animals	5.0	6.6	11.9	1.7	1.1	3.5	5.4	13.0	1.7	1.1
04. Cereals and preparations	17.8	10.0	2.7	3.5	1.2	24.6	5.6	5.4	9.8	6.1
22. Oil seeds	0.1	0.0	0.2	1.3	0.0	0.3	0.1	0.4	3.3	0.2
26. Textile fibres	0.0	0.0	0.1	0.3	0.3	0.8	0.6	1.0	3.9	6.1
TOTAL BULK PRODUCTS	22.9	16.7	14.9	6.8	2.8	29.2	11.7	19.8	18.6	13.5
06. Sugar	0.1	0.0	0.1	0.1	0.0	0.6	0.0	0.4	0.5	0.0
07. Coffee, tea, cocoa and spices	0.1	0.1	0.2	0.2	0.2	0.5	0.7	1.0	0.9	1.0
TOTAL PLANTATION PRODUCTS	0.2	0.1	0.2	0.3	0.2	1.1	0.7	1.3	1.4	1.0
01. Meat	0.2	0.0	0.1	0.1	0.1	0.2	0.0	0.0	0.1	0.0
02. Dairy products and eggs	0.2	0.2	0.1	0.0	0.0	0.1	0.1	0.0	0.0	0.0
05. Fruits and vegetables	25.0	19.4	25.6	25.4	34.3	22.5	21.1	27.5	26.5	36.2
08. Animal feed	0.8	0.7	0.2	0.1	0.2	0.1	0.2	0.0	0.0	0.0
11. Beverages	25.4	45.4	33.2	27.1	17.1	20.0	43.3	26.0	18.0	10.9
12. Tobacco	0.9	0.3	0.0	0.0	0.0	1.1	0.5	0.0	0.0	0.0
21. Leather and hides	0.3	0.6	1.0	1.9	4.1	0.2	0.6	0.9	1.3	3.3
41. Animal fats	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
42. Vegetable oils	24.1	16.6	24.6	38.3	41.2	25.5	21.7	24.3	34.1	35.1
TOTAL HIGH VALUE PRODUCTS	76.8	83.2	84.9	92.9	97.0	69.7	87.5	78.9	80.0	85.5
TOTAL	100	100	100	100	100	100	100	100	100	100

Source: Authors' elaboration based on Statistics of Spain for foreign trade and extracted by Gallego and Pinilla (1996). VWX: Virtual water exports.

Table 5.1 shows that throughout the period three product groups constituted over 70% of green virtual water exports: olive oil, wine, and fruit and vegetables. Until 1891, the importance of wine rose, while from the end of the golden era of exports to France they declined continuously. In parallel, fruits and vegetables occupied a key position, initially as a consequence of the great importance of exports of nuts, which were not particularly water intensive but were exported in great quantities, due to the strong growth of fresh fruits and vegetables. Olive oil was always important, but after 1914, following an improvement in the refining of oil that gave low quality oils a mild taste adequate for food consumption, its weight increased still further (Zambrana, 1985). Finally, two types of products which were initially important, cereals and live animals, declined sharply: the export of wheat to Cuba disappeared following the Spanish-American War and the loss of the last remaining colonies, while exports of cattle to Great Britain also fell drastically.

In the case of virtual blue water, fruits and fresh vegetables were one of the most important products in this group. Initially, products such as nuts, raisins and table grapes were the most important within this group, but from the final decades of the ninetieth century onwards, fresh fruits and vegetables were predominant. During the first decades, hazelnuts, almonds, and raisins were the most significant products, but from 1880 onwards oranges became the most important, accounting for approximately 25% of total virtual water exports of fruits and vegetables. The importance of exports of olive oil and wine explains the significant contribution of the product groups included in virtual blue water exports[15]. The last important group is that of cereals, initially as a consequence of the importance of the above mentioned exports of wheat to Cuba, and from the end of the ninetieth century, exports of rice, a crop with a high blue water content, increased markedly.

Table 5.2 shows the average shares of Spanish virtual water imports. In this case, the compositional change appears to be less sharp than that observed in the case of exports. Firstly, coffee and cocoa were important drivers of Spanish virtual green water imports. Secondly, the other plantation product, sugar, notably decreased its contribution to virtual green water imports over the period of study. The high tariffs placed on sugar from abroad, following the loss of Cuba and Puerto Rico in 1898, made imports marginal. Textile fibres also made an important contribution to green water imports, with cotton, an essential raw material for the growing textile industry, being

[15]These crops can be grown under arid conditions reasonably well, yet traditionally occupied important areas of irrigation, to ensure high and reliable yields.

the most representative fibre. Virtual green water imports of cereals were quite variable. The oscillations of tariff policies regarding wheat, which were prohibitionist between 1820 and 1869, subsequently liberal, and then protectionist after 1891 (although there were significant imports in years of poor national production), form part of the explanation (Gallego, 2003 and 2004). Furthermore, it must be taken into account that considerable imports of maize took place following the First World War, to feed livestock. In the case of virtual blue water imports, cotton -almost alone- accounted for over two thirds of such imports throughout the period. Without the key role of cotton, imports of this type of virtual water products would have been drastically reduced.

Table 5.2: Green and blue virtual water imports by product group (average share %)

	1850-1870	*1871-1890*	*1891-1914*	*1915-1929*	*1930-1935*	*1850-1870*	*1871-1890*	*1891-1914*	*1915-1929*	*1930-1935*
Sitc rev.1 product classification	**Green VWM**					**Blue VWM**				
00. Live animals	11.0	7.3	9.7	2.2	1.4	4.0	3.9	5.2	1.1	0.4
04. Cereals and preparations	12.7	29.3	31.3	28.9	9.0	7.6	14.2	12.6	9.2	1.5
22. Oilseeds	0.1	0.8	10.3	9.4	7.2	0.0	0.2	3.1	3.7	3.8
26. Textile fibres	33.6	33.9	33.9	39.4	51.0	79.0	72.8	73.0	72.1	70.8
TOTAL BULK PRODUCTS	57.4	71.3	85.2	79.9	68.5	90.5	91.1	93.9	86.0	76.6
06. Sugar	8.6	5.9	1.1	0.9	0.0	7.6	5.2	1.1	1.1	0.0
07. Coffee, tea, cocoa and spices	27.4	13.2	7.1	10.6	13.0	1.4	1.3	1.7	3.1	3.0
TOTAL PLANTATION PRODUCTS	36.0	19.1	8.1	11.5	13.0	8.9	6.5	2.8	4.2	3.0
01. Meat	0.0	0.8	0.1	0.1	0.2	0.0	0.7	0.2	0.2	0.1
02. Dairy products and eggs	0.2	0.8	1.5	4.0	13.1	0.2	1.1	2.6	7.4	18.3
05. Fruits and vegetables	0.9	2.7	1.9	1.8	2.0	0.2	0.4	0.3	1.9	1.7
08. Animal feed	0.0	0.2	0.3	0.5	0.4	0.0	0.1	0.2	0.3	0.2
11. Beverages	1.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
12. Tobacco	4.1	4.2	2.2	2.0	2.5	0.0	0.0	0.0	0.0	0.0
21. Leather and hides	0.0	0.1	0.1	0.1	0.3	0.0	0.0	0.1	0.1	0.1
41. Animal fats	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
42. Vegetable oils	0.2	0.8	0.4	0.1	0.1	0.0	0.1	0.1	0.0	0.0
TOTAL HIGH VALUE PRODUCTS	6.6	9.7	6.7	8.6	18.5	0.5	2.4	3.3	9.8	20.4
TOTAL	100	100	100	100	100	100	100	100	100	100

Source: Authors' elaboration, based on Statistics of Spain for foreign trade and extracted by Gallego and Pinilla (1996). VWM: Virtual water imports.

4.2. Decomposition analysis of virtual water trade flows

Having identified virtual water trade trends and composition patterns, we proceed to quantify the forces which may have driven the increase in virtual water flows in the long term. Adopting the Decomposition Analysis (DA) approach, virtual water flows are decomposed into three components, showing the effects of trade growth, composition patterns and water intensity changes. The results are presented in Table 5.3.

Firstly, we examine the average contribution of such effects from 1850 to 1930. We then study the four different sub-periods into which we have divided our sample, corresponding to four distinct stages of historical Spanish trade flows (1850-1869, 1870-1890, 1891-1914 and 1915-1930). Due to the marked volatility of trade data, we take a three-year average for each reference period, and subsequently we apply DA.

Table 5.3: Decomposition analysis of virtual water exports and imports

	Effects	*1849-1869*	*1870-1890*	*1891-1914*	*1915-1930*	*1849-1930*
Green VWX	**composition (%)**	36.74	-2.55	-78.22	17.48	14.81
	scale (%)	63.26	102.55	219.93	-20.76	92.79
	water intensity (%)	0.00	0.00	-41.71	103.28	-7.60
	Δ VWX (hm^3)	1,242	2,801	555	-317	4,280
Blue VWX	**composition (%)**	6.80	-9.06	57.60	-81.32	16.37
	scale (%)	93.20	109.06	52.48	-51.79	90.24
	water intensity (%)	0.00	0.00	-10.08	233.11	-6.62
	Δ VWX (hm^3)	184	494	507	-33	1,152
Total VWX	**composition (%)**	32.87	-3.52	-13.38	8.08	15.14
	scale (%)	67.13	103.52	140.00	-23.71	92.25
	water intensity (%)	0.00	0.00	-26.61	115.63	-7.39
	Δ VWX (hm^3)	1,426	3,295	1,063	-351	5,433
Green VWM	**composition (%)**	21.39	20.23	98.46	174.72	33.23
	scale (%)	78.61	79.77	7.35	-97.44	72.51
	water intensity (%)	0.00	0.00	-5.81	22.73	-5.74
	Δ VWM (hm^3)	400	2,259	2,520	-932	4,247
Blue VWM	**composition (%)**	-21.98	-8.69	93.40	-673.92	14.50
	scale (%)	121.98	108.69	8.74	808.44	86.80
	water intensity (%)	0.00	0.00	-2.14	-34.52	-1.30
	Δ VWM (hm^3)	47	257	280	16	600
Total VWM	**composition (%)**	16.80	17.27	97.95	189.12	30.91
	scale (%)	83.20	82.73	7.49	-112.82	74.28
	water intensity (%)	0.00	0.00	-5.44	23.70	-5.19
	Δ VWM (hm^3)	447	2,516	2,800	-916	4,847

Source: Authors' elaboration,based on Statistics of Spain for foreign trade and extracted by Gallego and Pinilla (1996). VWX: Virtual water exports, VWM: Virtual water imports.

As shown above, virtual water exports (Table 5.3) rose by 5,433 hm^3 from 1849 to 1930, the growth in volume of Spanish trade being responsible for 92.2% of this increase. Only 15.4% was due to changes in the composition of trade towards products with a higher content of virtual water, and decreasing water intensities due to yield improvements contributed 7.4% to the moderation of virtual water exports. DA permits the quantification of how far virtual water exports would have risen if one component had changed while the other remained constant. That is to say, if we only took into account composition and scale effects, the growth in virtual water exports would have been 401 hm^3 higher, since we would be neglecting the reduction of water intensity taking place in the study period.

Exports of virtual blue water grew by 1,152 hm^3 during these years; however, the share of the composition effect is higher, reaching 16.4%, indicating that despite Spanish agricultural exports moving towards intensive products, especially Mediterranean horticultural products, with a higher content of blue water, the scale effect was dominant. An examination of the different sub-periods shows that in the period from 1891 to 1914 blue virtual water exports increased mainly because of the reorientation of Spanish exports towards water-intensive products, with the composition effect reaching 57.6%. However, the strong export boom in Mediterranean horticultural products meant that the blue water scale effect was very important once more. In the case of virtual green water exports, the scale effect was more important. Thus, virtual water exports increased as a result of both changes in the volume of trade and variations in trade patterns, and decelerated as a result of yield improvements.

On the other hand, virtual water imports (Table 5.3) displayed an increase of 4,847 hm^3 during the period 1849-1930. Changes in both blue and green virtual water imports were determined by the vast growth of Spanish purchases of agricultural and food products from the rest of the world. On average, the composition and water intensity effects had a significant effect on virtual water imports in these years. Blue virtual water import growth would have been even greater without the role of changes in agricultural yields, which partially compensated for the great boost in the volume of imports, accounting for -5% throughout the entire period.

5. Understanding the virtual water trade

In our opinion, the most important challenge is to examine the consequences of the evolution of foreign trade with respect to water resources. The expansion of exports and the substitution of certain imports due to protectionist policies involved various requirements in the supply of blue water to distinct crops. Considering only those goods which, as a result of climatic and soil conditions, could be produced in Spain, trade represented overall savings of blue water. As an example, to produce cotton Spain needed twice as much blue water as the USA, the main trade partner for this crop. On the other hand, overall trade involved greater green water use until 1921. Producing wheat, maize or sugar was less green water intense in Spain than in the USA, Argentina or Cuba, from where these commodities came. For instance, maize water intensity in Argentina was five times higher than in Spain.

For a hypothetical country with an unlimited supply of irrigation water at zero cost, we could say that the evolution of the need for blue water would have no economic consequences, beyond those produced by foreign trade itself, for national income. However, the obtaining of water for irrigation requires heavy capital investment and the results of such investment may on occasion be uncertain. In addition, the increase in irrigation has had a far-reaching impact on the natural environment.

The balance of green water is also of a certain interest and the use of such water is not completely independent of that of blue water. Although it could be said that exports of green water do not have significant consequences in terms of water consumption (the argument being that substituting exports of crops for 'natural vegetation' could produce even greater consumption of green water and therefore a reduced availability of blue water[16]), these consequences could be significant from the perspective of land use (Fader et al., 2011).

The first question to be answered is to what extent the expansion of irrigation in Spain

[16]This probably occurred, for example, in the Ebro basin in the second half of the XX century, since the growing needs of new vegetation, as a consequence of the decline due to depopulation processes in agriculture and forestry in some areas, had allowed the development of a 'sponge', which absorbed a considerable part of rainfall and affected the volume of water available in water courses (Bielsa et al., 2011),

was driven by production for export. The answer lies in estimating what part of the growth in blue water use by Spanish agriculture between 1860 and 1930 was due to the foreign sector.

Table 5.4: Comparison of water embodied in exports and production

	EWP (hm^3)	**VWX** (hm^3)	**VWM** (hm^3)	**External balance** (hm^3)	**VWX/ EWP**	**VWM/ EWP**	**Ext. balance/ EWP**
Green water							
1860	32,677	1,243	1,710	-467	3.8	5.2	-1.4
1900	39,669	3,703	4,782	-1,079	9.3	12.1	-2.7
1930	47,605	5,620	5,753	-133	11.8	12.1	-0.3
Blue water							
1860	5,657	294	353	-59	5.2	6.2	-1.0
1900	7,725	886	578	308	11.5	7.5	4.0
1930	9,841	1,573	885	688	16.0	9.0	7.0
	Δ EWP (hm^3)	**ΔVWX** (hm^3)	**ΔVWM** (hm^3)	**ΔExternal balance** (hm^3)	**ΔVWX/Δ EWP**	**ΔVWM/Δ EWP**	**ΔExt. balance/Δ EWP**
Green water							
1860-1900	6,992	2,460	3,072	-612	35.2	43.9	-8.8
1900-1930	7,936	1,917	971	946	24.2	12.2	11.9
1860-1930	14,928	4,378	4,043	334	29.3	27.1	2.2
Blue water							
1860-1900	2,068	593	226	367	28.7	10.9	17.8
1900-1930	2,116	686	306	380	32.4	14.5	17.9
1860-1930	4,184	1,279	532	747	30.6	12.7	17.8

Source: Authors' elaboration, based on Statistics of Spain for foreign trade and extracted by Gallego and Pinilla (1996), and agricultural production data (see appendix 4.2). EWP: Embodied water in production, VWX: Virtual water exports, VWM: Virtual water imports, External balance: VWX-VWM

Table 5.4 displays embodied water in production (EWP), virtual water exports (VWX), virtual water imports (VWM) and the external balance, obtained as the difference between virtual water exports and virtual water imports (VWX-VWM). As Table 5.4 shows, blue virtual water exports represented a notable percentage of the water needed for Spanish agricultural production (from a minimum of 5% in 1860 to a maximum of 16% in 1930). The increase in agricultural production between these two years was substantial, and consequently the need for blue water increased by approximately 4,184 hm^3 (51% of this increase took place during the twentieth century). Throughout these years, approximately 31% of this increase was a direct consequence of the increase in exports of agricultural products and food (see appendix 4.2 for more detail on production data sources). If we bear in mind the savings of blue water from imports, the result is that the net balance of virtual blue water in Spanish foreign trade in agricultural products and food meant an 18% increase in the need for blue water in agriculture between 1860 and 1930.

It is reasonable to conclude, therefore, that the growing incorporation of Spain into international markets as a major exporter of Mediterranean products substantially increased pressure on water resources and required the expansion of irrigation. This increase was a very important topic in public and political debate during that period, and had a significant effect on agricultural production (Pinilla, 2005). In fact, the need to overcome or at least ameliorate natural conditions has resulted in a very long tradition of exploiting the fluvial system to irrigate arid land in Spain. From the middle of the ninetieth century many initiatives were proposed, in an attempt to extend the irrigated land area.

The shift from rain feed to irrigated farming perfectly reflected liberal ideas, which sought to expand farm output by raising land productivity. Private investors were entrusted with the undertaking of the works necessary for irrigation. However the majority of development projects proposed came to nothing. At the end of the ninetieth century the Regenerationist movement, led by Joaquín Costa, broke with the tradition of economic liberalism by granting the state a role in encouraging the development of irrigation. Increased irrigation was seen as the solution to the modernization of Spanish agriculture. Owing to the agricultural depression at the end of the century, these ideas were widely accepted. Successive governments proposed numerous plans that aimed to expand irrigation, approving and launching several major waterworks. As a consequence, from the end of the ninetieth century the public sector increasingly intervened to increase the amount of irrigated land, which required increased public and private investment.[17]

6. Conclusions

The volume of water embodied in agricultural products exchanged through international trade rose sharply from 1849 to 1935, a period of intensive development

[17] The investment in hydro-infrastructure of all kinds (not only for irrigation) increased by a factor of approximately 10 between 1860 and 1930 (Herranz, 2004: 129-132).

in the Spanish foreign sector. Spain was notable as a net exporter of blue water resources but tended to be a net importer of green water. Spanish integration into the first globalisation had a significant impact on domestic agricultural production systems, and consequently put strong pressure on water, an essential input for the development of this strategic industry. In fact, from 1860 to 1930 approximately 30% of the increase in blue water requirements was due to the rise in exports. Irrigation played a key role, since without its far-reaching development during these years, this expansion of trade would not have been possible.

Our analysis of long-term virtual water trends in Spain suggests the need to be conscious of the implications and consequences of globalisation processes. As we have seen at the country level, successful agricultural trade expansion, as in the Spanish case, leads to growing pressures on natural resources. Thus, the first globalisation in Spain can be seen as an important lesson for those emerging countries which are chiefly net exporters of agricultural products and primary inputs and are gradually integrating into international trade. In a context where water scarcity is increasingly becoming both a local and a global concern, developing regions must be aware of their environmental constraints, since without water no primary production is possible. In the light of historical processes, it is essential to adopt a global and long-term approach to virtual water, in order to understand changes in sustainability problems associated with unequal exchanges of water resources. Furthermore, it is essential to avoid massive transfers of environmental burdens to the most deprived areas in the world.

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Appendix 5.1: Alternative results assuming constant water intensity

Assuming constant evapotranspiration does not appear to involve a strong bias. Nevertheless, water intensities depend on both evapotranspiration and yields. The results of this study have been calculated considering water intensities, that is to say water consumption per physical unit of product (m^3/QM), which is variable and dependent on yield series. However, an alternative method of calculation may assume water intensities to be identical to those obtained by Mekonnen and Hoekstra (2011; 2012) and which are constant over time.

Table 5.5: Comparison of water embodied in exports and production using constant water intensities

	VWX/ EWP	VWM/ EWP	Ext.Bal./ EWP
	Green water		
1860	3.9	8.9	-5.0
1900	10.0	14.9	-5.0
1930	12.4	11.3	1.1
	Blue water		
1860	5.6	8.7	-3.2
1900	14.7	9.5	5.2
1930	18.1	7.5	10.6
	ΔVWX/Δ EWP	**ΔVWM/Δ EWP**	**ΔExt.Bal./Δ EWP**
	Green water		
1860-1900	30.8	35.8	-5.0
1900-1930	17.7	3.6	14.1
1860-1930	22.0	14.1	7.9
	Blue water		
1860-1900	36.6	11.3	25.2
1900-1930	23.1	4.6	18.5
1860-1930	27.2	6.6	20.6

EWP: Embodied water in production, VWX: Virtual water exports;
VWM: Virtual water imports; External balance: VWX-VWM

The first option (variable intensities) entails larger volumes of water consumption, since taking into account yield improvements from 1849 to the present day means subtracting technological developments from water intensities, thereby increasing them. By contrast, the second alternative (constant intensities) results in lower water consumption since we are assuming that livestock and crop yield changes have had no significant effects on water intensities. Although the scale of these two scenarios is somewhat different, the results in terms of the effect of trade expansion on water resources are quite similar. Table 5.5 displays some of the most important figures from the constant water intensities estimation method, and these can be compared with Table 5.4, where variable water intensities have been utilized.

CHAPTER 6.

GLOBALISATION AND NATURAL RESOURCES: THE EXPANSION OF SPANISH AGRIFOOD TRADE AND ITS IMPACT ON WATER CONSUMPTION, 1965-2010

1. Introduction

The relationship between economic growth and the environment has been an issue of growing interest particularly from the release of the Brundtland Report (UNWCED, 1987), since by merging environment and development, the foundations of sustainable development were laid. That way, today it is possible to find vast literature that aim to establish the impact that long term socio-economic transitions exerted on natural resources such as timber, fossil fuels, minerals, land, water or gas emissions (Krausmann et al., 2008 and 2009; Marull et al., 2010; Erb, 2012; Iriarte-Goñi and Ayuda, 2012; Rubio and Folchi, 2012; Steen-Olsen et al., 2012; Duarte et al., 2013 and 2014a).

These processes of economic growth also involved a growing integration of the international economy. From the early decades of the nineteenth century until 1929, the first major wave of globalisation took place, hardly affecting the Atlantic economy (O'Rourke and Williamson, 1999). The interwar period, but especially from 1929, can be considered a deglobalisation phase, with a very important decline in the levels of economic integration. After the Second World War a new wave of globalisation, which still lasts today, affected the world. The second globalisation has reached levels of integration that, from the eighties, have surpassed the milestone of 1914. Today's economies are very opened, with large flows of factors and products. Therefore, from an environmental perspective, it is also necessary to integrate the role played by the globalisation processes in the analysis of the relationship between growth and natural resources (Duarte et al., 2014b; Antweiler et al., 2001).

Our work must be placed in this context of a growing concern on the effect that the second globalisation had on natural resources. Following this line, our study focuses on the way that long term international economic integration has influenced water resources, key for life and essential for the development of societies.

