The Role and Use of Water in Agriculture in the Western Balkans: The Case of Macedonia

Jordan Hristov
Faculty of Natural Resources and Agricultural Sciences
Department of Economics
Uppsala

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Abstract

This thesis examines the role and demand for water in Macedonia from an economic perspective with an emphasis on agricultural use. The first paper provides an overview of the Macedonian agricultural sector and assesses the productivity growth in the period 1999-2010. In the study period, the sector experienced an average increase in volume of 1.52% per annum and a productivity growth rate of 1.34% per annum. Family farms were found to be the major contributor to overall productivity growth, despite their small and heterogeneous features.

In order to assess and understand the interaction between agriculture and the other sectors, an environmental input-output model framework, with agriculture disaggregated into 11 sub-sectors, is applied to the Macedonian economy. In the second paper it is acknowledged that the Macedonian economy is characterized by a water-intensive structure, mainly focused on agriculture (rice, fruit, and grape production) and some other industrial sectors (other mining, food and beverages, and energy production). It is confirmed that the agricultural sector uses a majority of the water available, with around 38% of total water consumption, and the sector thus imposes a significant pressure to the water resource in Macedonia. In the third paper a greater transparency in terms of aggregation is achieved by using fuzzy modeling. This allows a better identification of the key water users. Still, these results suggest that agriculture and some industrial sectors practice intensive use of water resources. In the fourth paper we conduct a deeper analysis of the relationship between production and commercial trade by using the notion of virtual water. The findings reveal that due to significant net exports by vegetables, fruits, grapes, sheep and lamb, a significant amount of water exits the country (124 million m^3 at 2005 level). This is not sustainable in the long-run given the water intensive structure of the agricultural sub-sectors and the scarcity of water during summer. In the final, fifth paper we assess how the direct effects of climate change on agricultural production will alter water consumption, given that the agricultural sector is the major water user. The impact of investing capital in irrigation infrastructure will support and increase the necessary water consumption. It may be necessary to introduce changes in production technology, to promote a change in agricultural specialization in the country, or revise the existing water pricing policy based on comprehensive research.

Keywords: input-output, water consumption, Macedonia, agriculture, productivity, fuzzy logic, virtual water, climate change

Author's address: Jordan Hristov, SLU, Department of Economics,
P.O. Box 7013, SE 750 07 Uppsala, Sweden
E-mail: jordan.hristov@ slu.se

Dedication

To Tatjana…

Thank you for being my biggest support and encouragement. Without your patience and love all this would have never been accomplished. This is your achievement as well…

Contents

List of Publications

This thesis is based on the work contained in the following papers, referred to by Roman numerals in the text:

I Martinovska-Stojcheska, A., Hristov, J. and Surry, Y. (2014). Assessment of the Macedonian agriculture sector through productivity analysis. Submitted to *Post-Communist Economies*.

II Hristov, J., Martinovska-Stojcheska, A. and Surry, Y. (2014). The economic role of water in Macedonia: an input-output analysis. To be submitted to *International Journal of Water Resources Development*.

III Hristov, J. and Surry, Y. (2013). The effect of uncertainty in a fuzzy input-output analysis of water consumption applied to Macedonia. *Acta Agriculturae Slovenica* 102/2, 87-98.

IV Hristov, J., Martinovska-Stojcheska, A. and Surry, Y. (2014). Virtual water and input-output framework: an alternative method for assessing trade and water consumption in Macedonia. To be submitted to *Water Resource Management*.

V Hristov, J. (2014). An exploratory analysis of the impact of climate change on Macedonian agriculture. (manuscript).

Paper III is reproduced with the permission of the publisher.

1 Background

1.1 Western Balkans agriculture: An overview

After gaining its independence in the early 1990s, the Republic of Macedonia[1] oriented itself towards market economy principles and adopted a concept of "economic development that is socially responsible and righteous, ecologically acceptable and based on the essential postulates of human society" (MOEEP, 2008a, p.7). The country gained candidate status for membership of the European Union (EU) in 2005. In order to apply the paradigm of sustainable development in practice in a transition economy, economic growth, largely influenced by the prospect of EU membership, requires profound reform processes. The main intention of the Macedonian economy is to integrate into the international market (Dimitrievski and Kotevska, 2008). The small economy is relatively sensitive to internal and external factors, especially to the trade flows with the neighboring countries in the Western Balkan (WB)[2] (Angelova and Bojnec, 2011).

Most of the WB countries are on the same path as Macedonia, albeit at different economic and political stages. Croatia has made significant progress and developed faster in terms of institutional and legal reforms, and it became an EU member in 2013. Hence, the present discussion mainly includes the remaining six WB countries[3]. In the past two decades there have been radical political changes in the region, followed by conflicts and wars, which have had a tremendous impact on the economies and their growth (Dimitrievski and

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[1] Macedonia's constitutional name is the Republic of Macedonia and this country is being provisionally referred within the United Nations system as "the former Yugoslav Republic of Macedonia – FYROM" (UNSC Resolution 817/1993).