Water has been traditionally considered as a local resource (Katerji et al., 2008; Gleick, 2010), since water used in a region was defined as the volume of surface or groundwater resources withdrawn for agricultural, industrial or domestic purposes. However, the growing processes of internationalization all over the world are involving important exchanges of agricultural commodities related to large volumes of upstream water use (Hoekstra et al., 2011; Mekonnen and Hoekstra, 2011 and 2012). As a result, there is a growing need for analysing water resources from a global perspective, addressing responsibilities of water consumption. In this regard, the concept of virtual water was introduced to define the volume of water required for the production of a commodity (Allan, 1997 and 1999; Zimmer and Renault, 2003; Merrett, 2003; Hoekstra and Hung, 2005; Yang et al., 2007) and is closely linked to virtual water trade, or the volume of water embodied in products traded internationally. Green water - precipitation stored in soil as moisture- appears as the most important component in virtual water, followed by grey water -water required to dilute a certain amount of pollutants- and blue water -surface or ground water- (Hoekstra et al., 2011).

According to the UN (2009), "the global volume of virtual water flows in commodities is 1,625 billion cubic metres a year, being about 80% of these virtual water flows related to agricultural products trade".

By using the bottom-up approach developed by Hoekstra and Hung (2005), this study tries to obtain and analyse trends in agricultural and food virtual water trade flows in the long term[18]. To that aim, we use bilateral trade data provided by COMTRADE for the whole period analysed as well as water intensities given by Mekonnen and Hoekstra (2011, 2012). Once the main trajectories and compositional patterns are established, Decomposition Analysis (DA) is applied to identify and quantify the main driving forces responsible for changes in virtual water flows. This methodology, commonly used in environmental analysis (Guan et al., 2008; Muñoz and Hubacek, 2008; Cazcarro et al., 2013), appears as an accurate tool for the study of the factors that lie behind the great increase seen for virtual water trade flows. In this paper we will focus on Spain, a semi-arid country that went through an intense process of economic modernization and trade liberalization from 1965 to 2010. More specifically, we want to assess the impact that this internalization process, taken place during a period of profound social and political changes had on domestic water resources. This

[18]Many studies have examined environmental impacts recently. They follow either a top-down approach (Guan et. al., 2008; Feng et al., 2012; Steen-Olsen et al., 2012; Yu et al., 2013) by adopting environmental input-output analysis, or the bottom-up approach (Hoekstra and Mekonnen, 2012; Gerbens-Leenes et al., 2012).

study is particularly important in Spain, a Mediterranean country with spatial and temporal variability of rainfall and where the imbalances between water needs and existing water resources have been traditionally managed with supply-side measures (water channels, dumps, reservoirs, etc.), which usually involve significant social, economic and environmental impacts.

Besides, the Spanish case during the period studied is particularly interesting for other two reasons. On the one hand, Spain had reached before the Second World War an important share in international markets of agricultural products, especially as an exporter of Mediterranean products (olive oil, wine and fruit and vegetables) (Pinilla and Ayuda, 2002, 2009 and 2010; Ramon, 2000). The Civil War and the early decades of the Franco's dictatorship represented a very significant loss of these markets and in general an autarkic policy that isolated the country from the rest of the world. However, since 1959 there was a shift towards openness, with the entry to the European Union in 1986. As a result, Spain has become one of the most important exporters of agri-food products. It is estimated that Spain more than doubled its participation in agricultural world trade, representing over 4% in the beginning of the twentieth century (Clar et al., 2014). On the other hand, Spain completed its industrialization process during the period analyzed, becoming a high-income country. Despite their agri-food exports significantly lost weight over total exports, they grew at the strongest rate in its history. Thus, the Spanish case could offer lessons for countries that are experiencing intense economic growth and opening rates, as happens in some emerging areas.

Our findings point at a gradual growth in virtual water exports and imports taken place from 1965 to 2010. Although Spain tended to be a net exporter of blue water, it appears as a net importer of green water, meaning that while a significant pressure on regulated local resources was due to exports production, Spain also avoided additional pressures by way of imports. Without the large imports of green water, Spain would have had three possibilities. Firstly, it would have not been able to consume products with no substitutes as coffee or tea. Secondly, it would have had to increase the agricultural area or it would have exerted even more pressures on blue water resources. On the one hand, two groups of products, fruit and vegetables as well as fixed vegetable oils, consumed most water embodied in exports. On the other hand, water was mainly imported by means of Coffee, tea, cocoa and spices, textile products and cereals. In summary, the great internationalization experienced in Spain throughout these years triggered the increase in virtual water trade flows to a great extent. Therefore, this paper contributes to the existing literature by giving an historical background of the link between trade expansion and the trends in the consumption of water resources.

The rest of the paper is organized as follows. Section 2 reviews the methodology as well as the materials used. Then, section 3 shows the main findings of the study and is divided into two subsections. Section 3.1 focuses on the main trends and composition of virtual water trade flows while section 3.2 performs a decomposition analysis on virtual water exports and imports. Section 4 presents a discussion of the main results of the work. Section 5 closes the paper with a review of the main conclusions and some policy implications.

2. Some stylized facts: the Spanish agri-food trade between 1965 and 2010

The first two decades of the Franco's dictatorship entailed the halt of the profound economic transformations that the Spanish economy was experiencing since the beginning of the twentieth century. The autarkic policies from 1939 to 1959 (less intense in the fifties) meant not only the isolation of the Spanish economy, but also a very slow recovery of the production levels prior to the Civil War of 1936-39. Until the mid-fifties, the GDP per capita or agricultural production did not reach the levels of 1935. The stabilization plan of 1959 supposed a turnaround in the Spanish economy, leading to internal and external liberalization. Growth was explosive from 1960. Only Japan had a faster GDP growth from 1960 to 1973. Moreover, the industrialization of the Spanish economy that began in the nineteenth century, finished during this decade and for the first time, employed in industry exceed those in agricultural sector.

The agricultural sector, especially after an intense crisis in the forties, resumed its modernization. Traditional agriculture gave way to modern agriculture, an increase in production and factors productivity, being some of the highest in Europe during the second half of the twentieth century (Martin-Retortillo and Pinilla, 2013).

Agri-food exports and imports also grew rapidly since 1959. Particularly exports growth was sharp, with an annual average growth over 5.3% between 1959 and 1986. The integration in the European Union in 1986 entailed an even greater boost to commercial exchanges. From 1986 to 2011 exports and imports respectively increased at 6% and 4.9% yearly. Although food products significantly lost weight on total exports, they reached high absolute levels, showing the highest growth rates in the nineteenth and twentieth centuries. Agri-food sector trade opening strongly grew, especially from 1986, being exports plus imports higher than agricultural production. Exports and imports composition also changed notably. The growing exports of products derived from livestock were outstanding. Whereas meat and dairy products represented less than 0.5% of exports in 1959-1966, they accounted for more than 15% in 2008-2011. The development of the modern intensive farming was determinant (Domínguez, 2000). On the contrary, the growing imports of feed stuff tipped the trade balance during the seventies and eighties. Thus, cereals, oil seed cakes and other feed stuff imports that were 12.5% of total agri-food imports in 1952-1959 became more than 40% by 1973-1980. Exports of agri-food products, especially of processed food, also followed an upward trend. If in 1959-1966 they were only 0.7% of total agri-food exports, they were more than 11% in 2008-2011 (Clar et al., 2014).

3. Methodology and Data

3.1. Methodological aspects

In this study, we follow a bottom-up perspective to quantify blue and green virtual water trade flows in agricultural and food products on the basis of the approach developed by Hoekstra and Hung (2005). For a country *c* in year *t,* virtual water exports (m^3/year) can be expressed as:

$$VWX(c,t) = \sum_{p} d_p^c(c,p,t) * x_p^c(c,p,t) \qquad (6.1)$$

Where x_p^c is the quantity (Tons) of product p exported and d_p^c expresses the physical water intensity in the exporting country (m^3/Ton). Depending on whether d_p^c represents green or blue water, we will distinguish between green and blue virtual water flows.

Similarly, virtual water imports for country *c* can be calculated as the sum of the virtual water content of the imported goods *p* coming from the different countries *z* (origin of imported products).

$$VWM(c,t) = \sum_p d_p^Z(z,p,t) * m_p^z(z,p,t) \qquad (6.2)$$

with $\mathrm{d}_\mathrm{p}^\mathrm{Z}$ being the physical water intensity (m3/Tons) in country *z* for product *p*, and m_p^z the volume of imports (Tons) of product *p* emanating from country *z*. Thus, the virtual water trade balance for a country is defined as:

$$VWB(c,t) = VWX(c,t) - VWM(c,t) \qquad (6.3)$$

Once virtual water flows and balances are identified, we proceed with the study of the economic factors behind changes in these flows. To that aim, virtual water exports and imports are expressed as a function of trade volume, product and country composition. Moreover, in order to analytically study trends in virtual water flows and disentangle the forces behind trends, a sort of Decomposition Analysis (DA) is applied.

Departing from (6.1) and (6.2), water exports can be expressed, in general terms, as dependent on three types of factors representative of water intensities/content per crop, trade patterns and scale, which yields:

$$VWX(c,t) = \sum_p w_{cpt}\cdot\left(\frac{e_{cpt}}{e_{ct}}\right) e_{ct} \qquad (6.4)$$

This can be expressed in matrix form as:

$$VWX(c,t) = \mathbf{w}'_{\mathbf{ct}}\mathbf{f}_{\mathbf{ct}}e_{ct} \qquad (6.5)$$

With $\mathbf{w}'_{\mathbf{ct}}$ being a row vector of the water necessary for the production of each product in Spain in year t measured in m^3/\$, i.e., the water intensity.$\mathbf{f}_{\mathbf{ct}}$ is a vector of Spanish exports product composition in period t and e_{ct} is a scalar of the total value of the Spanish exports in year *t* (measured in constant 1985\$).

Similarly, we express virtual water imports as a result of four factors; water intensities, scale of trade, product composition and country composition.

$$VWM(c,t) = \sum_{p,z} w_{cpzt} \cdot \frac{m_{cpzt}}{m_{cpt}} \cdot \frac{m_{cpt}}{m_{ct}} m_{ct} \qquad (6.6)$$

or, in matrix form,

$$VWM(c,t) = \mathbf{w}'_{\mathbf{czt}} \mathbf{M}_{\mathbf{czt}} \mathbf{b}_{\mathbf{ct}} m_{ct} \qquad (6.7)$$

Where $\mathbf{w}'_{\mathbf{czt}}$ is a row vector of adequate dimension including the virtual water content for each product in each country of origin *z* measured in m^3/\$, i.e., the water intensity. $\mathbf{M}_{\mathbf{czt}}$ is a matrix of the share that each country *z* represents in Spanish imports of each product, $\mathbf{b}_{\mathbf{ct}}$ is a vector of product composition of imports and m_{ct} is a scalar of the total value of the Spanish imports (in constant 1985 dollars).

As can be seen, all physical and economic factors underlying trade flows are time and country-product variable. That way, we offer an interesting approximation to the effect that changes in trade relationships such as scale of trade, product orientation, trade partners or technological changes can have on domestic and foreign consumption of water resources in time. More specifically, to go deeper into these factors, DA has been applied to equations (6.6) and (6.7) to synthesize the factors driving virtual water trade flows. Broadly speaking, this approach tries to separate a time trend of an aggregated variable into a group of driving forces that can act as accelerators or retardants (Dietzenbacher and Los 1998; Hoekstra and van den Bergh 2002; Lenzen et. al. 2001).

In general terms, considering a variable *y* depending on *n* explicative factors $y=f(x_1,\dots x_n)$, additive structural decomposition can be obtained through its total differential.

$$dy = \frac{\partial y}{\partial x_1}\partial x_1 + \frac{\partial y}{\partial x_2}\partial x_2 + \cdots + \frac{\partial y}{\partial x_n}\partial x_n \qquad (6.8)$$

On the basis of a multiplicative relationship, that is $y=x_1 \dots x_n$, expression (6.8) holds:

$$dy = (x_2 x_3 \dots x_n) dx_1 + \cdots + (x_1 x_2 x_3 \dots x_{n-1}) dx_n = \sum_{i=1}^{n} \left(\prod_{j \neq i} x_j \, dx_i \right) \qquad (6.9)$$

In a discrete schema, when we try to measure the changes in the dependent variable between two periods, *t-1* and *t*, there are different ways of solving this expression by way of exact decompositions, which leads the well-known problem of non-uniqueness of DA solution. In our case, decomposition is based on four factors for imports and three factors for exports; therefore we can obtain the following 4! and 3! exact decompositions respectively. In practice, as a commitment solution, the average of the two polar solutions can be considered as a good approximation to the average of the n! solutions (Dietzenbacher and Los 1998), being the option followed in this paper.

Therefore, the two polar decompositions of (6.5) can be written as follows:

$$\Delta VWX(c) = \Delta \mathbf{w}_{\mathbf{c}}' \mathbf{f}_{\mathbf{ct-1}} e_{ct-1} + \mathbf{w}_{\mathbf{ct}}' \Delta \mathbf{f}_{\mathbf{c}} e_{ct-1} + \mathbf{w}_{\mathbf{ct}}' \mathbf{f}_{\mathbf{ct}} \Delta e_c \qquad (6.10)$$

$$\Delta VWX(c) = \Delta \mathbf{w}_{\mathbf{c}}' \mathbf{f}_{\mathbf{ct}} e_{ct} + \mathbf{w}_{\mathbf{ct-1}}' \Delta \mathbf{f}_{\mathbf{c}} e_{ct} + \mathbf{w}_{\mathbf{ct-1}}' \mathbf{f}_{\mathbf{ct-1}} \Delta e_c \qquad (6.11)$$

Moreover, based on (6.7) we get two polar decompositions, (6.12) and (6.13):

$$\Delta VWM(c) = \Delta \mathbf{w}_{\mathbf{cz}}' \mathbf{M}_{\mathbf{czt-1}} \mathbf{b}_{\mathbf{ct-1}} m_{ct-1} + \mathbf{w}_{\mathbf{czt}}' \Delta \mathbf{M}_{\mathbf{cz}} \mathbf{b}_{\mathbf{ct-1}} m_{ct-1} + \mathbf{w}_{\mathbf{czt}}' \mathbf{M}_{\mathbf{czt}} \Delta \mathbf{b}_{\mathbf{c}} m_{ct-1} + \mathbf{w}_{\mathbf{czt}}' \mathbf{M}_{\mathbf{czt}} \mathbf{b}_{\mathbf{ct}} \Delta m_c \qquad (6.12)$$

$$\Delta VWM(c) = \Delta \mathbf{w}_{\mathbf{cz}}' \mathbf{M}_{\mathbf{czt}} \mathbf{b}_{\mathbf{ct}} m_{ct} + \mathbf{w}_{\mathbf{czt-1}}' \Delta \mathbf{M}_{\mathbf{cz}} \mathbf{b}_{\mathbf{ct}} m_{ct} + \mathbf{w}_{\mathbf{czt-1}}' \mathbf{M}_{\mathbf{czt-1}} \Delta \mathbf{b}_{\mathbf{c}} m_{ct} + \mathbf{w}_{\mathbf{czt-1}}' \mathbf{M}_{\mathbf{czt-1}} \mathbf{b}_{\mathbf{ct-1}} \Delta m_c \qquad (6.13)$$

Taking the average of (6.10) and (6.11) we get (6.14):

$$\Delta VWX(c) = \frac{\Delta \mathbf{w}_{\mathbf{c}}' \mathbf{f}_{\mathbf{ct-1}} e_{ct-1} + \Delta \mathbf{w}_{\mathbf{c}}' \mathbf{f}_{\mathbf{ct}} e_{ct}}{2} + \frac{\mathbf{w}_{\mathbf{ct}}' \Delta \mathbf{f}_{\mathbf{c}} e_{ct-1} + \mathbf{w}_{\mathbf{ct-1}}' \Delta \mathbf{f}_{\mathbf{c}} e_{ct}}{2} + \frac{\mathbf{w}_{\mathbf{ct}}' \mathbf{f}_{\mathbf{ct}} \Delta e_c + \mathbf{w}_{\mathbf{ct-1}}' \mathbf{f}_{\mathbf{ct-1}} \Delta e_c}{2} \qquad (6.14)$$

Proceeding the same way with (6.12) and (6.13) gives equation (6.15):

$$\Delta VWM(c) = \frac{\Delta \mathbf{w}_{\mathbf{cz}}' \mathbf{M}_{\mathbf{czt-1}} \mathbf{b}_{\mathbf{ct-1}} m_{ct-1} + \Delta \mathbf{w}_{\mathbf{cz}}' \mathbf{M}_{\mathbf{czt}} \mathbf{b}_{\mathbf{ct}} m_{ct}}{2} + \frac{\mathbf{w}_{\mathbf{czt}}' \Delta \mathbf{M}_{\mathbf{cz}} \mathbf{b}_{\mathbf{ct-1}} m_{ct-1} + \mathbf{w}_{\mathbf{czt-1}}' \Delta \mathbf{M}_{\mathbf{cz}} \mathbf{b}_{\mathbf{ct}} m_{ct}}{2} + \frac{\mathbf{w}_{\mathbf{czt}}' \mathbf{M}_{\mathbf{czt}} \Delta \mathbf{b}_{\mathbf{c}} m_{ct-1} + \mathbf{w}_{\mathbf{czt-1}}' \mathbf{M}_{\mathbf{czt-1}} \Delta \mathbf{b}_{\mathbf{c}} m_{ct}}{2} + \frac{\mathbf{w}_{\mathbf{czt}}' \mathbf{M}_{\mathbf{czt}} \mathbf{b}_{\mathbf{ct}} \Delta m_c + \mathbf{w}_{\mathbf{czt-1}}' \mathbf{M}_{\mathbf{czt-1}} \mathbf{b}_{\mathbf{ct-1}} \Delta m_c}{2} \qquad (6.15)$$

Thus, changes in virtual water trade flows will be explained on the basis of:

- The scale effect, which explains changes in virtual water trade flows depending on changes in the volume of trade; it is given by (6.16) for exports and (6.17) for imports:

$$SE_e(c) = \frac{\mathbf{w}'_{\mathbf{ct}}\mathbf{f}_{\mathbf{ct}}\Delta e_c + \mathbf{w}'_{\mathbf{ct-1}}\mathbf{f}_{\mathbf{ct-1}}\Delta e_c}{2} \qquad (6.16)$$

$$SE_m(c) = \frac{\mathbf{w}'_{\mathbf{czt}}\mathbf{M}_{\mathbf{czt}}\mathbf{b}_{\mathbf{ct}}\,\Delta m_c + \mathbf{w}'_{\mathbf{czt-1}}\mathbf{M}_{\mathbf{czt-1}}\mathbf{b}_{\mathbf{ct-1}}\,\Delta m_c}{2} \qquad (6.17)$$

- The composition effect, which links changes in water virtual trade flows to changes in products trade patterns; it is expressed by (6.18) for exports and (6.19) for imports:

$$CE_e(c) = \frac{\mathbf{w}'_{\mathbf{ct}}\Delta\mathbf{f}_{\mathbf{c}}e_{ct-1} + \mathbf{w}'_{\mathbf{ct-1}}\Delta\mathbf{f}_{\mathbf{c}}e_{ct}}{2} \qquad (6.18)$$

$$CE_m(c) = \frac{\mathbf{w}'_{\mathbf{czt}}\mathbf{M}_{\mathbf{czt}}\Delta\mathbf{b}_{\mathbf{c}}m_{ct-1} + \mathbf{w}'_{\mathbf{czt-1}}\mathbf{M}_{\mathbf{czt-1}}\Delta\mathbf{b}_{\mathbf{c}}m_{ct}}{2} \qquad (6.19)$$

- The water intensity effect, which measures the contribution of variations in water intensities to changes in virtual water trade flows. It is shown in (6.20) for exports and (6.21) for imports:

$$IE_e(c) = \frac{\Delta\mathbf{w}'_{\mathbf{c}}\mathbf{f}_{\mathbf{ct-1}}e_{ct-1} + \Delta\mathbf{w}'_{\mathbf{c}}\mathbf{f}_{\mathbf{ct}}e_{ct}}{2} \qquad (6.20)$$

$$IE_m(c) = \frac{\Delta\mathbf{w}'_{\mathbf{cz}}\mathbf{M}_{\mathbf{czt-1}}\mathbf{b}_{\mathbf{ct-1}}m_{ct-1} + \Delta\mathbf{w}'_{\mathbf{cz}}\mathbf{M}_{\mathbf{czt}}\mathbf{b}_{\mathbf{ct}}m_{ct}}{2} \qquad (6.21)$$

- The localization effect, which indicates to what extent changes in the origin of products influence the volume of water embodied in imports. It is given by (6.22):

$$LE_m(c) = \frac{\mathbf{w}'_{\mathbf{czt}}\Delta\mathbf{M}_{\mathbf{cz}}\mathbf{b}_{\mathbf{ct-1}}m_{ct-1} + \mathbf{w}'_{\mathbf{czt-1}}\Delta\mathbf{M}_{\mathbf{cz}}\mathbf{b}_{\mathbf{ct}}m_{ct}}{2} \qquad (6.22)$$

3.2. Data

In order to obtain the components presented below, data on agricultural and food products trade published by United Nations Statistics Division (COMTRADE, 2014) at the four-digit level of the Standard International Trade Classification (SITC, revision 1) are used. We work with 133 products for exports and imports and with 89 commercial partners in the case of imports. COMTRADE data on trade value are deflated and expressed in constant 1985 dollars. Our sample accounts for more than 75% of the total Spanish international trade of agricultural and food products in the period studied. In order to link water involved in trade with the water consumed in production, we use data on the volume of agricultural and food production in Spain taken from “Anuario Estadístico de la Producción Agraria” (MAGRAMA, 1965-2010).

Average crop water intensities (m^3/Ton) for the period 1996-2005 have been taken from Mekonnen and Hoekstra (2011), while livestock water intensities (m^3/Ton) stem from Mekonnen and Hoekstra (2012). These coefficients express the volume of water consumption (m^3) per unit of production measured in Tons and are obtained as the ratio between evapotranspiration (ET) and yields (Y). As shown in appendix 4.1, while it is feasible to assume that climatic and crop characteristics in Spain, (i.e., ET) have remained constant over time, technological developments such as irrigation or improvements in seeds have entailed notable yield improvements that could have affected water intensities from 1965 to 2010. Thus, in line with Dalin et al. (2012) and Konar et al. (2013), water coefficients have been adapted varying depending on yield series as follows:

$$w_{cpt} = w_{cp}\frac{Y_{cp}}{Y_{cpt}} \quad (6.23)$$

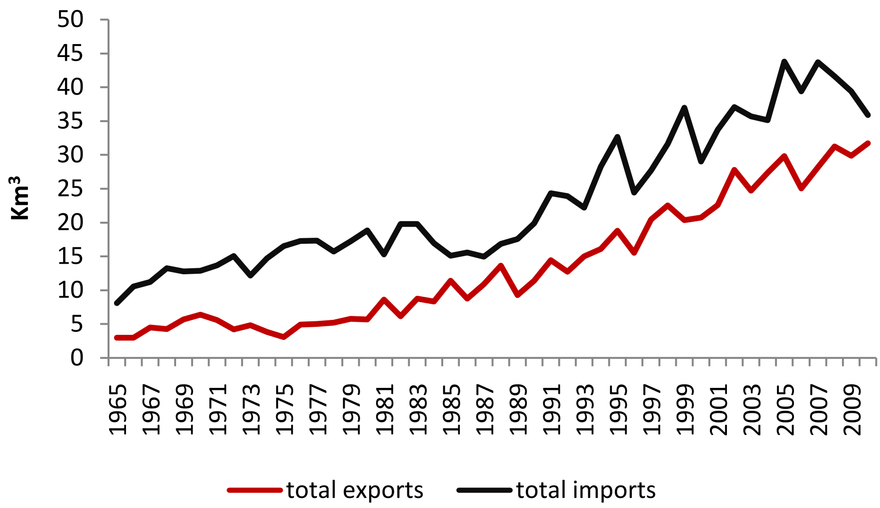
with w_{cpt}, the water coefficient for each product in the period of analysis (t from 1965 to 2010), $\mathrm{w_{cp}}$ represents the crop or livestock water intensity given by Mekonnen and Hoekstra (2011, 2012). Y_{cp} expresses the average yield of the reference period (1996-2005) and Y_{cpt} are the annual product yields for each specific year studied. The hypothesis underlying this approach is that technological advances have affected crop and livestock yields in the long term, also influencing water consumption per ton. Data on crop and livestock yields from 1965 to 2010 have been taken from Food and Agriculture Organisation of the United Nations (FAO, 2013).

4. Results

4.1. Analysis of virtual water trade flows

Figure 6.1 shows the evolution of virtual water trade during the period studied. As it can be observed, these flows experienced a continuous growth from 1965 to 2010, being particularly intense from 1986.

Figure 6.1: Total virtual water exports and imports (1965-2010)



On the one hand, total virtual water exports went from 2,975 hm^3 in 1965 to 31,705 hm^3 in 2009, involving an absolute increase over 28,730 hm^3. It is important to note that approximately 80% of this growth took place from 1986. On the other hand, virtual water imports experienced an increase of 27,777 hm^3 from 8,064 Hm^3 in 1965 to 35,841 hm^3 in 2010, 74% of this increase happening from 1986. We can say therefore that Spain was a net importer of virtual water. Both blue and green virtual water exports increased during these years.

Green water exports (Figure 6.2) average annual growth rate was 2.3% for the period 1965-1985, and accelerated from 1986 onwards, increasing at 5.6% yearly. Quite opposite, blue water exports (Figure 6.3) depict a pace growth during the first 27 years

(8.2%), but this increase tended to flatten during the second period (3.9%). Blue water represented between 30-40% of total water exports and reached its highest share (over 45%) during the eighties. Virtual water imports also displayed a great increase during these years. Green water imports experienced approximately 3.1% annual increase between 1965 and 2010. On the contrary, blue water imports grew at 2.2% until 1986, when they tended to rocket (3.7%). In this case the share of blue virtual water imports seems to be less significant, being quite stable over 7%.

Figure 6.2: Green virtual water exports and imports (1965-2010)

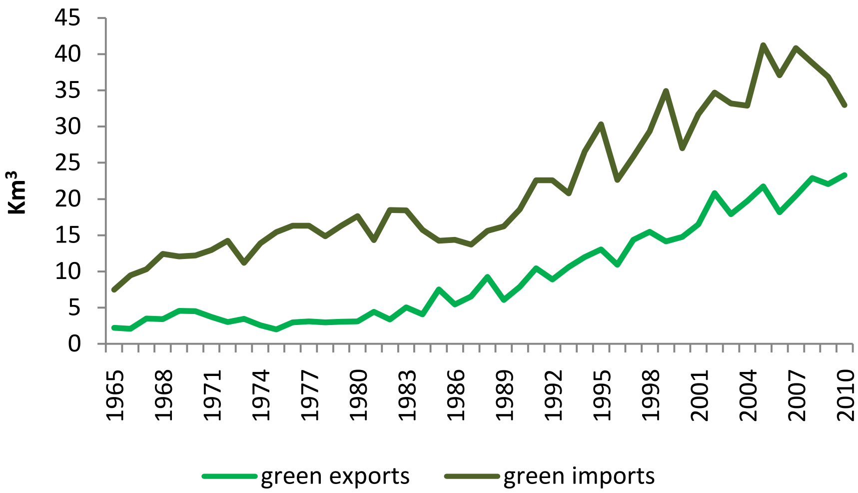
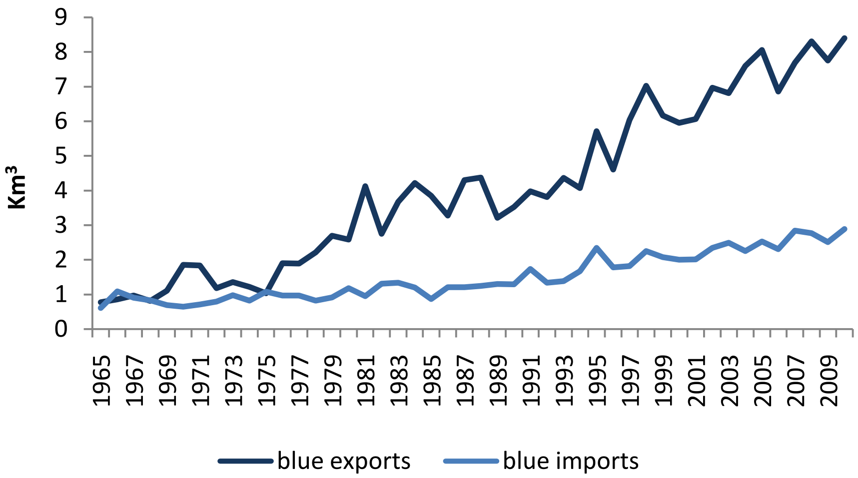


Figure 6.3: Blue virtual water exports and imports (1965-2010)



Comparing virtual water exports and imports it is possible to observe that on balance, Spain was a net exporter of blue water but a net importer of green water (Figures 6.2 and 6.3). This means that the impact exerted in domestic blue water resources to supply agricultural and food products to other countries was higher than the effect generated by Spanish imports in foreign resources, and quite the opposite for green water. The gap between blue virtual water exports and imports is notable and appears to gradually widen the years after the accession to the European Union and from 2000. On the contrary, there is less distance between green virtual water exports and imports, remaining quite stable during all the period.

Table 6.1: Virtual exports by group of product (average share and average annual growth rates)

Sitc rev.1 products classification	Share (%)				Growth (%)			
	Green water		Blue water		Green water		Blue water	
	1965-1985	**1986-2010**	**1965-1985**	**1986-2010**	**1965-1985**	**1986-2010**	**1965-1985**	**1986-2010**
00 Live animals	4.17	3.23	2.70	1.09	-13.2	13.6	-14.3	11.9
01 Meat and meat preparations	2.80	15.55	1.05	4.60	13.7	18.0	16.6	19.8
02 Dairy products and eggs	1.62	5.91	0.32	2.05	12.7	17.2	24.9	17.0
04 Cereals and cereal preparations	13.60	9.61	7.60	9.99	-0.6	4.6	0.2	6.1
05 Fruit and vegetables	29.99	19.06	28.74	28.08	2.1	4.5	4.8	4.9
06 Sugar, sugar preparations and honey	0.16	0.70	0.47	2.22	46.8	-3.6	60.1	-3.6
07 Coffee, tea, cocoa, spices & manufacs.	0.92	0.37	1.52	0.65	6.9	2.1	4.4	1.7
08 Feed. Stuff for animals excl. Unmilled cereals	2.10	1.19	3.05	3.06	34.1	5.2	27.3	5.2
11 Beverages	15.76	6.76	5.70	2.93	3.1	4.4	2.6	4.4
12 Tobacco, unmanufactured	0.01	0.11	0.00	0.08	30.3	16.6	23.2	16.6
21 Hides, skins and fur skins, undressed	0.36	1.61	0.06	0.34	-1.1	6.9	4.6	6.7
22 Oil seeds, oil nuts and oil kernels	0.25	0.79	1.12	2.18	9.2	14.9	13.4	18.6
26 Textile fibres, not manufactured, and waste	0.23	0.31	2.07	3.79	14.8	3.9	16.6	4.2
29 Crude animal and vegetable materials, nes	0.05	0.01	0.01	0.00	13.4	-17.4	17.3	-17.4
42 Fixed vegetable oils and fats	27.19	33.59	45.25	38.51	18.7	4.2	20.5	1.9
59 Chemical materials and products, nes	0.21	0.14	0.23	0.15	n.a.	16.1	n.a.	17.0
61 Leather, leather. Manufs & dressed fur skins	0.55	1.05	0.09	0.25	9.3	10.3	9.6	10.1
Total	**100**	**100**	**100**	**100**	**6.3**	**6.2**	**7.5**	**4.0**

On the whole two items, fruits and vegetables and vegetal oils, represented more than 50% of both green and blue virtual water exports (Table 6.1). From 1965 to 2010 fruits and vegetables were the most important group with approximately 30% of blue water exports, being oranges the most significant product. As for green water, it was exported mostly through olive oil and fruits such as oranges. The loose of weight shown by fruits and vegetables, beverages (being wine the most representative product) and cereals from 1986 was partially made up for the great increase in the share of green water embodied in meat, dairy products and eggs. Whereas the former, insignificant in 1965, turned to 15.5% of total green exports from 1986 growing at 11.1% every year; the latter displayed modest shares but also experienced a sharp growth rate, 10% from 1986.

In sum, Table 6.1 shows a notable loss of share of water embodied in traditional Mediterranean exports products like fruits and vegetables, cereals or wine in favour of goods like meat, dairy products or eggs that have been growingly introduced in current diets. As we have explained, the change in demand patterns, caused by the increase in income, was associated with a notable growth of meat and milk production. During the nineties and the first decade of the twentieth century, Spain started to export considerable volumes of these products, particularly of pork and derived products.

Looking at the composition of imports (Table 6.2) we observe that during the period 1965-2010 Spain imported water embodied basically on cereals, coffee and cocoa, soya beans and fruits and vegetables. Green water was embodied mainly in imports of soya beans, coffee or cereals with maize as the main crop. These products accounted for 70% of green virtual water imports on average. From 1986 Spain continued to import green water by means of the former products but these three groups went through a notable loss of share that was offset by the increase of water embodied in feed stuff, fruit and vegetables or vegetable oils. Most products behind the increase in imports were used as feed stuff for the intensive farming.

If we move on to blue virtual water imports, cereals with maize as the most important product entailed over 35% of these flows between 1962 and 1985. Textile fibres, mostly cotton, and soya beans also depict a considerable influence on blue water imports. These water intensive crops exerted a notable contribution during all the period. From 1986, cereals, soya beans and cotton were still the most representative groups, although their weight deeply fell. On the contrary, imports of blue water through fruits and vegetables or feed stuff like oil seed cakes were more relevant. Feed stuff also had a significant weight in blue virtual water imports, but the high level of development made Spain to become an importer of fresh fruits and vegetables, its main export product. As we have seen, an important change in trade patterns took place from 1965 to 2010 in Spain. This not only happened in terms of product composition, but also, although in a less extent, if we refer to the origin of agricultural and food products.

Table 6.2: Virtual imports by group of product (average share and average annual growth rates)

	Share (%)				Growth (%)			
	Green water		Blue water		Green water		Blue water	
Sitc rev.1 products classification	**1965-1985**	**1986-2010**	**1965-1985**	**1986-2010**	**1965-1985**	**1986-2010**	**1965-1985**	**1986-2010**
00 Live animals	0.24	1.82	0.15	1.61	12.5	1.4	6.9	2.7
01 Meat and meat preparations	7.08	4.43	3.02	3.32	-4.8	3.4	-2.4	3.6
02 Dairy products and eggs	3.26	3.50	3.85	4.98	1.4	4.7	1.3	6.1
04 Cereals and cereal preparations	34.74	20.81	35.30	24.23	0.8	5.6	-0.7	1.8
05 Fruit and vegetables	1.41	5.91	3.31	13.87	1.4	7.1	9.6	7.6
06 Sugar, sugar preparations and honey	0.15	0.40	0.49	6.03	6.1	10.5	25.8	12.8
07 Coffee, tea, cocoa, spices & manufacs.	13.77	10.27	0.70	1.05	5.9	-0.7	10.1	4.2
08 Feed. Stuff for animals excl. Unmilled cereals	2.96	14.72	4.82	14.25	13.8	3.7	10.6	2.0
09 Miscellaneous food preparations	0.01	0.03	0.04	0.12	9.9	5.2	14.8	15.2
11 Beverages	0.27	0.97	0.57	0.37	0.5	-3.3	9.9	2.3
12 Tobacco, unmanufactured	0.73	0.26	0.12	0.16	3.7	-2.7	6.6	0.8
21 Hides, skins and fur skins, undressed	2.00	1.30	1.19	0.89	7.4	1.7	4.3	1.2
22 Oil seeds, oil nuts and oil kernels	26.62	21.79	18.80	11.63	1.1	-6.0	-0.7	-9.6
26 Textile fibres, not manufactured, and waste	3.01	1.27	25.28	7.99	-3.3	10.8	-5.1	12.6
29 Crude animal and vegetable materials, nes	0.02	0.02	0.02	0.02	27.1	2.7	28.2	10.8
42 Fixed vegetable oils and fats	3.16	9.69	1.96	7.43	24.2	6.9	24.7	5.1
59 Chemical materials and products, nes	0.03	0.07	0.01	0.06	n.a.	42.9	n.a.	50.1
61 Leather, leather. Manufs & dressed fur skins	0.54	2.74	0.38	1.99	-14.8	10.5	4.0	6.2
Total	**100**	**100**	**100**	**100**	**3.3**	**3.5**	**1.8**	**3.7**

On average, during the sixties 34% of green water (Figure 6.4) was imported from United States embodied mainly in Soya beans and Maize or from Argentina and Brazil (22% and 10% of total green water imports) transferred in virtual form through cereals like wheat or maize or through coffee produced in Brazil. The former two countries keep on being an important provider of green water for Spain nowadays (Figure 6.5) with 18% and 13% of Spanish green water imports respectively. Today Spain mostly buys soya beans from Brazil and oil seed cakes from Argentina. France, with 8% of green Spanish imports transfers green water embodied in maize and wheat.

Figure 6.4: Origin of green water embodied in products imported by Spain, 1965 (thousand m^3)

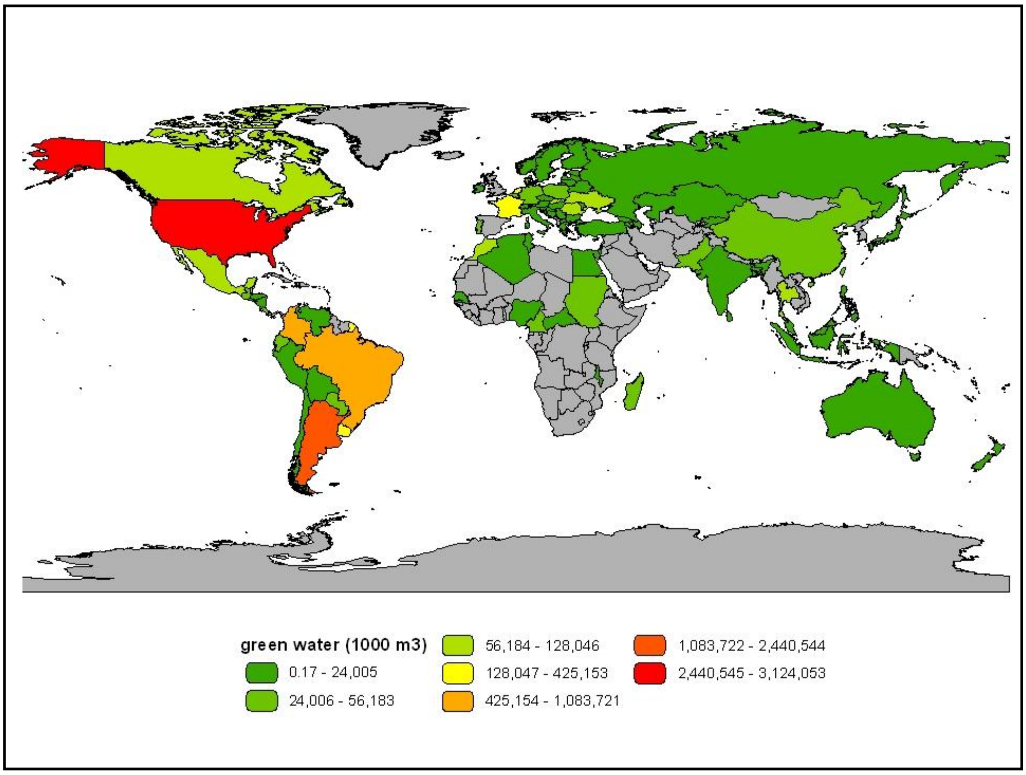


Figure 6.5: Origin of green water embodied in products imported by Spain, 2010 (thousand m^3)

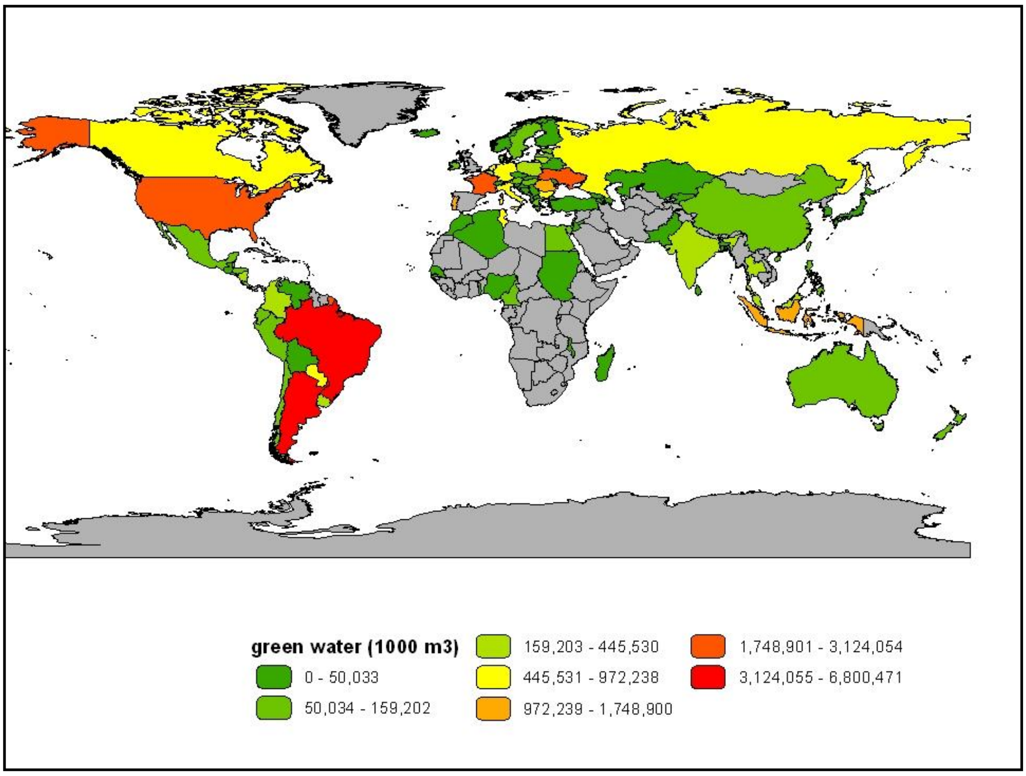


Figure 6.6: Origin of blue water embodied in products imported by Spain, 1965 (thousand m^3)

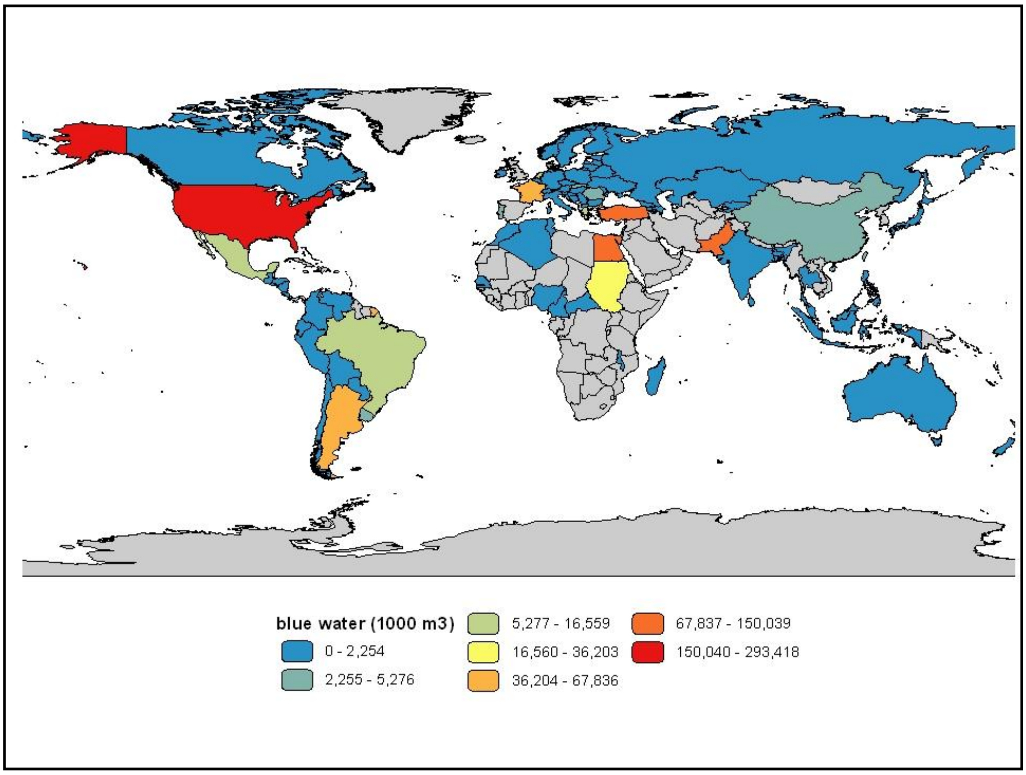
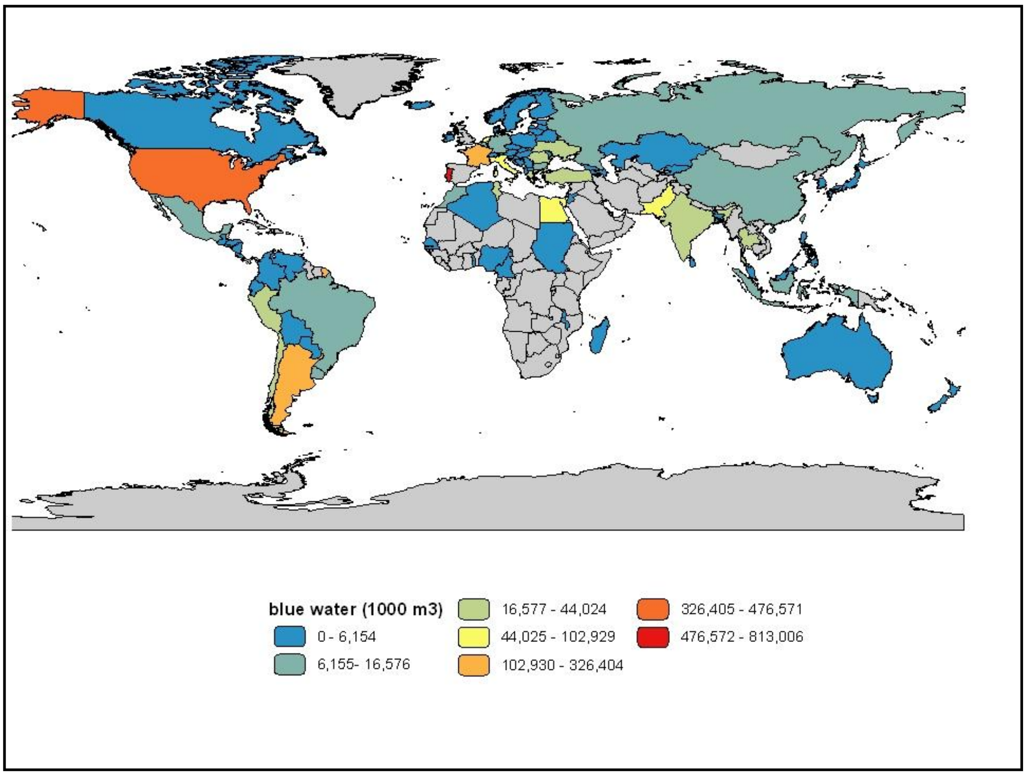


Figure 6.7: Origin of blue water embodied in products imported by Spain, 2010 (thousand m^3)



Regarding blue water (Figures 6.6 and 6.7), the change in the origin of products was more marked. In the beginning of the period analysed, blue virtual water flows from

USA were 34% of total blue water imports. Maize and soya beans were the most significant traded goods, together with cotton, an intensive blue water crop that mostly came from Arabic countries like Egypt and Turkey. Blue water imports from these two nations accounted for approximately 24% total blue water imports. The accession of Spain in the European Community entailed a gradual loss of share of American countries like USA in favour of its European partners. Currently, Portugal with 30% on total blue water imports is the main provider of blue water in Spain. Sugar, sunflower seed oil or oil seed cakes were intensively exchanged. Again, Spain imported blue water through cereals and soya beans trade from USA. Finally, France an outstanding provider of maize represented 12% of Spanish blue virtual water imports.