[2] Besides Macedonia, the following countries are considered part of the WB region: Croatia, Bosnia & Herzegovina, Montenegro, Serbia, Kosovo and Albania (Volk *et al.,* 2012).

[3] The World Bank refers to Macedonia, Bosnia & Herzegovina, Montenegro, Serbia, Kosovo and Albania as the South East Europe (SEE6) (World Bank, 2011).

Kotevska, 2008). The Stabilization and Association Process (SAP) launched by the European Commission in 1999 supported the recovery from such shocks and facilitated the process for integration of WB countries into the EU (Speck, 2005). This course of political stabilization enabled considerable economic progress in the WB economies, with relatively high annual growth rates in the period 2001-2008, *e.g.*, average growth in GDP of 5.7% (Penev, 2012). The region's growth was based on high domestic consumption but also liberalization of foreign trade and financial markets. Rather strict monetary discipline in all WB countries was possible largely due to the rapid expansion of banking and inflow of foreign capital, followed by low inflation and a reduction in interest rates (*ibid*). Following the recovery from the global financial crisis in 2009, WB countries experienced a double-dip recession in 2012 (World Bank, 2012). The economies began to recover in 2013, growing by 2.2% on average and with growth rates at or exceeding 3% in Kosovo, Macedonia, and Montenegro (World Bank, 2014). Compared with the pre-crisis period (2001-2008), the growth was mainly due to an increase in external demand, especially by the EU, and the good agricultural production in that year. One economic dimension that still poses a challenge for all WB countries is the high rate of unemployment, which was 24.2% on average in 2013, and success in creating jobs is limited in Macedonia, Montenegro and, to a smaller extent, in Bosnia and Herzegovina (B&H) (*ibid*).

Over the last two decades, agriculture has played an important buffer role in maintaining the social equilibrium in the deteriorated economic situation of WB countries. The contribution of agriculture in terms of gross value added (GVA) relative to the total economy is significant, ranging from 10% in Serbia and Macedonia to 20% in Albania (Volk, 2010). Although the agricultural situation has gradually improved in most WB countries, many issues still pose challenges on the way to EU accession. The EU Common Agricultural Policy (CAP) regulations regarding food safety and quality require pre-accession investments (Swinnen and Van Herck, 2009). Furthermore, one of the main impediments to harmonizing the CAP reforms is the small-scale, fragmented nature of private farms in all WB countries, which range in size from 1.2 ha in Albania to less than 4 ha in Serbia (Volk *et al.,* 2012). Agricultural employment and the presence of (semi)subsistence farming is an important and significant dimension for all countries in the WB region; agricultural employment is especially important in Albania (over 50%), as well as in Serbia, B&H and Macedonia (around 20%) (*ibid*). The resilience of these small-scale subsistence farms and their current and future role are questionable, particularly in relation to EU membership, where they will have to compete on a single market (Davidova *et al.,* 2009). (Semi)subsistence farming is often associated with market failures and high transaction costs, as is evident in all WB countries. In addition, (semi)subsistence farming is associated with traditional technology, inefficiency, and the use of scarce resources (Kostov and Lingard, 2004). Nevertheless, in the period 2000-2008 there was an increase in the volume of agricultural production in most WB countries, mainly due to the increase in yields arising from improvements in technology (Volk *et al.,* 2012). Rungsuriyawiboon and Wang (2012) stress that transition countries have the potential to supply a substantial share of the expected growth in food demand given the increase in population. Since agriculture is an important economic sector in all WB countries, an increase in production and productivity will be an important dimension during the EU accession process. Efficient use of inputs may create a comparative advantage and increase in competitiveness. In the WB countries, the key issue for EU accession remains "the competitiveness of agriculture and related sectors, which has been mostly forgotten in the debate on the impact of accession and necessary policy and administrative reforms" (Volk *et al.,* 2012, p.112). For economic and policy adjustment, competitiveness is an important issue and as a base for this, necessary attention should be paid to research and knowledge transfer (Erjavec and Salputra, 2012). An increase in competitiveness, which is directly linked to factor productivity, *i.e.*, the ability to provide adequate returns on the resources employed or consumed in producing agricultural commodities, does not automatically mean growth (*ibid*).