4.2. Decomposition analysis of virtual water trade of flows

As we have previously seen, Spain underwent an intense process of trade openness from 1965 to 2010 that entailed an unprecedented increase in virtual water imports and exports. This growth was particularly deep from 1986, when Spain became a member of the European Union. In this section, we will try to analyse the driving factors responsible for the increase in virtual water flows through the results obtained with a Decomposition Analysis.

Firstly, Table 6.3 shows that the total increase in water embodied in exports was about 27.6 km^3 from 1965 to 2010. It is interesting to note that the increase in total virtual water exports exceed virtual water imports. Despite Spain kept on being a net importer of water, its negative water balance decreased, what seems quite paradoxical given its extreme aridity. This growth was particularly intense from 1986, accounting for 22 km^3 and representing 80% on total. On the whole, the great commercial expansion taken place during these years, that is scale effect, triggered the increase in both blue and green virtual water exports. On the opposite, trade pattern changes as well as yield improvements, notably contributed to the moderation of water consumption increase.

If we look at green virtual water exports, that represented more than 70% of total water increase, it is clear that the growing volume of trade (scale effect) was the most important explaining factor. Composition effect encouraged the reduction of green virtual water exports until 1985; however it could not offset the great boost of the scale factor. From 1986, the growing exports of green water intensive products like meat, made composition effect to trigger the increase in water embodied in exports. All other things constant, the expansion of trade would have generated an increase in water consumption of 134% from 1965 to nowadays. However, technological changes affecting water intensity taken place from 1986 resulted in growing yields and partially moderated the increasing consumption of water resources. More concretely, they prevented an additional green water consumption of approximately 3.9 km^3. Changes in products traded, also contributed to alleviate water pressures in the first part of the period, while boosted water consumption from 1986.

Table 6.3: Decomposition analysis of virtual water flows

	Effects	1965-1985	1986-2010	1965-2010
Green virtual water exports	**Composition (%)**	-31	3	-15
	Scale (%)	115	131	134
	Intensity (%)	17	-34	-19
	Δ VWE (km^3)	2.79	17.50	20.29
Blue virtual water exports	**Composition (%)**	51	-140	-8
	Scale (%)	57	278	127
	Intensity (%)	-8	-38	-19
	Δ VWE (km^3)	2.81	4.53	7.35
Green virtual water imports	**Composition (%)**	-3	-67	-54
	Scale (%)	153	177	187
	Localization (%)	-6	16	-7
	Intensity (%)	-43	-26	-26
	Δ VWM (km^3)	5.65	18.83	24.48
Blue virtual water imports	**Composition (%)**	-28	-16	-52
	Scale (%)	276	161	215
	Localization (%)	-63	-37	-61
	Intensity (%)	-84	-7	-1
	Δ VWM (km^3)	0.26	1.56	1.81

Blue virtual water exports also rose from 1965 to 2010 although to a less extent than virtual green water exports. In general, considering the whole period, scale effect encouraged blue virtual water exports expansion while composition and intensity effect prevented a higher water consumption. We observe some differences when examining the two different periods. From 1965 to 1985 both scale and composition effects gave a boost to blue virtual water exports. It was not only the growth of trade but also the exports of blue water intensive products like fruits and vegetables what triggered the increase in blue virtual water exports. Only the reduction of water intensities, contributed to a partial levelling off. Nonetheless, from 1986 the great increase seen for blue virtual water exports was only due to the rise of the volume of trade, since both composition and intensity effect showed negative sign. The decreasing share of olive oil associated with the increasing weight of meat made composition to foster water consumption moderation. According to our results, if composition and yield changes had not occurred, the growth in blue virtual water exports would have been 8 km^3 greater.

Tuning to virtual water imports, Table 6.3 shows the great increase taken place particularly from 1986. Actually, virtual water imports grew about 26 km^3 during these years of intense internationalisation in Spain, and again the rise experienced from 1986 was about 77% of total increase. Spain imported mostly green water, which on average represented 93% of total water imports. Green water imports rise was driven by scale effect, whereas composition, localization and intensity effects contributed to virtual water imports levelling off. Without the key role of the last three components, virtual water imports would have been 21 km^3 higher. That is to say, from 1965 to 2010 Spain increased its volume of green water embodied in imports as a result of its broad globalising process. Quite opposite, trade pattern changes with decreasing imports of oil seeds, coffee or cereals were a determining element for water consumption moderation. Yield improvements in the producing nations were also beneficial for water resources from 1965 to 2010. Despite localization effect was also negative until 1985; the accession in the European Union and therefore the changing origin of products towards higher exchanges with close areas such as France and Portugal made green water embodied in imports to increase. As Table 6.3 shows, blue imports only represented about 6% of the increase in total virtual water imports. Scale effect triggered the rise from 1965 to 2010 and again as happened with green water; composition, intensity and localization effects prevented a higher increase in blue virtual water imports. This means that Spain was gradually importing more blue water because of the increasing exchanges of commodities. In this case, localization effect was the most relevant negative factor, since there was a significant variation in the countries from blue water was imported. As we have seen, countries that produce cotton in a water intensive way like Egypt or Turkey were important commercial partners of Spain in the sixties. Today, these areas are less important and Spain imports most blue water from USA, France or Portugal.

5. Discussion

As we have seen, virtual water flows followed a rising trend from 1965 to 2010 driven by the great increase in the volume of trade. To what extent this long term process of internationalization influenced the consumption of water in Spain? In other words, was the foreign sector a determining element for the increase in water consumption? To address this issue, we compare the water embodied in virtual water flows with the volume of water embodied in Spanish agricultural and food production[19].

Table 6.4 offers an overview of the volume of water required for the production of agricultural and food products and water embodied in Spanish exports and imports.

Table 6.4: Comparison of green and blue water embodied in exports and production

	EWP (hm^3)	VWX (hm^3)	VWM (hm^3)	External balance (hm^3)	VWX/ EWP (%)	VWM/ EWP (%)	Ext. bal./ EWP (%)
Green							
1966	54,682	2,288	9,064	-6,776	4.2	16.6	-12.4
2008	79,952	20,070	36,205	-16,134	25.1	45.3	-20.2
Blue							
1966	14,353	711	864	-153	5.0	6.0	-1.1
2008	21,953	7,159	2,704	4,456	32.6	12.3	20.3
	Δ EWP (hm^3)	**ΔVWX** (hm^3)	**ΔVWM** (hm^3)	**Δ External balance** (hm^3)	**ΔVWX/Δ EWP** (%)	**ΔVWM/Δ EWP** (%)	**Δ Ext. bal./Δ EWP** (%)
Green							
66-08	25,270	17,783	27,141	-9,359	70.4	107.4	-37.0
Blue							
66-08	7,600	6,448	1,840	4,609	84.8	24.2	60.6

Source: own elaboration based on foreign trade Statics of Spain and agricultural production data.
EWP: Embodied water in production, VWX: Virtual water exports, VWM: Virtual water imports, External Balance: VWX-VWM. As we do not have data of manufactured crops and livestock production, these items have not been included in virtual water exports for comparability reasons.

[19]To approximate this later volume, we calculate water embodied in production using data from "Anuario Estadístico de la Producción Agraria" (1965-2010). Production data in the selected years have been obtained as a three-year average centered in the year of reference, trying to soften production volatility. Water intensity coefficients are taken from Mekonnen and Hoekstra (2011, 2012).

As we can see, in 1965 green and blue virtual water exports represented 4.2% and 5% of green and blue embodied water in production, respectively. These percentages were lower than those achieved in Duarte et al. (2014b), what highlights the negative effect of the crisis of 1929, the Spanish Civil War, the Second World War but mostly of the autarkic policies developed in the first two decades of the Franco's dictatorship. They involved a notable isolation of the Spanish economy and its agricultural sector, which apart from having declined in foreign markets, oriented its production to domestic markets to a greater extent than before. These percentages notably increased by the end of the period of study, reaching approximately 30%, particularly in the case of blue water. This formidable increase in virtual water exports highlights the importance of the integration of the agricultural sector in international markets during the second globalisation (Clar et al., 2014). The great increase in agri-food exports was even higher than world trade, which experienced an abrupt growth throughout the second half of the twentieth century (Serrano and Pinilla, 2011). During these years the volume of blue water embodied in production grew by 7,600 hm^3 whereas blue virtual water exports increased about 6,448 hm^3, what basically means that 85% of the increase in blue water consumption for production was due to the growing Spanish exports. As for green water, the pressure of the foreign sector on domestic resources was less intense, since the former ratio reached 70%. If we consider the volume of imported blue water, the increase of net exports explains 60% of the rise of the volume of blue water embodied in production.

In sum, Spain went through an intense process of integration in the world economy that profoundly affected the consumption of domestic water resources. The implications of the enormous weight of external demand (or net balance of trade in blue virtual water) in the Spanish economy are very important. Water policy formed an important part of the Franco dictatorship's (1939-75) farm policy. This was based on earlier irrigation plans, which required the construction of ever larger dams. This policy led to a major expansion in the irrigated area. The construction of dams to store water for irrigation reached its zenith between 1951 and 1990. Between these two dates the capacity of dams built to store water for irrigation rose by 24,500 hm^3. This entails about 80% of the current storage capacity. The period studied is therefore crucial for the expansion of large waterworks in Spain. As a consequence, the area of irrigated farmland grew sharply and by 1995 it was a 133% greater than before the Civil War (Pinilla, 2006). The fact that irrigated area more than doubled over the period analyzed was mostly due to the high foreign demand of agri-food products and to the capacity of the agricultural sector to meet these needs. Nonetheless, the development of large irrigation schemes involving the construction of large dams, canals, and fitting up plots, entailed a formidable public and private investment. The public sector gradually funded large infrastructures. As an example, 100% of large dams for irrigation were built between 1960 and 1990 in the river Ebro basin, one of the main basins in the country, where more than 20% of irrigated area is located (Ibarra and Pinilla, 1999).

It is also necessary to examine the impact that the increase in irrigated agriculture had on the natural environment. This was particularly marked in the last 30 years. Some of the significant environmental impacts affecting water resources were the salinity of the agricultural land, the problems for the preservation of the river's deltas as a result of the decline in the volume of water flowing down, and the contribution to the widespread pollution of water by nitrates and phosphates due to the intensive use of chemical fertilizers and phytosanitary products (Duarte et al., 2002; Pinilla, 2008).

From a social point of view, it is also important to acknowledge the consequences of the big water projects. There was a clash between the interests of people living in the affected areas by the big dams and those of the farmers. Large-scale projects enforced the movement of populations as a consequence of reservoir construction (Herranz, 2004).

However, despite the great impact that the second globalisation had in blue water domestic resources, it is important to note that Spain was a net importer of water. That is, in spite of exporting large volumes of blue water, growing imports of green water embodied in cereals and feed stuff, meant that the impact exerted by Spain on foreign water resources was higher than the impact on domestic water resources.

6. Conclusions

From 1965 to 2010, Spain went through profound economic, political and social changes. From an economic perspective the culmination of the process of industrialization and economic modernization that meant that Spain would become a high-income country was outstanding (Prados de la Escosura, 2000; Prados de la Escosura and Rosés, 2009). Modern economic growth was attained when the profound isolation of the first decades of Franco's dictatorship, following an autarky policy inspired in nazi Germany and fascist Italy, was abandoned. Although the food industry lost weight both in the overall economic activity and in the external trade flows, it also experienced significant changes. The most important was the end of traditional agriculture that became a modern and high productive sector (Clar and Pinilla, 2009; Reig and Picazo, 2002; Martín-Retortillo and Pinilla, 2012 and 2013). Agri-food exports and imports grew at a high pace exceeding previous periods (Gallego and Pinilla, 1996; Clar et al., 2014). Its growing integration in international markets entailed large pressures on both domestic and foreign water resources. Spain was a net exporter of blue water, being the growth in net exports over 60% of the growth of blue water embodied in production. Nevertheless, on balance, it imported large volumes of green water, meaning that on whole, Spain exerted larger pressures on foreign resources. The growing commercial exchanges were the determining factor driving virtual water trade flows. Despite yield improvements, compositional patterns changes and variations in the origin of products had a significant contribution; these effects were not enough to offset the large increase in the volume of trade.

Given the great pressure exerted on water resources, the main solution adopted was the increase in the regulated water supply, that is, an important construction of large reservoirs and canals to make the development of irrigation possible. Most of the increase in agriculture was due to the expansion of Spanish agri-food exports. This meant large public and private investments, significant environmental impacts and from the seventies, important political debates. Two types of conflicts arose. Firstly, inter basin conflicts, as a result of the huge needs of water in the export oriented Mediterranean region that demanded water transfers. Water was transferred from the Tajo basin, but not from the Ebro basin. Secondly, in some basins, there were also disputes between supporters of continuing the implementation of water projects, mainly farmers, and protesters, mostly people living in the affected mountain areas. From our perspective the importance of water demand from the agri-food export sector has not so far been sufficiently present in this debate, which we think has been demonstrated.

As we have seen, the growing integration of Spain in international markets meant notable pressures on water ecosystems. Although it is true that there exit some factors that seem to slow down the strong consumption of water resources, water demands keep on increasing nowadays. In this background, it is necessary that countries assess the environmental consequences of long term socio-economic transitions. Furthermore, it is crucial taking into account that in the current globalised context, the consumption of products in one nation may entail serious social and environmental problems in distant places. This seems particularly important for those developing countries that are abundant in natural resources and are experiencing fast processes of economic growth with remarkable shares of the foreign sector in their GDP.

In conclusion, water resources should be jointly managed at the global level, preventing the displacements of environmental pressures. In this context, demand-side policies seeking for reducing water needs or changes in consumption patterns, together with supply side actions such as technological developments or productive reallocations towards water efficient areas seem to be urgent to address the well-known global water scarcity.

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CHAPTER 7.

GLOBAL WATER IN A GLOBAL WORLD: A LONG TERM STUDY ON VIRTUAL WATER FLOWS IN THE WORLD

1. Introduction

Food production has experienced a marked increase during the last fifty years (FAOSTAT, 2013; Rask and Rask, 2011). Together with it, commercial exchanges of agricultural and food products have gone through a great growth in the past half century (Serrano and Pinilla, 2010 and 2011a). This globalisation process has involved not only an important trade of commodities, but also huge exchanges of natural resources embodied in these goods (Schmitz et al., 2012). Consequently, people consuming products from other parts in the word, are at the same time consuming water, biomass or land from distant places. Therefore, a mismatch between the responsibilities of producer and consumer regions appears.

The relationship between the use of natural resources and economic growth has been widely examined in recent years. In this line, today there are many studies that assess the path followed by timber (Iriarte-Goñi and Ayuda, 2008 and 2012), land (Weinzettel, 2013; Krausmann et al., 2013; Kohlheb and Krausmann, 2009), biomass or minerals (Krausmann et al., 2009). Many of them are socio-metabolism studies that try to account for exchanges of materials and energy between societies and their natural environment (Fischer-Kowalski and Hüttler, 1998).

As for water, a large number of studies have been carried out over the last decade. They consider water not only as a local, but also as a global resource since it is virtually transferred embodied in products that are internationally exchanged. In this framework, the concept of virtual water first defined by Allan (1997) is the volume of water necessary for the production of a commodity. Very close to it, the water footprint is an indicator of freshwater use that looks at both direct and indirect water use of a consumer or producer (Hoekstra et al., 2011). These studies tend to distinguish between green and blue water. Green water is the rainwater evaporated as a result of the production of a commodity and blue water is surface or groundwater evaporated during a production process (Hoekstra and Chapagain, 2008). Both are interrelated in the hydrological system, however blue water is said to have higher opportunity costs, as it can be reallocated among the different users (Yang et. al., 2007). Virtual water has been methodologically studied from the top-down and bottom-up approaches. The former adopts environmental input-output analysis to obtain virtual water and water footprints by accounting for regional, national or/and global supply chains (Feng et al., 2012; Steen-Olsen et al., 2012). The latter gets footprints on the basis of virtual water content of internationally traded goods and services determined from detailed process data (Feng et al., 2011). In this paper we will use the bottom-up methodology that according to Feng et al. (2011) "has become one of the most popular approaches in water footprinting studies due to its simplicity and relatively good data availability, concentrating mainly on agricultural and food products". Whereas many of these studies focus on the short term, to our knowledge there are no papers addressing virtual water in the long run. From our viewpoint, the long term approach is essential to assess the way that water displacements have occurred in history, addressing the trajectories and feedbacks lying behind the relationship between societies and water resources. As Schandl and Schulz (2002) said, an environmental history perspective "may enable society to consciously intervene in these natural relations and might even eventually foster our understanding of sustainability". This seems particularly important in the period studied, when the second globalisation took place. This long term process has entailed an outstanding economic and commercial integration that has resulted in growing exchanges of factors and products that embody large volumes of water. In this context, it is essential to examine the role played by the second globalisation in the link between growth and water resources at a global level.

Therefore, this paper assesses the trends in virtual water transfers in the world from 1965 to 2010, a period of intense internationalization that meant important environmental impacts. To that aim, we will analyze global trends paying special attention to those areas that exert the largest pressures on their domestic water resources to be consumed in other parts of the world, studying the amount and direction of global virtual water flows. We will use the bottom-up approach, that will allow us to study global water displacements of agricultural and food products in a highly disaggregated way. Besides, we will obtain and quantify those factors that may lie behind the path followed by virtual water imports and exports. By means of a Decomposition Analysis (DA), trends in water exchanges will be explained on the basis of changes in the volume of trade, in the trade composition by products, in the origin of flows as well as in the main commercial countries concerning agricultural and food products.

We will utilize bilateral trade data given by United Nations Statistics Division (UN COMTRADE, 2013) and coefficients on water use intensity provided by Mekonnen and Hoekstra, 2011 and 2012). From them, we will obtain the volume of water exchanged between world regions and countries throughout the period 1965-2010.

The following section addresses the main methodological aspects and explains the data. Section 3 deals with the main findings of the work. Section 4 goes with the discussion of the results and section 5 ends with the main conclusions.

2. Methodology and Data

2.1. Methodological aspects

As a first step, we estimate virtual water trade flows following the method proposed by Hoekstra and Hung (2005). Thus, virtual water exports of country *c* in year *t* are obtained as:

$$VWX(c,t) = \sum_{p} d_p^c(c,p,t) * e_p^c(c,p,t) \qquad (7.1)$$

Being e_p^c the quantity of product *p* exported (Tons) and d_p^c a coefficient indicating the volume of water necessary to produce a ton of each commodity in the exporting country, i.e., water intensity (m^3/Ton). d_p^c will distinguish between green or blue water.

Virtual water imports are the sum of the water embodied in the imported goods coming from country *z*.

$$VWM(c,t) = \sum_{pz} d_p^Z(z,p,t) * m_p^z(z,p,t) \qquad (7.2)$$

With m_p^z being the bilateral import flow from country *z* to country *c* (Tons) and d_p^Z representing the water required in country z to produce *p* (m^3/Ton). Thus, calculating the difference between virtual water exports and virtual water imports we get the virtual water trade balance for each country *c*:

$$VWB(c,t) = VWX(c,t) - VWM(c,t) \qquad (7.3)$$

Secondly, we apply a Decomposition Analysis (DA) to obtain the factors driving virtual water exports and imports changes. Embodied water in exports can be explained on the basis of four elements: water content per unit of crop, product composition of trade, country shares and scale, obtaining:

$$VWX(c,t) = \sum_{p} w_{cpt}.\frac{e_{cpt}}{e_{ct}}\frac{e_{ct}}{e_t}e_t \qquad (7.4)$$

The former expression in matrix form yields:

$$VWX(c,t) = \mathbf{w}'_{\mathbf{ct}}\mathbf{f}_{\mathbf{ct}}s_{\mathrm{ct}}e_t \qquad (7.5)$$

With $\mathbf{w}'_{\mathbf{ct}}$ being a row vector of the water intensity per unit of product in m^3/$ in country c, $\mathbf{f}_{ct}$ is a vector showing the share that each product represents in total exports of country *c* in period *t*. s_{ct} is a scalar with the percentage of the country in total exports and e_t is the total value of exports in the world in year *t* (in dollars).

For the whole world economy, we would write:

$$VWX(t) = \mathbf{w}'_{\mathbf{t}}\mathbf{X}_{\mathbf{t}}\mathbf{s}_{\mathrm{t}}e_t \qquad (7.6)$$

Being $\mathbf{w}'_{\mathbf{t}}$ a vector of water intensities per product and country, $\mathbf{X}_{\mathbf{t}}$ a matrix of the share of product exports per country, $\mathbf{s}_{\mathbf{t}}$ is a vector showing the country shares in total world exports and e_t the total volume of world exports.

Virtual water imports can be explained on the basis of five drivers; water intensities, the origin of flows, product composition, country shares and scale of trade.

$$VWM(c,t) = \sum_{p,z} w_{cpzt}.\frac{m_{cpzt}}{m_{cpt}}.\frac{m_{cpt}}{m_{ct}}\frac{m_{ct}}{m_t}m_t \qquad (7.7)$$

or, in matrix form,

$$VWM(c,t) = \mathbf{w}'_{\mathbf{czt}}\mathbf{M}_{\mathbf{czt}}\mathbf{b}_{\mathbf{ct}}r_{ct}m_t \qquad (7.8)$$

being $\mathbf{w}'_{\mathbf{czt}}$ a row vector of the embodied water per product in each of the countries *z* from which country *c* imports, measured in m³/\$. $\mathbf{M}_{\mathbf{czt}}$ is a matrix that includes, for each product *p*, the percentage imported by *c* from each country *z*. Moreover, $\mathbf{b}_{\mathbf{ct}}$ is a vector of product import composition in country *c*, r_{ct} is a scalar showing the participation of country *c* in the world imports and m_t is a scalar with the total value of imports in the world in year *t* (in dollars).

Similarly, for the world economy, the total volume of water imports can be expressed as follows:

$$VWM(t) = \mathbf{w}'_{\mathbf{t}}\mathbf{M}_{\mathbf{t}}\mathbf{P}_{\mathbf{t}}\mathbf{r}_{t}m_t \qquad (7.9)$$

Being $\mathbf{w}'_{\mathbf{t}}$ a vector of water intensities per product and country, $\mathbf{M}_{\mathbf{t}}$ a matrix of the share of imports (per country of origin and per product, with main diagonal blocks equal to cero), $\mathbf{P}_{\mathbf{t}}$ is a matrix of product composition of imports (for each country), $\mathbf{r}_{t}$ is a vector of import country shares in total world imports and m_t is the total volume of world imports.

Note that while $VWX(c,t)$ differ from $VWM(c,t)$ at the country level, $VWX(t) = VWM(t)$ holds for the whole world economy, so aggregated water balance is zero from this perspective.

The above equations can be handled at the country level or at the world level. Similarly, it is possible to derive by-product expressions for water exports and imports on the bases of the above developments.

Departing from equations (7.5) and (7.8), we utilize the DA. This approach tries to separate a time trend of an aggregated variable into a group of driving forces that can act as accelerators or retardants (Dietzenbacher and Los, 1998; Hoekstra and van den Bergh, 2002; Lenzen et. al., 2001).

In a discrete schema, when we try to measure the changes in the dependent variable between two periods, *t-1* and *t*, there are different ways of solving this expression by way of exact decompositions, which leads the well-known problem of non-uniqueness of DA solution. In our case, decomposition is based on five factors for imports and fours factors for exports; therefore we can obtain the following 5! and 4! exact decompositions respectively. In practice, as a "commitment solution", the average of two polar solutions is considered (Dietzenbacher and Los, 1998).

Therefore, the polar decompositions of (7.5) can be written as follows:

$$\Delta VWX(c) = \Delta\mathbf{w_c'}\mathbf{f_{ct}}s_{\mathrm{ct}}e_t + \mathbf{w_{ct-1}'}\Delta\mathbf{f_c}s_{\mathrm{ct}}e_t + \mathbf{w_{ct-1}'}\mathbf{f_{ct-1}}\Delta s_c e_t + \mathbf{w_{ct-1}'}\mathbf{f_{ct-1}}s_{\mathrm{ct-1}}\Delta e \qquad (7.10)$$

$$\Delta VWX(c) = \Delta\mathbf{w_c'}\mathbf{f_{ct-1}}s_{\mathrm{ct-1}}e_{t-1} + \mathbf{w_{ct}'}\Delta\mathbf{f_c}s_{\mathrm{ct-1}}e_{t-1} + \mathbf{w_{ct}'}\mathbf{f_{ct}}\Delta s_c e_{t-1} + \mathbf{w_{ct}'}\mathbf{f_{ct}}s_{\mathrm{ct}}\Delta e \qquad (7.11)$$

Furthermore, based on (7.8) we get the two polar decompositions of imports, which yields:

$$\Delta VWM(c) = \Delta\mathbf{w_{cz}'}\mathbf{M_{czt}}\mathbf{b_{ct}}r_{ct}m_t + \mathbf{w_{czt-1}'}\Delta\mathbf{M_{cz}}\mathbf{b_{ct}}r_{ct}m_t + \mathbf{w_{czt-1}'}\mathbf{M_{czt-1}}\Delta\mathbf{b_c}r_{ct}m_t + \mathbf{w_{czt-1}'}\mathbf{M_{czt-1}}\mathbf{b_{ct-1}}\Delta r_c m_t + \mathbf{w_{czt-1}'}\mathbf{M_{czt-1}}\mathbf{b_{ct-1}}r_{ct-1}\Delta m \qquad (7.12)$$

$$\Delta VWM(c) = \Delta\mathbf{w_{cz}'}\mathbf{M_{czt-1}}\mathbf{b_{ct-1}}r_{ct-1}m_{t-1} + \mathbf{w_{czt}'}\Delta\mathbf{M_{cz}}\mathbf{b_{ct-1}}r_{ct-1}m_{t-1} + \mathbf{w_{czt}'}\mathbf{M_{czt}}\Delta\mathbf{b_c}r_{ct-1}m_{t-1} + \mathbf{w_{czt}'}\mathbf{M_{czt}}\mathbf{b_{ct}}\Delta r_c m_{t-1} + \mathbf{w_{czt}'}\mathbf{M_{czt}}\mathbf{b_{ct}}r_{ct}\Delta m \qquad (7.13)$$

Taking the average of (7.10) and (7.11) we obtain (7.14)

$$\Delta VWX(c) = \frac{\Delta\mathbf{w_c'}\mathbf{f_{ct}}s_{\mathrm{ct}}e_t + \Delta\mathbf{w_c'}\mathbf{f_{ct-1}}s_{\mathrm{ct-1}}e_{t-1}}{2} + \frac{\mathbf{w_{ct-1}'}\Delta\mathbf{f_c}s_{\mathrm{ct}}e_t + \mathbf{w_{ct}'}\Delta\mathbf{f_c}s_{\mathrm{ct-1}}e_{t-1}}{2} + \frac{\mathbf{w_{ct-1}'}\mathbf{f_{ct-1}}\Delta s_c e_t + \mathbf{w_{ct}'}\mathbf{f_{ct}}\Delta s_c e_{t-1}}{2} + \frac{\mathbf{w_{ct-1}'}\mathbf{f_{ct-1}}s_{\mathrm{ct-1}}\Delta e + \mathbf{w_{ct}'}\mathbf{f_{ct}}s_{\mathrm{ct}}\Delta e}{2} \qquad (7.14)$$

Proceeding the same way with (7.11) and (7.13) gives equation (7.15)

$$\Delta VWM(c) = \frac{\Delta \mathbf{w'_{cz}M_{czt}b_{ct}}r_{ct}m_t + \Delta \mathbf{w'_{cz}M_{czt-1}b_{ct-1}}r_{ct-1}m_{t-1}}{2} + \frac{\mathbf{w'_{czt-1}}\Delta \mathbf{M_{cz}b_{ct}}r_{ct}m_t + \mathbf{w'_{czt}}\Delta \mathbf{M_{cz}b_{ct-1}}r_{ct-1}m_{t-1}}{2} + \frac{\mathbf{w'_{czt-1}M_{czt-1}}\Delta \mathbf{b_c}r_{ct}m_t + \mathbf{w'_{czt}M_{czt}}\Delta \mathbf{b_c}r_{ct-1}m_{t-1}}{2} + \frac{\mathbf{w'_{czt-1}M_{czt-1}b_{ct-1}}\Delta r_c m_t + \mathbf{w'_{czt}M_{czt}b_{ct}}\Delta r_c m_{t-1}}{2} + \frac{\mathbf{w'_{czt-1}M_{czt-1}b_{ct-1}}r_{ct-1}\Delta m + \mathbf{w'_{czt}M_{czt}b_{ct}}r_{ct}\Delta m}{2} \quad (7.15)$$

Accordingly, we obtain the following effects that explain changes in virtual water flows:

- Scale effect, which quantifies how much of the change in virtual water flows is explained by changes in the volume of exports or imports. It yields (7.16) for exports and (7.17) for imports:

$$SE_x(c) = \frac{\mathbf{w'_{ct-1}f_{ct-1}}s_{ct-1}\Delta e + \mathbf{w'_{ct}f_{ct}}s_{ct}\Delta e}{2} \quad (7.16)$$

$$SE_m(c) = \frac{\mathbf{w'_{czt-1}M_{czt-1}b_{ct-1}}r_{ct-1}\Delta m + \mathbf{w'_{czt}M_{czt}b_{ct}}r_{ct}\Delta m}{2} \quad (7.17)$$

- Composition effect, which measures the impact of changes of the product composition of trade flows in each country. It is represented by (7.18) for exports and (7.19) for imports:

$$CE_x(c) = \frac{\mathbf{w'_{ct-1}}\Delta \mathbf{f_c}s_{ct}e_t + \mathbf{w'_{ct}}\Delta \mathbf{f_c}s_{ct-1}e_{t-1}}{2} \quad (7.18)$$

$$CE_m(c) = \frac{\mathbf{w'_{czt-1}M_{czt-1}}\Delta \mathbf{b_c}r_{ct}m_t + \mathbf{w'_{czt}M_{czt}}\Delta \mathbf{b_c}r_{ct-1}m_{t-1}}{2} \quad (7.19)$$

- Trade share effect, which quantifies the effect that variations in the weight of countries in global trade have in virtual water trends. It is given by (7.20) for exports and (7.21) for imports:

$$TSE_x(c) = \frac{\mathbf{w'_{ct-1}f_{ct-1}}\Delta s_c e_t + \mathbf{w'_{ct}f_{ct}}\Delta s_c e_{t-1}}{2} \quad (7.20)$$

$$TSE_m(c) = \frac{\mathbf{w}'_{\mathbf{czt-1}}\mathbf{M}_{\mathbf{czt-1}}\mathbf{b}_{\mathbf{ct-1}}\Delta r_c m_t + \mathbf{w}'_{\mathbf{czt}}\mathbf{M}_{\mathbf{czt}}\mathbf{b}_{\mathbf{ct}}\Delta r_c m_{t-1}}{2} \quad (7.21)$$

- Localization effect, which indicates to what extent changes in the countries from importers buy each product affect virtual water flows. It only exists for virtual water imports and is given by (7.22).

$$LE_m(c) = \frac{\mathbf{w}'_{\mathbf{czt-1}}\Delta\mathbf{M}_{\mathbf{cz}}\mathbf{b}_{\mathbf{ct}}r_{ct}m_t + \mathbf{w}'_{\mathbf{czt}}\Delta\mathbf{M}_{\mathbf{cz}}\mathbf{b}_{\mathbf{ct-1}}r_{ct-1}m_{t-1}}{2} \quad (7.22)$$

- Intensity effect, which identifies the contribution of changes in water intensities to changes in virtual water trade flows. It is given by (7.23) for exports and (7.24) for imports:

$$IE_x(c) = \frac{\Delta\mathbf{w}'_{\mathbf{c}}\mathbf{f}_{\mathbf{ct}}s_{\mathrm{ct}}e_t + \Delta\mathbf{w}'_{\mathbf{c}}\mathbf{f}_{\mathbf{ct-1}}s_{\mathrm{ct-1}}e_{t-1}}{2} \quad (7.23)$$

$$IE_m(c) = \frac{\Delta\mathbf{w}'_{\mathbf{cz}}\mathbf{M}_{\mathbf{czt}}\mathbf{b}_{\mathbf{ct}}r_{ct}m_t + \Delta\mathbf{w}'_{\mathbf{cz}}\mathbf{M}_{\mathbf{czt-1}}\mathbf{b}_{\mathbf{ct-1}}r_{ct-1}m_{t-1}}{2} \quad (7.24)$$

2.2. Data

Trade data on agricultural and food products are taken form United Nations Statistics Division (UN COMTRADE, 2013) at the four-digit level of the Standard International Trade Classification (SITC, revision 1). Our sample considers 136 products and 104 countries, accounting for approximately 85% of agricultural and food commercial exchanges in the world during these years. DA requires trade data in monetary units. Thus, we calculate world prices of each product in 1985 and express trade data at constant 1985 dollars.

Water intensities stem from Mekonnen and Hoekstra (2011, 2012). They estimate water coefficients following the approach developed by Allen et al. (1998) and Hoekstra et al. (2009), i.e., dividing crop water use (green or blue) obtained as evapotranspiration (ET) under non optimal conditions by the crop yield. While climatic and crop characteristics (ET) can be assumed to be constant over time, technological advances such as irrigation or improvements in seeds involved notable yield improvements that could have affected water intensities from 1965 to 2010. Thus, in line with Dalin et al. (2012) and Konar et al. (2013), water coefficients have been adapted varying depending on national yield series as follows:

$$w_{cpt} = w_{cp}\frac{Y_{cp}}{Y_{cpt}} \qquad (7.25)$$

With w_{cpt} being the water coefficient for each product in the period of analysis (t from 1965 to 2010),$\mathrm{w_{cp}}$ is the crop or livestock water intensity given by Mekonnen and Hoekstra (2011, 2012).Y_{cp} represents the average yield of the reference period (1996-2005) and Y_{cpt} are the annual product yields for each specific year studied. The hypothesis underlying this approach is that technological developments have influenced crop and livestock yields in the long term, also affecting water consumption per ton. Data on crop and livestock yields from 1965 to 2010 have been taken from Food and Agriculture Organisation of the United Nations (FAO, 2013).

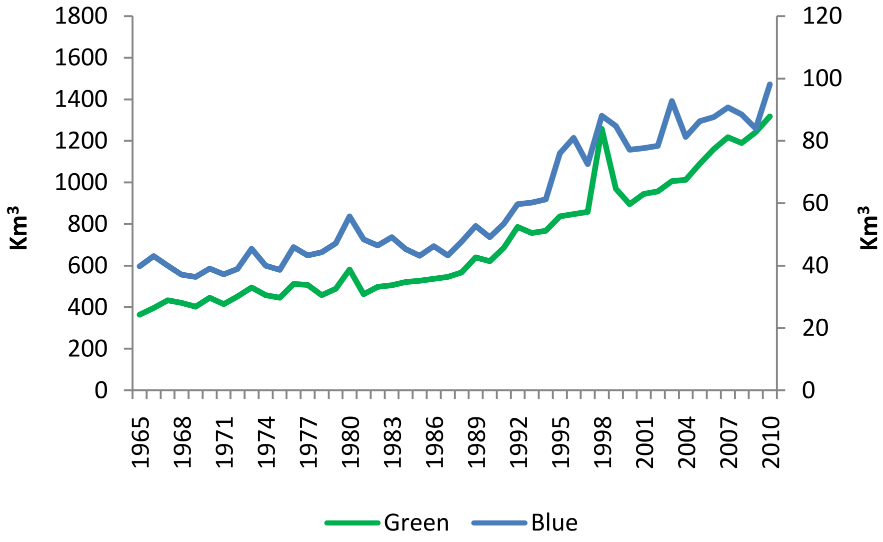
3. Results

3.1. Global virtual water flows assessment

Globally, virtual water flows experienced a continuous growth from 1965 to 2010, i.e., the volume of water embodied in agricultural and livestock products exchanged internationally through trade went from 403 km^3 in 1965 to 1,415 km^3 in 2010, growing at an average annual growth rate of 2.7%. As Figure 7.1 shows, green water was the most important component in total virtual water, since blue water only represented 8% over global water consumption on average. Besides, exchanges of green water depict a most vigorous increase, growing at 2.8% every year, opposite to blue water that rose at 2.7% annually.

This growing pattern was similar all over the world, with the exception of Africa and The Former Soviet Union where the trajectory was quite erratic. Nevertheless the contribution of each region to virtual water exports and imports rather diverges (see Table 7.1).

Figure 7.1: Global virtual water flows, 1965-2010 (km^3)



Green water is referred to the left axis. Blue water is referred the right axis.

On the whole, the percentages representing the share of the world regions on exports and imports, and its tendency, tend to be similar to those resulting when the results are analyzed in value, i.e., in monetary units (Serrano and Pinilla, 2011a). Obviously the figures are approximate, given the changes in the composition of trade by product and the differences of using prices or water intensities. The largest exporter of blue water was North America all over the period, followed by Europe or Asia and Pacific. The importance of the U.S. as an exporter of agri-food products and the enormous development of its irrigation system from the nineteenth century explain the high virtual water exports of North America. The intense intra-European trade of agricultural and food products, clearly influenced by the process of economic integration, together with its growing share on processed and high value added agri-food exports could lie behind the importance and growing weight of Europe in global virtual water trade (Serrano and Pinilla, 2011b). In the case of green water, Latin and North America appear as the most representative exporters, accounting for a share of 26.6% and 25.2% respectively. The downward trend in the Latin American share was caused by its poor agricultural exports performance from the fifties until the last decade of the twentieth century.

Looking at imports, Europe and Asia and Pacific were the largest buyers of both blue and green virtual water during the period considered. Europe supposed more than 50% of water imports in the world during the sixties but tended to decrease its importance, reaching a share of 36% today. This is related to the implementation of the Common Agricultural Policy that involved an increase in the agricultural protectionism and a drop in the weight of European agricultural imports (Pinilla and Serrano, 2009). On the contrary, Asia and Pacific used to increase its significance in blue virtual water imports. The very strong economic growth in Asian countries since the eighties, and especially in China, explain this rising importance in global virtual water imports.

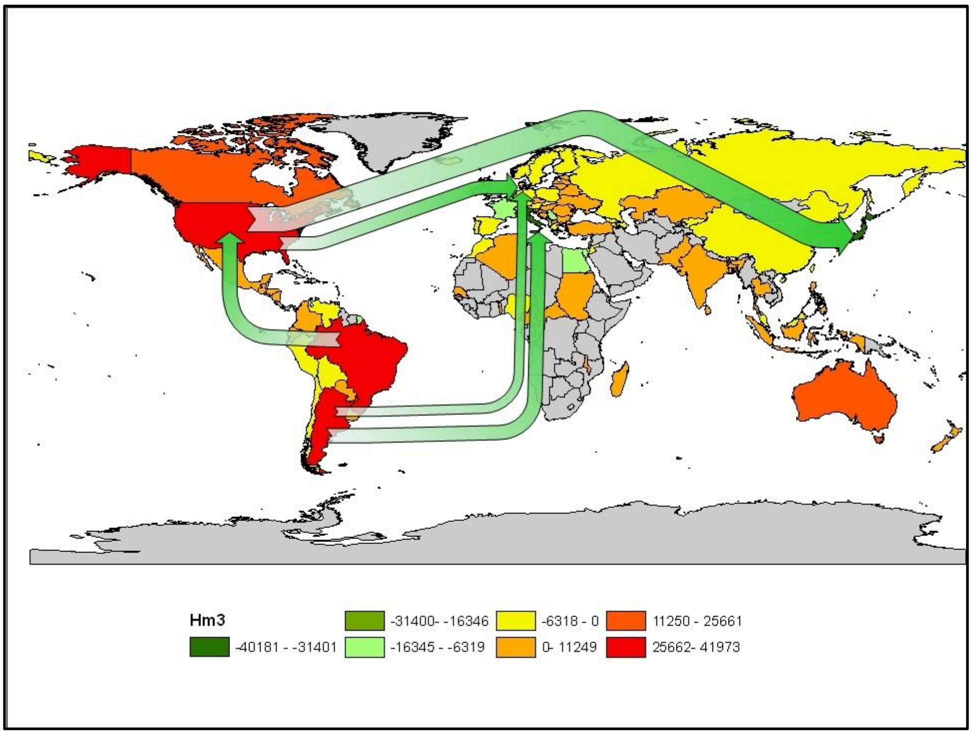
Table 7.1: Average contribution of world regions to virtual water exports and imports (%)

	1965-1969	1970-1979	1980-1989	1990-1999	2000-2010	1965-1969	1970-1979	1980-1989	1990-1999	2000-2010
	Blue water exports					**Green water exports**				
Africa	16.4	12.4	7.9	4.9	5.5	4.5	4.1	3.1	2.1	1.4
North America	26.8	35.9	34.5	30.8	30.4	24.7	30.7	28.5	24.8	22.1
Asia and Pacific	17.9	16.8	20.6	19.7	20.8	12.9	11.8	14.5	17.9	18.4
Europe	15.9	18.8	22.5	22.1	22.6	17.2	17.4	20.8	20.1	18.9
Former Soviet Union	0.5	0.3	0.2	6.0	3.4	2.0	0.7	0.2	5.8	6.3
Latin America	17.7	11.6	8.4	9.5	10.9	30.7	26.3	24.6	24.5	28.3
Oceania	4.8	4.2	5.8	7.1	6.4	7.9	9.0	8.4	4.7	4.5
Total	100	100	100	100	100	100	100	100	100	100
	Blue water imports					**Green water imports**				
Africa	3.0	6.1	8.5	5.3	6.4	3.4	4.8	6.4	5.2	6.4
North America	12.2	9.2	7.8	8.5	9.5	16.1	13.3	10.9	9.0	8.8
Asia and Pacific	26.4	33.4	34.6	32.9	33.1	21.9	26.7	29.5	26.7	32.6
Europe	53.0	45.3	40.4	37.3	33.8	51.8	48.0	44.4	39.9	36.2
Former Soviet Union	1.2	0.4	0.0	5.3	4.7	0.4	0.3	0.2	9.0	4.6
Latin America	3.8	5.3	8.3	10.3	12.0	5.9	6.6	8.2	9.8	10.8
Oceania	0.4	0.3	0.4	0.5	0.7	0.4	0.4	0.4	0.4	0.5
Total	100	100	100	100	100	100	100	100	100	100

Table 7.6 in the appendix 7.1 shows the average virtual water exports, imports and balance in each region during every period. North America and Oceania were net exporters of water in virtual form and tended to reinforce its character throughout the period of analysis. Our findings also show that Europe together with Asia and Pacific were net importers of blue and green water from 1965 to 2010. Both regions consolidated its net importer position particularly from the nineties. The case of Latin America is somehow different; although it was a net exporter of blue water until 1989 and then reverses turning into a slight net importer, it stands out as the most

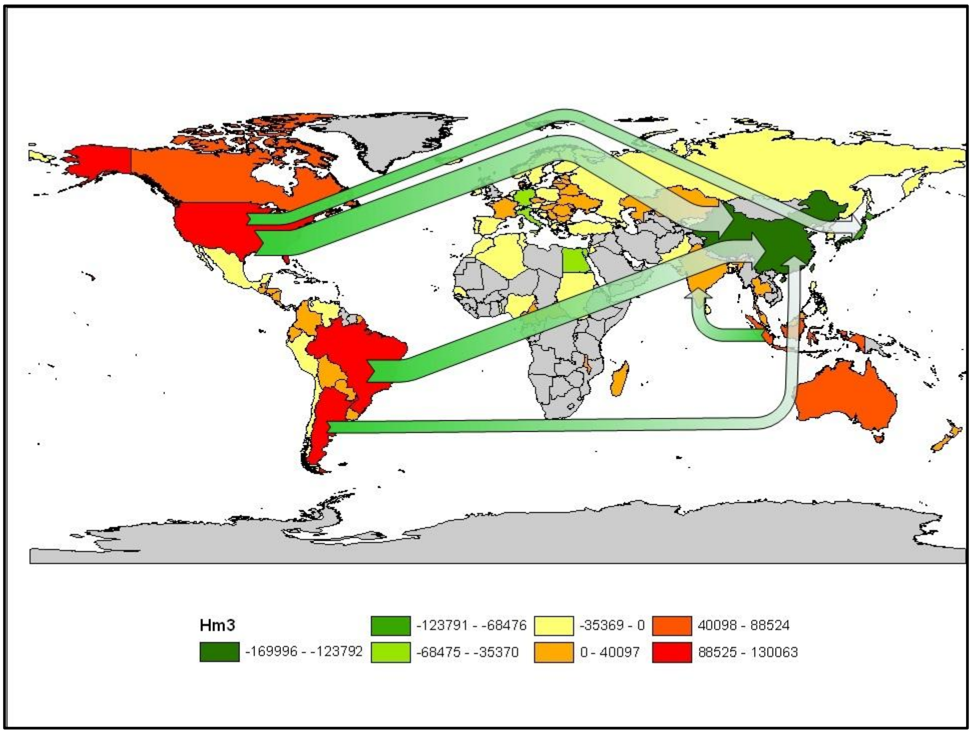
remarkable net exporter of green water particularly from 2000. Certainly the growing agricultural exports from South America to Asia, especially China, explain this turnaround. In this case, green water was mainly embodied in rainfed fodder and other feed stuff crops. Eventually, Africa appears as a net exporter of water until 1980 but becomes a net importer from this moment.