Erjavec (2007) stresses that the European model of agriculture or sustainable agriculture will need to become an integral part of WB national policies. However, this concept is difficult to understand and implement, especially for countries in the pre-accession process, such as most WB countries (Erjavec and Dimitrievski, 2008). Water, besides being recognized as an essential resource for economic and social development, is also a key input in agricultural production. In order to manage water resources in a sustainable manner and follow this new policy concept, the most important factor is to have knowledge of the ecosocial characteristics of water. The EU Stabilization and Association Agreements (SAA) from SAP are an attempt to establish bilateral agreements with neighboring countries in the region by covering environmental and transboundary water issues (Speck, 2005). National legislation and institutional frameworks of water management are revised in accordance with EU directives and regulations, in particular with the EU Water Framework Directive. Irrigation is an important element in agricultural production, especially in a semi-arid region such as WB (World Bank, 2003). Arable production dominates agriculture in all WB countries, ranging from 66% in B&H and Serbia to 76% in Macedonia (Mizik, 2012). Since such arable dominance requires irrigation to a large extent, the issue of water availability, demand, and use is an important dimension that ought to be investigated in depth. There are many economic lessons that can be learned from the investigation of key water issues at regional and national level.

1.2 Macedonian agriculture and water use: An overview

The agriculture sector in Macedonia has experienced significant fluctuations in its output, but also a deterioration of its structures, as a consequence of the political instability during the transition period (Dimitrievski and Kotevska, 2008). In the recent past, it exhibited a constant growth rate of around 1.3% in the period 2000-2007 (Sutton *et al.,* 2013). However, the severe droughts that occurred in 2000 and 2003 took their toll, with huge production losses (Mizik, 2011). The main reason for such losses is because three-quarters of the country's area is viewed as being semi-arid (World Bank, 2003). Hence, irrigation water is an essential element for producing many agricultural commodities. Farmers need this input at crucial stages of the crop growing season, when rainfall is in short supply and dry weather conditions prevail during summer months. Furthermore, there is an uneven spatial and temporal distribution of water resources throughout the country, with more favorable supply conditions in western areas. Under such conditions, the need to irrigate is imperative for many crops such as rice, grapes, fruit, vegetables, alfalfa, and corn (MAFWE, 2012). In a study of the Bregalnica region of Macedonia, Gorton *et al.* (2009) reported that about 94% of the farmers they interviewed viewed irrigation as very important for their livelihood. In addition to the need to irrigate, flooding and erosion can result in significant losses for the agriculture sector as consequences of the seasonal and geographical variation in precipitation. The quality of water also affects agricultural production. According to the annual report on the state and quality of the environment (MEOPP, 2008a), the quality of water in Macedonia has already deteriorated as a consequence of pollution with organic matter, heavy metals, pesticides, and other toxic components. All these causes have an impact on effective use of water by farmers and, consequently, productivity. Last but not least, in the long run, with the possibility of a warmer climate and drier weather conditions, there might be a need for better use of water resources to maintain and/or promote a more competitive and efficient agriculture sector (MOEPP, 2006). This could be hampered by the growing water needs of the other (non-agriculture) sectors of the Macedonian economy and by increasing demand by urban households.

Specific strategies regarding the water sector and predicted future water needs by 2040 are given in the National Strategy on Water Management (Official Gazette, 2012). The report itself is overly comprehensive, but one of its most important messages is efficient water use for irrigation purposes and securing the necessary quantity of water for such use. One reason for improvements in the efficiency of irrigated water use stems from the long-term exploitation of the already ageing irrigation schemes built in the 1960s and 1970s (World Bank, 2003). In addition, neglect or poor maintenance by the water management authorities has caused a deterioration in the functioning of existing irrigation schemes because these authorities cannot afford to pay the costs of historical bad debt and capital depreciation (Cornish *et al.*, 2004). The reasons for this financial situation are complex, but are partly linked to farmers' irrigation practices. For instance, some of the farmers who are at the beginning of the irrigation schemes use the water services, but do not pay for the water used. However, water still needs to be delivered to farmers who are at the end of the irrigation scheme and the water authority needs to be compensated for the service provided and water distributed, and hence there is a freerider problem. In addition, many farmers have adopted the practice of punching holes in the authority's concrete channels and irrigate without paying (Gorton *et al.,* 2009). Therefore, reduced income for suitable irrigation system maintenance results in high water losses in water supply systems (up to 40%) and a smaller irrigated area, accompanied by soil erosion and water quality issues (MAFWE, 2010). This significant inefficient utilization of irrigation water causes decreases in crop yields, and ultimately influences the performance and productivity of Macedonian farmers.

The importance of efficient water use is further emphasized by the fact that agriculture in Macedonia is the major water-consuming sector[4]. Agricultural freshwater requirements in 2010 accounted for 44% of the total water demand in Macedonia (UNECE, 2011). In comparison, the manufacturing sector consumed 14% and households 11%[5] (*ibid*). Water resources in Macedonia are considered to be abundant and are estimated to comprise around 6.4 billion m^3 surface water and 0.94 billion m^3 groundwater, with around 3150 m^3 *per capita*[6] (MOEPP, 2008b). However, this abundance is not well-utilized and water scarcity issues on farms can arise, especially during the summer months, due to the natural, institutional, technical and technological, and quality issues. In addition, there is intensive exploitation of the country's water resources

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[4] Agriculture worldwide accounts the round 70% on average of the total freshwater water consumption (Gleick *et al.*, 2011).