Figure 7.2: Country net exports of green water and top five net flows in the world, 1965



At the country level, it is possible to study not only the countries with the highest flows in the world, but also the origin and destination of these flows. Therefore, Figures 7.2 and 7.3 display the largest net importers and exporters of green water in the world and the five most important net exchanges of agricultural and food products for 1965 and 2010. Figure 7.2 shows that Latin American countries such as Brazil or Argentina exported most green water in 1965. Argentina mainly exported wheat and maize to European states such as Netherlands and Italy. Brazil transferred green water embodied in coffee mainly to USA. Although less important than Latin America areas, USA also exported large volumes of green water to Netherlands and mainly to Japan, the highest net importer of green water in the period, showing the most important flow. In this case, green water was embodied mainly in cereals like wheat and soya beans.

Figure 7.3: Country net exports of green water and top five net flows in the world, 2010



The picture is somehow different in 2010 (Figure 7.3). Despite the American continent (chiefly Brazil, Argentina, USA or Canada) keeps on being the largest provider of green water in the world, the destination of the most significant flows notably changed. Now China is the largest net importer of water in the world, and three of the five most important flows in the world go from USA (soya beans), Brazil (wheat) and Argentina (raw cotton) to the Asiatic Dragon. Moreover, the exchange of water mostly from USA to Japan is still noteworthy nowadays (maize).

As for blue water (Figures 7.4 and 7.5, for 1965 and 2010 respectively), USA appears as the highest net exporter in 1965 followed by Mexico or some countries in the north of Africa like Algeria, Egypt or Sudan. On the contrary, Japan or France imported most blue water. As happened in the case of green water, the largest blue virtual water flow went from USA to Japan. Cereals or cotton exchanges were behind these flows. Important blue water displacements also took place as a result of exchanges of wine from Algeria to France, of cotton from Mexico to USA or Japan or of cereals from USA to Netherlands. In 2010 USA was still the largest blue virtual water exporter in the world, followed by India. While USA blue water resources mainly went to China (soya beans), Japan (maize) and Mexico (cereals), Indian blue water was traded in a great amount with China embodied in cotton and also with Pakistan embodied in sugar.

Figure 7.4: Country net exports of blue water and top five net flows in the world, 1965

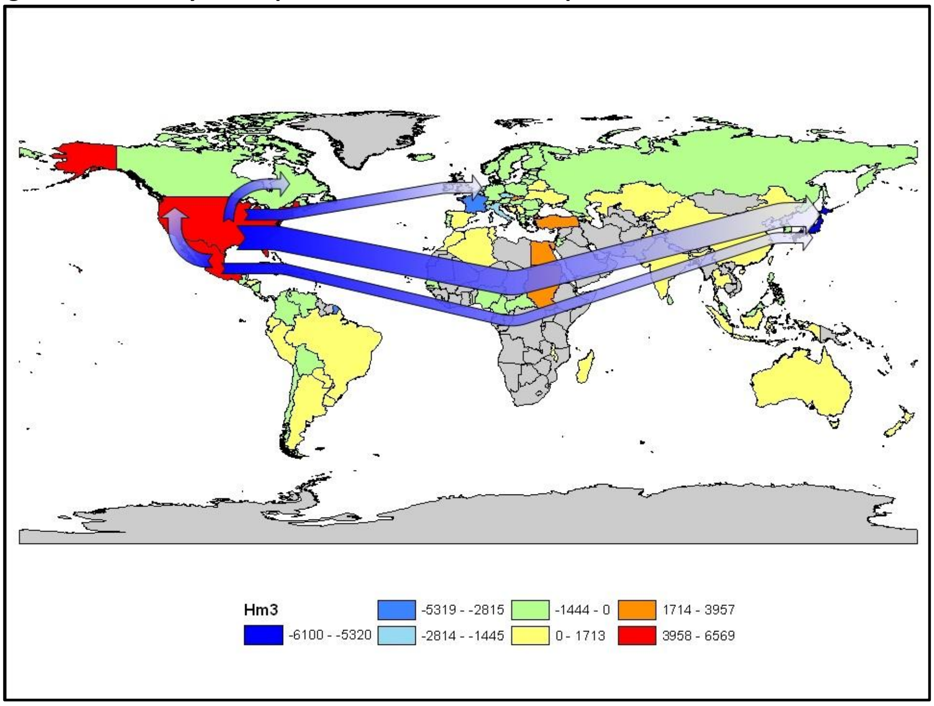
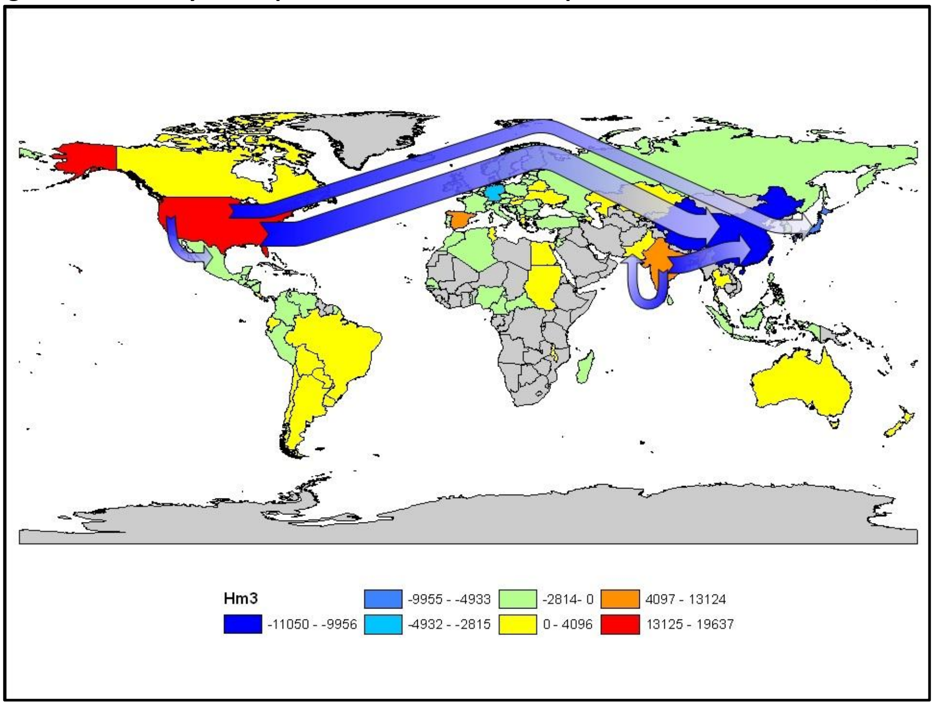


Figure 7.5: Country net exports of blue water and top five net flows in the world, 2010



Tables 7.2 and 7.3 display several water indicators (gross virtual imports and exports, net virtual water imports, scarcity, self-sufficiency and dependency indexes) at the country level for 1980 and for 2000. The scarcity index is obtained as the ratio

between water availability and water withdrawal. The self-sufficiency index is the ratio between water withdrawal and the sum of net virtual water imports and water withdrawal. It will be equal to 100 if the country is a net exporter of water resources. Finally the dependency index is calculated by dividing net virtual water imports with the sum of net virtual water imports and water withdrawal. This index equals zero if the country is a net exporter of water. Besides, the sum of the scarcity and dependency index equals 100. On the whole, it seems quite clear that the patterns of self-sufficiency and dependency remain constant on time. This is the case for most countries but for India or France that during the eighties used to be net importers and very dependent of water coming from abroad and now appear as net exporters of water resources. It is also possible to find some changes in the opposite direction, as the trajectory followed by Sri Lanka or Turkey, states that were net exporters over the eighties and now depict a great dependency on foreign virtual water.

Currently, countries such as Netherlands, Korea, Algeria or Jordan have a high dependency index as a result of agricultural and food products imports. In addition, it is important to note that some of the former areas have been affected by water scarcity throughout this period, as an example Sudan, India, Tunisia, Israel, Morocco, Spain, Algeria, Egypt or Jordan. Nevertheless, some of these countries (Sudan, India or Tunisia) are important net exporters of water in spite of being affected by a notable lack of water.

Table 7.2: Water availability, withdrawal, Gross VWM, Gross VWX and Net VWM in 1980 (km^3)

Country	Population	Water avail. (km^3)	Water with. (km^3)	Gross VWM (km^3)	Gross VWX (km^3)	Net VWM (km^3)	Scarcity index	Self-suff.index	Dep. index
USA	227,225,000	3,069	517.7	55.1	230.7	-175.6	6	100	0
Argentina	28,120,135	814	n.a.	1.8	28.4	-26.6	n.a.	100	0
Brazil	121,740,438	8,233	35.0	16.8	58.5	-41.7	235	100	0
Canada	24,593,000	2,902	42.2	10.0	33.6	-23.6	69	100	0
Australia	14,692,000	492	n.a.	1.5	39.8	-38.3	n.a.	100	0
Indonesia	145,494,452	2,019	74.3	11.3	8.9	2.4	27	97	3
Thailand	47,369,137	439	n.a.	2.5	16.1	-13.5	n.a.	100	0
Malaysia	13,833,739	580	10.1	5.6	10.8	-5.2	57	100	0
New Zealand	3,112,900	327	1.2	0.6	9.1	-8.5	273	100	0
Paraguay	3,198,848	336	0.4	0.3	1.7	-1.4	781	100	0
Hungary	10,711,122	104	4.8	1.9	2.2	-0.3	22	100	0
Colombia	26,934,591	2,132	n.a.	2.2	12.8	-10.5	n.a.	100	0
Guatemala	7,001,101	111	n.a.	0.6	3.5	-2.9	n.a.	100	0
Cameroon	8,932,121	286	0.4	1.5	3.2	-1.7	714	100	0
Bolivia	5,368,901	623	1.2	1.1	0.6	0.5	502	73	27
Nicaragua	3,250,470	197	n.a.	0.6	1.8	-1.2	n.a.	100	0
India	698,965,575	1,911	438.3	7.4	7.1	0.3	4	100	0
Sudan	14,418,063	53	14.1	0.8	4.4	-3.6	4	100	0
France	55,224,670	211	31.0	34.6	19.6	15.0	7	67	33
Uruguay	2,915,735	139	n.a.	0.5	2.4	-1.9	n.a.	100	0
Ireland	3,412,800	52	0.8	1.5	4.2	-2.6	66	100	0
Ecuador	7,909,432	424	n.a.	1.2	3.0	-1.8	n.a.	100	0
Tunisia	6,384,000	5	1.9	2.6	1.7	0.9	2	68	32
Madagascar	8,746,516	337	16.3	0.4	2.4	-2.1	21	100	0
Malawi	6,236,824	17	n.a.	0.0	0.8	-0.8	n.a.	100	0
Bulgaria	8,861,535	21	14.2	1.0	0.8	0.2	2	99	1
Romania	22,242,653	212	18.8	6.0	1.0	5.0	11	79	21
El Salvador	4,660,556	25	0.7	0.6	0.8	-0.2	35	100	0
Denmark	5,123,027	6	1.1	5.4	4.3	1.1	5	49	51
Austria	7,549,433	78	3.3	1.8	0.7	1.1	23	75	25
Albania	2,734,776	42	1.2	0.1	0.1	0.0	35	97	3
Finland	4,779,535	110	3.7	2.2	0.3	1.9	30	66	34
Senegal	5,568,908	39	1.4	2.1	1.5	0.7	29	67	33
Greece	9,642,505	74	5.0	5.8	1.2	4.6	15	52	48
Norway	4,085,620	382	2.0	3.7	0.3	3.4	191	37	63
Sweden	8,310,531	174	4.1	4.3	0.6	3.7	42	52	48
Poland	35,574,150	62	15.1	14.3	2.3	12.0	4	56	44
Peru	17,328,542	1,913	19.0	4.2	1.0	3.2	101	85	15
Jordan	2,181,000	1	0.5	1.5	0.0	1.5	2	27	73
Pakistan	79,984,297	247	155.6	3.2	6.4	-3.3	2	100	0
Chile	11,192,384	922	20.3	4.9	0.5	4.4	45	82	18
Venezuela	15,096,432	1,233	n.a.	5.8	0.2	5.6	n.a.	n.a.	n.a.
Israel	3,878,000	2	1.7	3.6	0.7	2.9	1	37	63
Portugal	9,766,312	69	n.a.	7.9	0.6	7.3	n.a.	n.a.	n.a.
Nigeria	73,698,099	286	3.6	5.1	0.1	5.1	79	42	58
Morocco	19,798,703	29	10.1	4.3	1.5	2.8	3	78	22
Turkey	43,905,790	212	31.6	1.1	3.1	-2.1	7	100	0
Spain	37,439,035	112	39.9	18.8	5.7	13.1	3	75	25
Algeria	19,475,204	12	3.0	7.9	1.5	6.3	4	32	68
United Kingdom	56,314,216	147	13.5	24.8	7.0	17.8	11	43	57
Egypt	44,931,971	57	n.a.	16.5	1.6	14.9	n.a.	n.a.	n.a.
China	981,235,000	2,840	443.7	42.6	5.7	36.9	6	92	8
Rep. of Korea	38,124,000	70	n.a.	16.2	0.3	15.9	n.a.	n.a.	n.a.
Netherlands	14,149,800	91	9.2	58.0	14.8	43.2	10	18	82
Mexico	70,353,013	457	56	21	6	14	8	80	20
Italy	56,433,883	191	n.a.	43	5	38	n.a.	n.a.	n.a.
Japan	116,782,000	430	88	81	1	80	5	53	47

Table 7.3: Water availability, withdrawal, Gross VWM, Gross VWX and Net VWM in 2000 (km^3)

Country	Population	Water avail. (km^3)	Water with. (km^3)	Gross VWM (km^3)	Gross VWX (km^3)	Net VWM (km^3)	Scarcity index	Self-suff.index	Dep. index
USA	282,162,411	3,069	473.4	77.2	187.6	-110.4	6	100	0
Argentina	36,903,067	814.0	32.57	10.6	89.6	-79.0	25	100	0
Brazil	174,504,898	8233.0	59.3	27.7	77.0	-49.3	139	100	0
Canada	30,769,700	2902.0	n.a.	16.4	62.2	-45.8	n.a.	100	0
Australia	19,153,000	492.0	22.58	2.8	36.3	-33.5	22	100	0
Indonesia	208,938,698	2019.0	113.3	19.1	37.1	-18.0	18	100	0
Thailand	62,343,379	438.6	57.31	10.4	25.6	-15.2	8	100	0
Malaysia	23,420,751	580.0	9.305	14.3	29.4	-15.1	62	100	0
New Zealand	3,857,700	327.0	4.753	1.1	15.3	-14.1	69	100	0
Paraguay	5,350,253	336.0	0.49	0.7	8.7	-8.0	686	100	0
Hungary	10,210,971	104.0	5.799	1.9	7.2	-5.3	18	100	0
Colombia	39,897,984	2132.0	12.65	7.5	11.8	-4.2	169	100	0
Guatemala	11,204,183	111.3	2.795	2.4	5.9	-3.5	40	100	0
Cameroon	15,927,713	285.5	0.9664	0.4	3.9	-3.4	295	100	0
Bolivia	8,495,271	622.5	2.644	1.4	4.6	-3.2	235	100	0
Nicaragua	5,100,920	196.6	1.388	0.7	3.4	-2.8	142	100	0
India	1,042,261,758	1911.0	610.4	26.3	29.0	-2.7	3	100	0
Sudan	27,729,798	52.8	27.22	1.1	2.9	-1.8	2	100	0
France	60,911,057	211.0	32.38	31.9	33.5	-1.6	7	100	0
Uruguay	3,320,841	139	3.66	3.3	4.9	-1.6	138	100	0
Ireland	3,805,174	52.0	n.a.	2.5	4.1	-1.5	n.a.	100	0
Ecuador	12,533,087	424.4	9.369	1.9	3.1	-1.2	45	100	0
Tunisia	9,563,500	4.6	2.85	4.8	5.8	-1.0	2	100	0
Madagascar	15,744,811	337.0	16.5	0.5	1.4	-1.0	20	100	0
Malawi	11,321,496	17.3	1.325	0.0	0.8	-0.8	13	100	0
Bulgaria	8,170,172	21.3	5.69	1.4	2.1	-0.8	4	100	0
Romania	22,442,971	211.9	9.22	2.8	3.2	-0.4	23	100	0
El Salvador	5,958,794	25.2	1.376	2.0	2.2	-0.2	18	100	0
Denmark	5,339,616	6.0	0.6842	7.0	7.1	-0.1	9	100	0
Austria	8,011,566	77.7	3.657	3.7	3.3	0.4	21	89	11
Albania	3,304,948	41.7	1.838	0.6	0.0	0.6	23	75	25
Finland	5,176,209	110.0	2.27	2.1	0.8	1.3	48	64	36
Senegal	9,861,679	38.8	2.221	2.5	1.1	1.4	17	62	38
Greece	10,917,482	74.3	9.278	6.7	4.9	1.9	8	83	17
Norway	4,490,967	382.0	2.393	2.5	0.3	2.3	160	51	49
Sweden	8,872,109	174.0	2.673	3.9	1.1	2.8	65	49	51
Poland	38,453,757	61.6	12.88	6.5	3.6	2.9	5	82	18
Peru	26,000,080	1913.0	19.34	5.4	2.0	3.5	99	85	15
Jordan	4,797,000	0.9	0.93	4.1	0.0	4.0	1	19	81
Pakistan	143,832,014	246.8	172.6	9.8	4.9	4.8	1	97	3
Chile	15,454,402	922.0	24.66	6.2	1.3	4.9	37	83	17
Venezuela	24,407,553	1,233	9.064	6.6	1.0	5.6	136	62	38
Israel	6,289,000	1.8	1.831	6.8	0.7	6.1	1	23	77
Portugal	10,225,836	68.7	8.463	9.7	3.1	6.6	8	56	44
Nigeria	122,876,727	286.2	10.31	6.7	0.0	6.7	28	60	40
Morocco	28,710,123	29.0	12.61	8.6	1.4	7.1	2	64	36
Turkey	63,174,483	211.6	42	14.3	6.9	7.5	5	85	15
Spain	40,263,216	111.5	36.04	29.0	20.7	8.3	3	81	19
Algeria	31,719,449	11.7	5.723	10.1	0.1	10.0	2	36	64
United Kingdom	58,892,514	147.0	15.59	24.8	9.2	15.6	9	50	50
Egypt	66,136,590	57.3	55.3	24.8	9.2	15.6	1	78	22
China	1,262,645,000	2840.0	554.1	46.7	22.4	24.4	5	96	4
Rep. of Korea	47,008,000	69.7	25.47	31.5	1.3	30.2	3	46	54
Netherlands	15,925,513	91.0	8.924	60.6	26.7	33.9	10	21	79
Mexico	103,873,607	457.2	72.6	49.5	14.7	34.8	6	68	32
Italy	56,942,108	191.3	45.41	55.9	13.1	42.7	4	52	48
Japan	126,870,000	430.0	90.04	81.7	0.4	81.3	5	53	47

In addition to the great increase in the volume of virtual water traded, variations in the agricultural and food products exchanged also took place (Table 7.4). An important group of goods like cereals and cereals preparations that entailed more than 32% of green virtual water trade during the seventies, has now experienced a notable loss of weight, representing about 22% in the case of green water and 27% for blue water. Not manufactured textile fibers also went through a reduction of their shares on time, particularly in the case of blue water, turning from 33% over the sixties to approximately 14% today, mainly due to the substitution of natural fibers for synthetic fibers. The same happened with the group coffee, tea and spices since a decline of their shares for green water was observed. Nevertheless other crops and products made up for these reductions. This was the case of fruits and vegetables that considerable increased their participation mainly in blue water, accounting for 15% of total exchanges of blue water nowadays. Dairy products and eggs (4% of blue water) as well as meat and meat preparations (6.9% of blue water currently), growing products in current diets, also experienced a rise of weight chiefly if we look at blue water. Regarding green water, the meat group has remained quite stable at 11%. Fixed vegetable oils and fats, also basic for human diets, more than doubled their participation concerning commercial exchanges of green water. Eventually, crops commonly used as animal feed such as feed stuff or oil seeds, oil nuts and kernels show growing and outstanding percentages for green water, reaching 8% and 15.4% respectively nowadays. We have seen that the increasing level of development in some world regions lead an important change in world diets, with a growing weight of high value added commodities such as fruits, vegetables, dairy products, vegetal oils or meat. Besides, the rise of meat and other goods derived from livestock resulted in an upward trend of animal feed crops like feed stuff or oil seeds. Thus, changes in the product composition of virtual water trade tend to be similar when the composition of world trade in agri-food products is analyzed in monetary value. In this case, processed and high value added commodities have also increased their share, whereas basic products have lost weight. Processed products of higher value have benefited from free trade and from the new intra-industry trade patterns (Serrano and Pinilla, 2013).

Table 7.4: Average contribution of products to virtual water exports and imports (%)

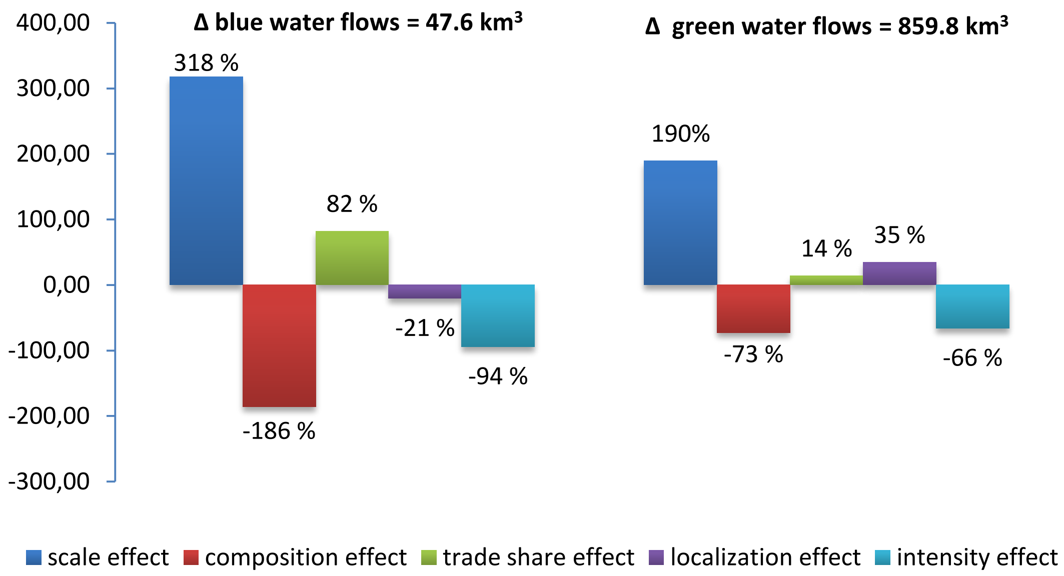
	Blue water					Green water				
Sitc rev.1 product classification	**1965-1969**	**1970-1979**	**1980-1989**	**1990-1999**	**2000-2010**	**1965-1969**	**1970-1979**	**1980-1989**	**1990-1999**	**2000-2010**
00 Live animals	1.1	0.9	0.8	0.6	0.5	3.6	2.6	2.2	1.3	1.0
01 Meat and meat prep.	5.3	5.6	5.5	5.9	6.9	13.2	11.3	11.6	10.0	11.1
02 Dairy products and eggs	2.7	3.2	3.4	3.7	4.1	3.2	3.6	4.0	3.9	4.0
04 Cereals and cereal prep.	26.2	31.5	29.7	28.8	26.9	34.5	33.8	27.0	26.5	22.1
05 Fruit and vegetables	6.9	7.9	9.2	12.9	15.0	2.6	3.5	4.2	4.9	5.6
06 Sugar, sugar prep., honey	5.2	5.9	5.2	6.5	5.5	2.1	2.3	2.0	2.2	2.2
07 Coffee, tea, spices	2.3	2.1	2.0	2.0	1.7	17.3	14.8	13.2	14.0	7.9
08 Feed. Stuff Unmilled cereals	3.5	3.9	4.8	5.6	5.6	3.1	3.9	6.6	8.3	8.0
09 Miscellaneous food prep.	0.0	0.0	0.1	0.3	0.4	0.0	0.0	0.0	0.1	0.1
11 Beverages	3.2	1.5	0.9	1.5	1.5	0.5	0.7	0.8	0.9	0.9
12 Tobacco	0.4	0.4	0.3	0.4	0.4	0.6	0.4	0.3	0.3	0.3
21 Hides, skins and fur skins	0.4	0.4	0.8	1.6	0.7	0.9	1.0	1.8	1.7	1.2
22 Oil seeds, oil nuts	6.3	7.6	8.4	8.8	10.0	7.6	10.1	12.3	11.5	15.8
26 Textile fibres, not manuf.	32.7	22.7	20.6	15.1	13.9	5.5	4.1	3.1	2.3	2.2
29 Crude anim. and veg. mat.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
42 Fixed veg. oils and fats	3.5	6.0	7.6	5.9	5.4	4.8	7.2	10.1	10.7	15.4
59 Chemical materials	0.1	0.1	0.1	0.1	0.2	0.2	0.1	0.2	0.2	0.3
61 Leather, lthr. Manufs.	0.1	0.2	0.4	0.6	1.3	0.3	0.5	0.8	1.2	1.7
Total	100	100	100	100	100	100	100	100	100	100

3.2. Factors driving global virtual water flows in the long term

We have seen that exchanges of water in virtual form experienced a great increase from 1965 to 2010. This process can be associated with the growth in the volume of trade, with changes in the main products traded, with changes in the origin of embodied water as well as with variations in the most important exporters and importers of water in the world. In the following we are going to apply a decomposition analysis to study the contribution that each of the previous factors could have had in the explanation of the growing trend followed by virtual water flows.

Figure 7.6 shows the impact that each of the factors previously defined had in the increase in blue and green water from 1965 to 2010 in the world. Scale effect, that is, the great growth of commercial exchanges during these years was responsible for most of the increase in blue and green water consumption. From 1965 to 2010 some Latin American states as Mexico or African areas like Egypt, Algeria or Sudan reduced their share in trade of embodied water resources. However Asiatic regions such as China, India or Indonesia, American countries like Canada as well as Spain hugely increased their weights. These changes in the share of countries in virtual water trade also involved a boost of water consumption. Nevertheless compositional changes (variations in traded products) together with yield improvements at the global level contributed to the slowdown of the growth in water consumption. It seems that without the key role of these two elements water consumption would have increased 1,328 km^3 more. On the one hand, the decreasing shares of cereals such as wheat and maize highly intensive in green water, as well as the reduction of importance of coffee, moderated green water consumption rise at a great extent. On the other hand, it is observed an outstanding loss of weight of raw sugar but particularly of raw cotton, crops that embodied large volumes of blue water and that consequently drove the leveling off of blue virtual water flows. Moreover, the fact that crops and livestock yields improved in most world regions, involved a decrease in the volume of water necessary to produce a ton of product and therefore a deceleration of water consumption.

Figure 7.6: Factors explaining global virtual water flows increase, 1965-2010



As it is observed in Figure 7.6, localization effect had a negative effect in blue water consumption, but a positive impact in the case of green water. As for blue water, on the whole, products were produced in less water intensive countries and then exported, resulting in a smoother water consumption growth. Mexico and USA were the most significant providers of blue water in the world, what seems to keep on time. Nevertheless, despite in 1965 African countries as Egypt or Algeria or Oceania areas such as New Zeeland and Australia also outstand as consumers of their own resources for exports, currently new states like India or Spain appear. On the contrary, the reallocation of the production of green water intensive goods made water consumption to increase. In this regard, green water had its origin mainly in USA and Argentina during all the years. However whereas Brazil, Australia, Colombia or Philippines could be highlighted as important origins of green water in 1965, Canada, Indonesia, Netherlands or India stand out nowadays.

After examining the impact that the different effects exert on virtual water at a global level, we are going to deal with their impact in the seven regions (Table 7.5) in which we have divided the world. Results at the country level are given in Tables 7.7 and 7.8 in the appendix 7.1. Regarding exports, blue and green virtual water increased in all areas except Africa where slight decreases happened. Scale effect appears as the most important factor driving blue and green water exports growth. However, there are some regional disparities in the case of composition and trade share effects. As for green water, compositional changes partially offset the water consumption increase being its magnitude more relevant in Latin America and North America. In the case of blue water, the former effect had an important contribution to water consumption moderation in Latin America, but triggers water consumption growth in Oceania and in the Former Soviet Union. Changes in the importance of countries in exports, i.e. trade share effect, clearly involves water consumption stabilization in North America, Latin America, Oceania and Africa. However it boosts water consumption in Europe and the Former Soviet Union. For Asia, trade share effect makes blue virtual water exports to level off but entails a slight growth of green water exports. Finally, yield improvements occurred in every world region and avoided larger increases in water consumption. As an example, technological advances prevented consuming approximately 204 km^3 of water in Asia and Europe.

If we turn to the explaining factors of virtual water imports increase at a regional level, again scale effect was the main contributing factor to virtual water imports growth. Compositional changes drove water consumption stabilization, with the exception of green water in Latin America where it showed a small but positive sign. In the third place, changes in the origin of products made embodied blue and green water in imports to moderate in Europe and Latin America. Changes in the share of countries in trade was a driving factor of water consumption slow down in the most developed regions of the sample, North America and Europe. As happened with exports, yield improvements boosted water consumption deceleration all over the world, particularly in Europe and North America. Eventually, whereas variations in the share of countries on international trade made blue water to slow down, trade share effect had the opposite impact for green water, triggering its consumption.

Table 7.5: Change in virtual water flows and decomposition analysis effects, 1965-2010

	VWE change (km^3)	**SE** (%)	**CE** (%)	**TE** (%)	**IE** (%)	**VWM change** (km^3)	**SE** (%)	**CE** (%)	**LE** (%)	**TE** (%)	**IE** (%)
						Blue water					
Africa	-3.1	-631	109	572	51	5.4	122	-26	59	-6	-49
North America	16.7	241	-25	-59	-57	3.4	480	-99	-159	-38	-83
Asia	10.4	274	11	-63	-122	19.1	225	-162	124	-6	-80
Europe	15.4	163	-11	29	-81	8.2	890	-378	-107	-71	-234
Fmr Soviet Union	3.6	54	13	58	-25	2.6	127	-833	854	0	-48
Latin America	3.7	630	-344	-74	-113	8.4	101	1	51	-14	-40
Oceania	2.2	362	14	-184	-92	0.6	162	-39	28	-6	-45
						Green water					
Africa	-6.2	-889	16	913	60	70.5	120	-50	66	12	-49
North America	144.6	274	-50	-54	-71	35.3	572	-180	-204	19	-107
Asia	184.4	142	-6	9	-45	353.6	127	-84	52	47	-42
Europe	183.5	142	-6	69	-104	235.8	314	-70	-54	34	-123
Fmr Soviet Union	101.2	62	-17	90	-35	58.4	51	-79	97	59	-27
Latin America	221.4	207	-55	2	-54	100.4	115	-17	35	6	-39
Oceania	30.5	346	-7	-175	-63	5.9	134	-30	18	16	-38

VWE change: change in virtual water exports (km$^{3)}$, VWM change: change in virtual water imports (km$^{3)}$, SE: Scale effect (%), CE: Composition effect (%), LE: localization effect (%), TE: Trade share effect (%), IE: Intensity effect (%)

4. Conclusions

Our study shows that the commercial integration happened between 1965 and 2010 entailed large pressures on water resources at the global level. The strong increase in agri-food trade in this period has been the main driver of the increase in virtual water trade. Changes in the composition of trade as a result of the decline of water intensive crops such as cotton, coffee, maize or rice have alleviated pressures on water. The same has happened with technological improvements that have also contributed to a lower pressure on water resources. It suggests the need to analyze the implications of globalising processes on the environment. The growing integration in international trade of many countries is essential to understand their water consumption.

It's difficult to find a general pattern to explain the situation of each country in terms of dependence on foreign water resources. On the whole, the availability of natural resources as water and land together with the level of economic development can be useful to understand it. Hence, developed countries with a low land/labor ratio usually show a high dependence on foreign water. This would be the case of European countries like United Kingdom, Italy, Spain, The Netherlands or Portugal. Some Asian countries as Israel, Japan or Korea would behave the same way. Likewise, developing countries that need to import large volumes of agricultural and food products are also dependent on foreign water in several degrees, as for instance, China, Egypt or Mexico. Quite the opposite, as for countries with high net exports of virtual water, we find different patterns. On the one hand, we find developed countries that are abundant in land and that have been exporters of agricultural products historically. This is the case of USA, Canada, Australia or New Zealand. On the other hand, we find emerging countries abundant in land with a long term specialization in agricultural exports like Argentina, Brazil, Indonesia, Thailand or Malaysia. These patterns have hardly changed throughout this period.

Some industrialized countries, with small relative availability of land tend to externalize the most intensive production systems to emerging regions that stand out for being mostly producers of primary inputs and agricultural goods and also to industrialized countries abundant in land.

Thus, we are facing a concerning situation that tends to consolidate and that is increasingly leading to a separation of consumer and producer responsibilities. In other words, water resources are overexploited and polluted to produce goods that are consumed in distant places different from the place where water was withdrawn. In the light of historical processes, it seems necessary to look for a global and sustainable notion of virtual water in order to address unequal exchanges of water, avoiding the displacements of environmental burdens to water scarce or inefficient areas. In this line, water should be priced accurately, so that each exchanged product reflected both the full environmental and economic cost of its production. On the one hand, consumers would bear the real cost of producing agricultural and food commodities, paying for its water consumption responsibility. On the other hand, producing areas could improve water efficiency or even restore water ecosystems with extra income. To that aim, it is essential to adopt multilateral agreements seeking for a joint management of water resources and to develop useful tools that help to measure accurately the water consumption throughout the whole production, distribution and consumption chains in the world.

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Appendix 7.1

Table 7.6: Average virtual water exports, imports and balance (km^3)

	1965-1969	1970-1979	1980-1989	1990-1999	2000-2010	1965-1969	1970-1979	1980-1989	1990-1999	2000-2010
	Blue water exports					Green water exports				
Africa	5.3	4.5	3.5	3.1	4.8	15.7	15.9	14.5	16.2	13.5
North America	7.2	11.1	13.5	19.6	27.3	67.3	107.3	123.9	194.3	249.4
Asia and Pacific	4.3	4.9	7.7	12.2	19.7	36.1	41.1	63.8	142.8	213.9
Europe	3.8	5.6	8.6	13.9	19.6	40.3	57.9	88.8	153.7	209.7
Ex Soviet Union	0.1	0.1	0.1	3.8	3.2	5.7	3.0	1.0	45.3	76.0
Latin America	5.0	4.1	3.4	5.8	10.0	77.3	88.0	106.1	183.2	334.8
Oceania	1.4	1.4	2.3	4.4	5.9	21.2	31.4	35.3	36.7	49.0
Total	27.1	31.6	39.1	62.8	90.5	263.6	344.7	433.5	772.2	1,146.3
	Blue water imports					Green water imports				
Africa	0.8	1.9	3.3	3.3	5.9	8.7	15.4	26.7	40.8	74.9
North America	3.5	3.1	3.2	5.3	8.3	45.4	48.3	48.9	70.4	98.6
Asia and Pacific	6.9	10.4	13.5	20.7	30.9	59.3	92.4	127.4	206.9	376.8
Europe	14.4	14.4	15.8	23.3	29.8	133.4	163.9	191.4	302.6	413.1
Ex Soviet Union	0.2	0.1	0.0	3.3	4.2	0.9	0.7	1.1	71.0	53.9
Latin America	1.0	1.7	3.3	6.6	10.8	14.9	22.6	36.1	77.4	122.9
Oceania	0.1	0.1	0.1	0.3	0.6	1.0	1.3	2.0	3.1	6.1
Total	27.1	31.6	39.1	62.8	90.5	263.6	344.7	433.5	772.2	1,146.3
	Blue balance					Green balance				
Africa	4.5	2.7	0.3	-0.1	-1.0	7.1	0.5	-12.2	-24.6	-61.4
North America	3.6	8.0	10.3	14.3	19.0	21.9	59.1	75.0	123.9	150.8
Asia and Pacific	-2.7	-5.5	-5.8	-8.5	-11.2	-23.2	-51.3	-63.6	-64.2	-163.0
Europe	-10.6	-8.9	-7.1	-9.4	-10.2	-93.2	-106.1	-102.6	-148.9	-203.4
Ex Soviet Union	-0.1	0.0	0.1	0.4	-1.0	4.8	2.3	0.0	-25.6	22.1
Latin America	4.0	2.4	0.1	-0.7	-0.8	62.4	65.4	70.0	105.8	211.9
Oceania	1.3	1.3	2.1	4.1	5.2	20.2	30.1	33.4	33.6	43.0
Total	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table 7.7: Change in virtual water exports and decomposition analysis at the country level, 1965-2010

	Green virtual water exports					Blue virtual water exports				
	VWE change (km^3)	SE (%)	CE (%)	TE (%)	IE (%)	VWE change (km^3)	SE (%)	CE (%)	TE (%)	IE (%)
Albania	0.07	115	-90	46	30	0.02	86	-41	29	26
Algeria	-1.21	-289	-20	377	31	-1.44	-267	19	321	27
Argentina	62.74	230	-53	-47	-30	1.81	270	-52	-57	-61
Australia	19.83	391	-17	-194	-81	1.45	402	24	-199	-126
Austria	3.55	90	-21	62	-31	0.11	76	12	45	-33
Barbados	-0.47	-306	2	370	34	0.00	471	517	-874	-14
Belgium-Lux.	12.16	97	-47	79	-29	0.42	83	-26	61	-18
Bolivia	5.16	50	-41	44	47	0.04	55	-42	67	20
Brazil	99.94	173	-52	63	-84	0.71	374	-341	155	-88
Bulgaria	5.01	156	-9	-48	1	0.14	117	1	-33	15
Cameroon	0.14	3982	-307	-3543	-32	0.00	152	80	-126	-5
Canada	58.77	163	-28	6	-41	3.23	76	27	2	-4
Cent. African Rep.	-2.84	-311	0	394	17	0.00	-300	-24	373	50
Sri Lanka	-0.82	-1140	-27	1126	141	0.03	73	113	-70	-15
Chile	1.89	65	-146	192	-10	0.68	95	-410	430	-16
China	5.28	492	-394	201	-199	-0.11	-2693	3190	-1204	807
Colombia	6.22	467	-58	-284	-26	0.06	178	9	-99	12
Costa Rica	5.36	207	-154	45	1	0.18	157	-64	32	-25
Czechoslovakia	5.53	394	705	1452	-2451	0.38	176	1403	558	-2037
Denmark	3.55	450	-26	-244	-80	0.17	423	-26	-228	-68
Ecuador	1.42	502	-339	-47	-17	0.26	166	-1	-13	-52
El Salvador	0.56	532	11	-444	1	0.02	424	127	-352	-100
Finland	0.76	188	-4	-24	-60	0.01	304	-81	-42	-80
France	22.63	146	-18	36	-64	1.38	127	1	29	-57
Germany	23.57	76	-15	66	-27	0.60	66	11	47	-23
Greece	1.36	364	-96	-118	-49	1.12	140	35	-39	-36
Guatemala	3.57	278	-73	-18	-87	0.15	70	88	-3	-55
Honduras	4.85	126	64	-15	-75	0.03	458	-230	-68	-61
Hungary	13.93	121	-53	40	-9	0.34	77	-14	19	18
Iceland	0.01	862	14	-745	-31	0.00	6394	-436	-5589	-269
India	40.60	113	58	0	-71	6.37	125	89	0	-114
Indonesia	88.65	60	9	54	-23	0.38	128	-235	233	-26
Ireland	2.52	175	4	-30	-49	0.16	181	4	-31	-54
Israel	0.38	137	41	-65	-12	0.59	175	27	-87	-14
Italy	12.62	89	12	24	-25	1.54	101	-8	29	-22
Japan	0.11	599	-39	-350	-111	0.00	1098	-42	-655	-301
Jordan	0.06	48	-804	832	24	0.03	43	-90	99	48
Rep. of Korea	1.10	67	9	62	-38	0.02	139	-226	223	-36
Madagascar	-1.72	-355	-16	459	12	0.11	254	338	-573	81
Malawi	-0.82	-538	14	480	143	0.02	1119	197	-968	-248
Malaysia	41.66	52	11	61	-24	0.09	119	-418	433	-34
Malta	0.00	-3553	-900	5238	-684	-0.01	-276	67	318	-9
Mexico	2.16	1422	-666	-522	-134	-0.19	-5753	2857	2171	825
Morocco	0.19	2339	-512	-1706	-21	0.03	1620	-204	-1177	-139
Netherlands	27.98	116	-39	48	-25	1.82	119	-44	50	-25
New Zealand	10.63	262	10	-141	-31	0.73	284	-5	-154	-25
Nicaragua	2.22	392	57	-225	-124	0.06	118	44	-57	-5
Nigeria	0.15	418	-639	289	32	0.02	74	-26	27	25
Norway	0.07	610	78	-464	-124	0.00	-3127	245	2466	516
Pakistan	0.20	2554	214	-2082	-587	0.37	2889	350	-2357	-782
Paraguay	20.43	56	2	53	-10	0.11	62	-73	75	36
Peru	1.72	265	0	-121	-44	-0.52	-405	256	221	28
Philippines	1.42	1578	-116	-1147	-216	-0.19	-322	137	252	33
Poland	7.76	153	-18	12	-47	0.15	225	-74	20	-71

Portugal	2.73	83	-17	20	14	0.93	63	-1	11	27
Romania	5.74	215	-14	-58	-42	0.20	176	5	-46	-35
Senegal	-2.30	-305	7	397	1	0.00	122	460	-502	20
Singapore	-14.84	-267	20	336	11	-0.25	-264	33	321	10
Spain	19.45	96	-25	50	-21	7.30	80	3	36	-19
Sudan	-1.63	-373	28	426	19	-1.45	-394	23	452	19
Sweden	0.63	398	-93	-150	-55	0.01	424	-130	-160	-33
Switzerland	0.24	143	-83	79	-40	0.01	136	-60	74	-50
Thailand	20.63	173	-106	59	-26	3.10	129	-25	39	-43
Togo	-0.02	-3727	3	4047	-223	0.00	109	71	-130	50
Trinidad Tobago	-0.67	-269	40	317	11	-0.02	-265	31	310	23
Tunisia	3.54	212	41	-124	-29	0.19	509	-68	-320	-22
Turkey	3.14	186	-32	-40	-13	-1.44	-486	377	136	73
Fmr USSR	101.21	62	-17	90	-35	3.59	54	13	58	-25
Egypt	0.31	187	44	-94	-36	-0.60	-1351	504	805	142
United Kingdom	6.88	127	-52	57	-33	0.13	511	-619	301	-92
USA	85.83	350	-64	-94	-92	13.46	281	-37	-74	-70
Uruguay	5.26	155	-35	13	-33	0.44	79	89	5	-73
Venezuela	-1.00	-332	23	371	38	-0.11	-279	35	307	38
Fmr Yugoslavia	1.65	887	-270	-445	-72	-0.03	-902	274	481	247

VWE change: change in virtual water exports (km^3), SE: Scale effect (%), CE: Composition effect (%),TE: Trade share effect (%), IE: Intensity effect (%)

Table 7.8: Change in virtual water imports and decomposition analysis at the country level, 1965-2010

	Green virtual water imports						Blue virtual water imports					
	VWM change(km^3)	**SE** (%)	**CE** (%)	**TE** (%)	**LE** (%)	**IE** (%)	**VWM change** (km^3)	**SE** (%)	**CE** (%)	**TE** (%)	**LE** (%)	**IE** (%)
Albania	0.93	123	-96	59	52	-37	0.07	86	-36	34	41	-26
Algeria	12.87	95	19	36	-2	-47	0.91	88	25	32	-1	-43
Argentina	2.27	299	-128	-26	1	-45	-0.01	-2194	1304	222	562	206
Australia	3.87	124	-10	9	13	-37	0.45	107	20	7	1	-36
Austria	6.65	113	-7	13	545	-563	0.28	221	-117	33	795	-832
Barbados	0.07	663	-542	88	-16	-93	0.02	154	-74	15	35	-30
Belgium-Lux.	14.92	343	-72	-60	-23	-89	0.11	4623	-	-1007	-1456	-780
Bolivia	0.35	424	-112	-129	40	-124	0.02	471	79	-143	-194	-113
Brazil	10.62	289	-38	-82	25	-94	0.65	202	32	-37	-34	-63
Bulgaria	0.72	624	-605	164	28	-112	0.03	2592	-	710	-190	-325
Cameroon	1.17	66	18	9	48	-42	0.25	72	81	15	-13	-55
Canada	6.71	447	-57	-198	2	-95	1.13	397	-60	-123	-25	-89
Cent. African Rep.	0.05	142	-156	115	22	-24	0.01	65	76	21	-56	-7
Sri Lanka	2.09	395	96	-261	-49	-80	0.20	651	-67	-440	135	-180
Chile	4.80	219	23	-109	29	-61	0.05	2085	95	-1166	-508	-405
China	142.12	78	-153	137	71	-34	8.10	82	0	150	-72	-60
Colombia	10.38	69	-99	142	18	-31	0.53	82	-120	208	-34	-35
Costa Rica	1.48	100	-22	115	-52	-40	0.20	86	-31	90	-8	-37
Czechoslovakia	2.86	479	-344	52	664	-751	-0.65	-438	466	-53	-55	180
Denmark	3.25	517	-20	-236	-63	-98	0.06	1879	63	-894	-680	-268
Ecuador	2.88	68	11	35	12	-26	0.14	93	8	65	-30	-35
El Salvador	1.46	168	-71	96	-47	-45	0.24	79	-6	31	35	-40
Finland	0.92	916	-313	-307	7	-204	-0.06	-881	496	232	141	113
France	8.39	904	-648	50	-60	-146	-0.33	-3291	2982	-403	312	500
Germany	63.41	74	72	23	15	-85	3.63	87	46	39	16	-88
Greece	5.95	170	-167	143	1	-47	0.19	567	-867	591	-83	-108
Guatemala	2.26	91	8	65	-35	-29	0.33	62	28	31	10	-30
Honduras	1.14	97	-9	97	-44	-41	0.23	64	0	41	29	-34
Hungary	1.52	482	-285	-22	575	-651	-0.18	-681	599	35	-231	377
Iceland	-0.01	-4536	2644	1130	89	774	0.00	-1338	1934	-984	319	169
India	43.30	53	-77	96	46	-18	0.63	221	-	1401	14	-43
Indonesia	26.92	53	-6	63	27	-37	2.22	86	-201	230	39	-53
Ireland	2.81	184	-131	106	-6	-53	0.20	219	-141	131	-50	-59
Israel	4.99	228	-30	-63	30	-65	0.30	358	-72	-104	-14	-68
Italy	22.64	561	-84	-222	-24	-131	1.11	796	-204	-321	-44	-127
Japan	22.07	649	-127	-279	-10	-133	-1.21	-1538	688	705	-3	247
Jordan	3.41	166	-170	142	-1	-37	0.28	290	-399	282	-17	-56
Rep. of Korea	29.36	73	-34	73	31	-43	1.86	121	-136	177	-10	-52
Madagascar	0.27	340	-633	497	-44	-60	0.20	133	-224	142	135	-86
Malawi	0.17	102	106	-49	-3	-55	0.00	175	58	-84	11	-60
Malaysia	5.90	962	-168	-621	49	-122	0.46	571	-287	-42	-32	-109
Malta	-0.01	-	51498	-39491	-7744	10303	0.03	346	-	1529	246	-237
Mexico	39.75	47	19	57	7	-30	4.95	48	21	63	-2	-30
Morocco	8.15	139	-213	225	12	-63	0.54	128	-107	129	-12	-38
Netherlands	35.29	297	-90	-29	-1	-77	0.54	1395	-622	-143	-221	-309
New Zealand	2.07	153	-69	34	21	-40	0.12	374	-267	108	-33	-82
Nicaragua	0.64	156	-110	131	-30	-47	0.13	105	-69	73	29	-39
Nigeria	9.94	58	-3	58	25	-38	0.99	51	107	36	-58	-37
Norway	-0.56	-1956	583	1134	-32	371	-0.05	-1067	405	469	117	176
Pakistan	41.66	43	16	30	42	-32	4.28	44	-55	83	81	-53
Paraguay	0.14	719	-1361	823	52	-132	0.03	115	-47	85	-29	-24
Peru	5.08	234	6	-81	-8	-51	0.24	318	43	-113	-47	-101
Philippines	11.53	120	-5	17	11	-43	0.72	265	-133	46	5	-83
Poland	6.43	344	-149	-18	198	-275	-0.34	-954	686	57	-59	370
Portugal	10.16	106	-62	99	2	-45	1.58	103	-93	99	25	-34

Romania	7.01	58	7	22	36	-23	0.03	3823	-	4166	-920	-469
Senegal	1.59	220	-170	112	4	-66	0.34	198	-161	108	39	-84
Singapore	6.69	238	-43	-61	14	-48	0.12	1352	-611	-476	78	-242
Spain	28.01	147	-3	8	1	-54	1.94	178	-61	22	-9	-30
Sudan	2.91	142	-12	22	-6	-47	0.29	143	-31	35	1	-47
Sweden	0.07	22122	-3455	-13412	-1336	-3819	0.03	2836	-208	-1890	-296	-342
Switzerland	-1.76	-1026	281	702	-23	165	-0.62	-402	236	169	54	44
Thailand	13.60	57	37	6	47	-48	1.11	69	60	0	26	-56
Togo	0.99	52	-8	36	51	-30	0.18	50	38	36	27	-50
Trinidad Tobago	0.30	497	-199	-112	6	-93	0.04	237	-37	-44	2	-59
Tunisia	5.06	117	-15	24	18	-44	0.37	111	-22	24	27	-40
Turkey	22.39	54	-67	98	49	-34	2.58	52	107	79	-107	-31
Fmr USSR	58.37	51	-79	97	59	-27	2.60	127	-833	854	0	-48
Egypt	27.31	145	-53	46	13	-51	1.28	197	-94	67	-17	-53
United Kingdom	-13.43	-863	94	733	31	105	-2.18	-626	71	535	48	73
USA	28.55	601	-209	-206	23	-110	2.27	522	-119	-177	-45	-81
Uruguay	4.11	70	-44	93	2	-21	0.03	303	-954	819	4	-71
Venezuela	12.63	99	-14	36	-2	-20	0.58	153	-10	64	-60	-48
Fmr Yugoslavia	7.23	96	-3	84	-7	-69	0.19	272	-367	420	-127	-98

VWM change: change in virtual water imports (km^3), SE: Scale effect (%), CE: Composition effect (%), LE: localization effect (%), TE: Trade share effect (%), IE: Intensity effect (%)

CONCLUSIONS

This PhD dissertation has analyzed the long-term relationship between the processes of economic growth and water resources, in a period of significant economic, social, institutional, and environmental change. It is quite clear that economic development and commercial integration have resulted in large pressures on water resources.

The global and regional evidence in chapters one and two illustrates an upward trend for water use during the twentieth century, an expansion largely driven by economic and demographic growth as well as by the intensification of agriculture. Whereas in developed regions, demand grew mainly as a result of large increases in income, in emerging regions, population growth contributed notably to changes in water use. From 1980, a slight slowdown in global water use took place, basically due to efficiency improvements, structural changes, burgeoning environmental concerns, and the increasing costs of supplying water in many areas of the world. This path is quite similar when we look at per capita water use, which shows a growth spurt until 1980, when the trend reversed. Although it is true that, between 1980 and 2000, per-capita water withdrawal declined, this decrease appears to soften as GDP per capita continued to grow. Thus, a peculiar Environmental Kuznets Curve is found. As discussed in chapter two, when per-capita income is low, the highest priority consists of meeting basic needs without paying much attention to excessive water use. When a country reaches a certain level of development, technical, managerial, and institutional incentives trigger water efficiency and accordingly, a stabilization or decline in per-capita water use. In this context, our results suggest that the quality of institutions encourage a more sustainable water management. Nonetheless, the positive effect arising from the introduction of new techniques and water saving measures flattens out as time goes on.

Our findings on water withdrawal are in line with those obtained for water consumption. Chapter three shows that water consumption experienced a great increase in absolute terms between 1995 and 2009, again boosted by demand growth - not only domestic, but also foreign - as a result of growing commercial integration. The strong population growth in the less-developed regions, together with remarkable economic growth, makes emerging nations particularly vulnerable. This is the case of China, where, apart from the sharp increase in water consumption, water resources have been polluted to produce goods largely marked for exported. In any case, the limited penetration of technological advances hinders efficiency improvements. Although production processes in emerging countries can be described as "dirty", the incorporation of clean technologies in developed countries has not been strong enough to offset the increase in demand. Within this framework, agriculture appears as the main water consumer in the world. However, other sectors with strong interdependencies with agriculture, like the food industry, the textile sector, and hotels and restaurants have generated notable impacts on water resources. The construction and electricity sectors are also responsible for significant global water consumption.

In many countries, water consumption cannot be explained without considering their growing integration in international trade. Hence, given the importance of the agri-food sector, chapter seven has examined the intense internationalization from 1965 to 2010 and its impact on global water resources, in the framework of the second globalisation. During these years, there were notable improvements in crop and livestock yields and the composition of international trade evolved to reflect a decline in water-intensive products such as coffee, cotton, maize, and rice. However, the great expansion of agricultural and food product trade prevailed, leading the growth in global water consumption. This level of development, together with the availability of two key natural resources - water and land - appear to determine the degree of foreign dependence of certain countries. The trend toward separation of consumer and producer responsibilities appears to strengthen.

In this respect, Spain is among those developed countries with a low land/labor ratio, thus presenting a significant dependency on foreign water resources. Throughout this PhD dissertation (chapters four, five and six), Spain has been chosen as a case study, given its semi-arid character and its significant participation in the global agricultural and food trade. From 1860, the Spanish agricultural sector experienced a great expansion, resulting in a parallel growth in demand for water. This growth was driven by the development of the domestic market, associated with significant economic and demographic changes, and by a strong integration with international markets. During this period (and particularly from 1960), traditional Spanish agriculture underwent a process of profound changes, becoming a modern industry with high productivity. On the one hand, this involved an increase in harvested land, exerting great pressure on green water. On the other hand, a marked crop substitution (that would have not been possible without the development of irrigation) took place, entailing the growth of blue water consumption. This process occurred via crucial technological advances during these years, involving a notable improvement in crop and livestock yields, and preventing higher water consumption. Similarly, technical developments facilitated the expansion of hydraulic infrastructure, essential for the spread of irrigation. Most waterworks were funded by the government, and paid scant attention to social and environmental impacts, provoking national and regional debates. Chapters five and six show the significant impact of Spanish integration, in the first and second globalisations, on water resources. Around 1850, Spain began its process of integration in international markets that lasted until the 1930s. During these years, Spain excelled as an exporter of blue virtual water, and as an importer of green virtual water. Again, irrigation was essential to this process, being mostly devoted to export crops. As a result, about 30% of the increase in the water demands of agriculture was due to a strong boost from the external sector. This process came to a halt with the beginning of the Civil War in 1936 and the subsequent years of autarky during Franco's Dictatorship. Nonetheless, the Stabilization Plan of 1959 entailed an important trade liberalization, and Spain's integration into the second globalisation. Spain continued to be a net exporter of blue water, although it was still highly dependent on green water resources, due to the increasing imports of feed for the still-developing intensive stock-breeding sector. During this period, the greatest expansion of water infrastructure in Spain's history took place, making possible the massive exports of high value-added agri-food products, such as fruit and vegetables, olive oil, and processed food. Consequently, the growth of water needs arising from the development of the external sector represented 60% of the increase of total water embodied in agricultural production.

Our results offer important lessons for water management at both the global and the regional levels. On the one hand, water use is expected to keep on growing during the first half of the twenty-first century, a path that tends to exacerbate the concern in emerging countries, and that poses a global challenge. Although innovations were adopted in developing countries with relatively short lags regarding most developed regions, urgent managerial, institutional and technological actions to alleviate water pressures in the near future are required. In this context, demand-side policies seeking to reduce water demand, or changes in consumption patterns, together with supply-side actions such as technological innovation or productive reallocation towards water-efficient areas, is essential to address the global water scarcity. In the light of historical processes and long term socio-economic transitions, it is necessary to look for a global, sustainable and multi-lateral management of water resources.

On the other hand, at the regional level, the Spanish case displays a long-term agricultural transition, neglecting its environmental consequences. It should be taken as an illustration of unsustainable water-resource management, and as an object-lesson for those emerging countries that are net exporters of agricultural products and primary inputs, and are gradually becoming integrated into international trade.

The work developed through this PhD dissertation has allowed us to highlight certain important issues and, at the same time, has suggested new research questions that we would like to address in the future.

First, although we have seen that water resources are essential for production and trade in many, if not most, countries, they are not the only determining factor in explaining the virtual water trade. Following the approach of trade gravity models and using panel data techniques, exchanges of virtual water can be estimated, depending on economic variables such as the level of income of exporter and importer countries, on geographic variables such as distance between nations or contiguity, on environmental variables such as land or water availability, and on political variables, among others. Thus, using models of this kind, we will attempt to measure and quantify the contribution of a variety of economic, environmental, geographic, and institutional aspects to virtual water transfers. This analysis would shed light on policy strategies of multi-lateral management of water resources, in an attempt to prevent the displacement of environmental burdens to water-scarce or water-inefficient regions of the world.

Second, as we have shown, water resources are increasingly transferred embodied in internationally-traded products. These water displacements involve global inequalities that must be addressed by setting consumption and production responsibilities. Although Multi-Regional Input Output models are powerful tools to assess the interrelations among countries and sectors of the global supply chains, the lack of sufficiently disaggregated sectorial data in the empirical applications presents a potential obstacle in assessing regional problems. This is particularly important when studying water resources, since agriculture accounts for 70% of global water consumption. Thus, a second research line is intended to combine bilateral trade data on agricultural products with multi-regional input-output tables. In other words, our next challenge is to combine the bottom-up and top-down approaches to study the role of the range of goods produced in the agri-food sector in international supply chains. This integration has long been needed in the international literature regarding the environmentally-extended MRIO models applied to water consumption. Similarly, the comprehensive identification of supply chains opens the research to a more detailed geographic assessment of direct and indirect consumers - and polluters - of water, linking the productive pressures on the environment with other physical and environmental conditions in the territory (local water stress, vulnerable areas,...). Finally, MRIO models applied to the environment, and specifically to water, face a new challenge in integration with more flexible representations of technology and consumer behaviours. The extension of our analysis to the use of Computable General Equilibrium models is a natural extension of this work that we expect to confront in the near future.

CONCLUSIONES

La tesis doctoral ha analizado la relación de largo plazo entre los procesos de crecimiento económico y los recursos hídricos durante un período de importantes cambios económicos, sociales, institucionales y ambientales. Parece bastante claro que el desarrollo económico y la integración comercial han generado fuertes presiones sobre los recursos hídricos.

La evidencia empírica ofrecida por los capítulos unos y dos muestra que el uso de agua siguió una senda creciente durante el siglo veinte tanto a nivel mundial como regional. Esta expansión fue impulsada principalmente por el crecimiento económico y demográfico, así como por la intensificación de la agricultura. Mientras que en las regiones desarrolladas la demanda creció en gran parte como resultado del intenso aumento de la renta, en las economías emergentes el crecimiento demográfico contribuyó especialmente a los cambios en el uso del agua. Desde 1980 las mejoras de eficiencia, los cambios estructurales, la creciente concienciación medioambiental y los altos costes del suministro de agua conllevaron una ligera desaceleración en la extracción de agua en muchas zonas del mundo. Si nos fijamos en el uso de agua per cápita, el patrón fue muy similar. Así, éste muestra un crecimiento abrupto hasta 1980, cuando la tendencia se invirtió. Si bien es cierto que el uso de agua por habitante disminuyó entre 1980 y 2000, este decrecimiento tiende a moderarse a medida que la renta por habitante aumenta. Por lo tanto, podemos decir que el uso de agua siguió un peculiar Curva Ambiental de Kuznets. Como se discutió en el capítulo dos, cuando el ingreso per cápita es bajo, la principal prioridad consiste en satisfacer las necesidades básicas sin prestar atención al uso de agua excesivo. Cuando un país alcanza cierto nivel de desarrollo, los incentivos de gestión, institucionales o técnicos fomentan la eficiencia del agua y, en consecuencia, la estabilización o disminución del consumo de agua per cápita. En este contexto, nuestros resultados sugieren que la calidad de las instituciones es clave para promover una gestión más sostenible del agua. No obstante, el efecto positivo derivado de la introducción de nuevas técnicas y medidas de ahorro de agua parece perder peso con el tiempo.

Las conclusiones sobre la extracción de agua van en línea con los resultados obtenidos para el consumo de agua. El tercer capítulo muestra que el consumo de agua experimentó un gran aumento en términos absolutos entre 1995 y 2009. Esto se vio impulsado de nuevo por el crecimiento de la demanda, no sólo nacional sino también extranjera, como resultado de la creciente integración comercial. El fuerte aumento de la población en las zonas menos desarrolladas, junto con un notable crecimiento económico convierte a los países emergentes en lugares particularmente vulnerables. Este es el caso de China, donde además del fuerte incremento en el consumo de agua, los recursos hídricos han sido contaminados para producir bienes que son mayoritariamente exportados. Además, la limitada penetración de los avances tecnológicos impide mejoras en la eficiencia. Aunque los procesos de producción en los países emergentes pueden ser descritos como "sucios”, la incorporación de tecnologías limpias en los países desarrollados no ha sido suficiente para compensar el aumento de la demanda. En este marco, la agricultura aparece como el principal consumidor de agua en el mundo. Sin embargo, otros sectores con fuertes interdependencias con la agricultura como la industria alimentaria, el sector textil o servicios como hoteles y restaurantes han generado impactos notables sobre los recursos hídricos. Asimismo, los sectores de la construcción y la electricidad también participan notablemente en el consumo de agua en el mundo.

La senda seguida por el consumo de agua en muchos países no podría ser explicada sin tener en cuenta su creciente integración en el comercio internacional. Por lo tanto, dada la importancia del sector agroalimentario, en el capítulo siete se estudia la intensa internacionalización del periodo 1965-2010 y su impacto sobre los recursos hídricos mundiales en el marco de la segunda globalización. Durante estos años se produjeron notables mejoras en el rendimiento de la agricultura y la ganadería junto a importantes cambios en la composición del comercio internacional. En particular, se produjo una caída de los intercambios de productos intensivos en agua, como el café, el algodón, el maíz o el arroz. Sin embargo, la gran expansión del comercio agrícola y de productos alimenticios prevaleció, liderando el crecimiento del consumo mundial de agua. El nivel de desarrollo, junto con la disponibilidad de dos recursos naturales clave como el agua y la tierra parecen determinar el grado de dependencia externa de los diferentes países. En esta línea, el hecho de que las responsabilidades de consumidores y productores tiendan a separarse parece reforzase.

En este sentido, España se encuentra entre los países desarrollados con una baja ratio tierra/mano de obra, mostrando por lo tanto una dependencia significativa de los recursos hídricos extranjeros. A lo largo de la tesis doctoral España ha sido elegida como caso de estudio, dado su carácter de país semi-árido y su importante participación en el comercio agroalimentario mundial. A partir de 1860 el sector agrario español experimentó una gran expansión que se tradujo en el crecimiento de las necesidades de agua. Este crecimiento fue impulsado por el desarrollo del mercado interno asociado con importantes cambios económicos y demográficos y por una fuerte integración en los mercados internacionales.

A lo largo de este período (y sobre todo a partir de 1960), la agricultura tradicional española vivió un proceso de profundos cambios, convirtiéndose en una industria moderna con altas productividades. Por un lado, esto implicó un aumento de la superficie cultivada, lo cual supuso fuertes presiones sobre el agua verde. Por otro lado, la marcada sustitución de cultivos no habría sido posible sin el desarrollo del regadío, lo que a su vez implicó el crecimiento del consumo de agua azul. Este proceso se produjo gracias a los importantes avances tecnológicos ocurridos durante estos años que se tradujeron en una notable mejora de los rendimientos agrarios, frenando el consumo de agua. Además, el desarrollo técnico también permitió la construcción de infraestructuras hidráulicas, esenciales para la expansión del regadío. La mayoría de las obras hidráulicas fueron financiadas por el gobierno, sin atender a sus posibles impactos sociales y ambientales, generando en consecuencia importantes debates nacionales y regionales al respecto. Los capítulos cinco y seis muestran el efecto significativo que la integración española ocurrida durante la primera y segunda globalización tuvo sobre los recursos hídricos. Alrededor de 1850 España inició su proceso de integración en los mercados internacionales, el cual se detuvo en la década de 1930. Durante estos años España destacó como exportador de agua virtual azul y como importador de agua virtual verde. Una vez más, el regadío fue esencial en este proceso, fuertemente orientado a los cultivos de exportación. Como resultado, aproximadamente el 30 % del aumento en las necesidades de agua de la agricultura fue debido al fuerte impulso del sector exterior. Este proceso se detuvo con el comienzo de la Guerra Civil en 1936 y los años de autarquía durante la Dictadura

Franquista. No obstante, el Plan de Estabilización y Liberalización de 1959 supuso una importante apertura comercial y la integración española en la segunda globalización. España sigue siendo un exportador neto de agua azul, aunque muestra una alta dependencia de los recursos de agua verde, debido a las crecientes importaciones de alimentos para el ganado, claves para el desarrollo de la ganadería intensiva. Durante este período se produjo la mayor expansión de las infraestructuras hidráulicas, en la historia de España, haciendo posible la exportación masiva de productos agroalimentarios de alto valor añadido como el aceita de oliva, frutas y vegetales o alimentos procesados. En consecuencia, el crecimiento de las necesidades de agua derivadas del desarrollo del sector externo representó el 60 % del aumento del agua incorporada en la producción agraria.

Estos resultados ofrecen importantes lecciones para la gestión del agua, tanto a nivel global como regional. Por un lado, se prevé que el uso del agua siga creciendo durante la primera mitad del siglo veintiuno, un patrón que tiende a agravarse en los países emergentes y que supone un importante reto mundial. Aunque las innovaciones tecnológicas fuesen adoptadas en los países en desarrollo con poco retraso con respecto a las regiones más desarrolladas, se requieren acciones de gestión, institucionales y tecnológicas urgentes para aliviar la presión del agua en un futuro cercano. En este contexto, políticas de demanda en busca de la reducción de las necesidades de agua o cambios en los patrones de consumo, junto con acciones de oferta, como el desarrollo tecnológico o las reasignaciones productivas hacia las áreas más eficientes parecen ser esenciales para hacer frente a la escasez mundial de agua. Además, a la luz de los procesos históricos y las transiciones socio-económicos de largo plazo, parece necesario llevar a cabo una gestión global, sostenible y solidaria de los recursos hídricos, tratando de evitar los desplazamientos de las cargas ambientales.

Por otro lado, en el plano regional, el caso español es una clara ilustración de una transición agraria de largo plazo, que ha descuidado sus consecuencias ambientales. Esto debe ser tomado como un ejemplo de gestión no sostenible de los recursos hídricos y como una lección para aquellos países emergentes que son exportadores netos de productos primarios y que están en proceso de integración en el comercio internacional.

El trabajo desarrollado a través de esta tesis doctoral ha permitido desarrollar aspectos relevantes que dan lugar a nuevas preguntas de investigación que nos gustaría tratar en una futura investigación.

En primer lugar, aunque hemos visto que los recursos hídricos son esenciales para la producción y el comercio en muchos países del mundo, no son el único factor determinante para explicar el comercio de agua virtual. Así, siguiendo el enfoque de los modelos de gravedad del comercio y el uso de técnicas de datos de panel, el intercambio de agua virtual se pueden estimar en función de variables económicas, como el nivel de ingresos de los países exportadores e importadores, de variables geográficas como la distancia entre naciones o su contigüidad, de variables ambientales como la disponibilidad de tierra o de agua o de variables políticas, como puede ser el pasado colonial de los países, entre otros factores. Por lo tanto, mediante el uso de este tipo de modelos trataremos de medir y cuantificar la contribución de los diferentes aspectos económicos, ambientales, geográficos e institucionales a las transferencias mundiales de agua virtual. Este análisis puede servir en un futuro como marco de referencia para desarrollar estrategias de gestión conjunta de los recursos hídricos que traten de evitar el desplazamiento de las cargas ambientales a zonas ineficientes o con escasez de agua.

En segundo lugar, como hemos demostrado, los recursos hídricos son crecientemente intercambios contenidos en los productos comercializados internacionalmente. Estos desplazamientos de agua implican desigualdades globales que deben abordarse mediante el establecimiento de las responsabilidades de la producción y el consumo. Aunque tablas Multirregionales Input-Output son poderosas herramientas para evaluar las interrelaciones entre países y sectores en las cadenas de suministro globales, la falta de datos suficientemente desagregados a nivel sectorial puede implicar una desventaja notable para la evaluación de algunos de los problemas regionales. Esto es particularmente importante cuando se estudian los recursos hídricos, ya que la agricultura representa el 70 % del consumo de agua en todo el mundo. Por lo tanto, una segunda línea de investigación está destinada a unir los datos de comercio bilateral de productos agrícolas con las tablas input-output multirregionales. En otras palabras, nuestro próximo reto es combinar los enfoques conocidos como top-down y bottom-up para estudiar el papel de los diferentes bienes que se producen en el sector agroalimentario en las cadenas de producción internacionales. Esta integración ha sido muy demandada en la literatura internacional sobre los modelos multirregionales ampliados al medio ambiente, especialmente a los aplicados al consumo del agua. Del mismo modo, la plena identificación de las cadenas de producción abre la investigación hacia una evaluación geográfica más detallada de los consumidores o los contaminadores directos e indirectos del agua, uniendo las presiones productivas sobre el medio ambiente con otras condiciones físicas y ambientales en el territorio (de estrés de agua local, zonas vulnerables, etc.). Por último, los modelos multirregionales aplicados al medio ambiente y específicamente al agua presentan un nuevo reto con la integración de representaciones más flexibles de la tecnología y de los comportamientos de los consumidores. La extensión del análisis previamente comentado a la utilización de modelos de Equilibrio General Computable aparece como la vía natural a la que nos enfrentaremos en el futuro cercano.