[5] The remaining 31% are the minimum necessary accepted flows which the nature consumes.

[6] For comparison, the European average is around 1900 m^3/capita (ICID, 2011).

(Analytica, 2009), placing Macedonia among the top five European countries regarding water exploitation index (EEA, 2009), combined with an uneven spatial and temporal distribution of water at national level. This brings to the forefront the problem of future available water resources for agriculture.

Agricultural land and pastures in Macedonia represent around 44% (1.12 thousand ha) of the country's total area and around 46% of this land is used for arable farming (WTO, 2014). However, over the past few years there has been a noticeable decline in the area of total arable land, from 546 00 ha in 2005 to 511 000 ha in 2011. Concerning irrigated land, the 2007 Agricultural Census (SSO, 2007a) reported that the total area with possibilities for full control irrigation was 127 800 ha, representing 32% of total arable land, while the present irrigated area comprises 79 637 ha (with 69 069 ha (87%) of this occupied by family farms and 10 568 ha (13%) by agricultural companies). Regarding the distribution of the irrigated area, the largest proportion is occupied by cereals (35%), vegetables (22%), and grapes (12%), followed by fruit (9%), forage crops (6%), and industrial crops (7%) (*ibid*). However, the irrigated area in Macedonia is currently declining and the infrastructure is deteriorating as a consequence of the technical, financial, and institutional issues explained above. If there is an improvement in such inefficiently utilized irrigated land with the new planned capital investments in irrigation structures and if the current irrigation schemes are well maintained, the full irrigation potential is estimated to be 400 000 ha (MAFWE, 2012).

1.3 Aim

The priorities for growth in Macedonia and the other WB countries should be to improve competitiveness and enhance productivity (World Bank, 2014). Water, being considered an ecosocial asset, should be exploited in an environmentally sustainable pattern in order to preserve it for future generations (Velazquez, 2007). At present, there is still a lack of adequate knowledge of the environmental concerns relating to water within the agriculture, industry, and household sectors. Policy recommendations should thus be based on comprehensive knowledge of the main interactions between water and the major water use sectors at a transparent level, with as few gaps and uncertainties as possible.

In order to successfully implement Macedonia's National Water Management strategy for efficient water use for irrigation purposes, secure the necessary quantity of water for such use (Official Gazette, 2012), and facilitate the EU harmonization reforms, deeper insights are required concerning the water challenges that Macedonia and its agriculture sector are facing over the coming years. The past, present, and future challenges, especially the climate change issue, will affect every feature of the economy. Endangering the crucial resource of water will result in jobs reductions, as well as lowering the standard of living, given the high share of employment that agriculture provides and the importance of (semi)subsistence farming in Macedonia. One consequence of this would be food shortages and a reduction in consumption. Food shortages would also lead to increases in commodity prices, which could affect trade as an important aspect in transition economies such as Macedonia. Industrial output could be put at risk as water and water-dependent inputs become more expensive and limited. Deteriorating water quality would increase the cost of treatment, which in turn could affect productivity, not including the significant losses.

Against this background, the main aim of the present thesis was to fill gaps in existing knowledge concerning the demand for water in Macedonia from an economic perspective. Assessing and understanding the interaction between agriculture and the other sectors of the Macedonian economy, taking into account the increasing demand for water by other sectors, is necessary. Conducting research to better understand the role of water from an economic perspective is essential in order to create and implement water management strategies crucial to sustainable development, which will ensure increased competitiveness and productivity and thus economic growth. Regarding agricultural development, improved water management can improve production and productivity, which will satisfy the increased demand for food at affordable prices; provide equitable access to water and help food production; contribute to improved marginal quality water use; and integrate the principles of sustainable development and develop adaptation measures to mitigate the scarcity of this natural resource. The application of economic models in the field of environmental science, and in particular water management, has been reported by many authors to be an effective means to investigate the direct and indirect water relationships at regional and national level (see among others Lenzen and Foran, 2001; Dietzenbacher and Velazquez, 2007; Velazquez, 2006; Guan and Hubacek, 2007; Wang *et al.,* 2009; Zhao *et al.,* 2010; Yu *et al.,* 2010). The underlying economic model employed for that purpose in this thesis was an input-output (IO) model developed by Leontief (1936), applied to the Macedonian economy and combined with a detailed account of the country's water resources, as well as water usage by the agricultural, industrial, and service sectors.

1.4 Structure of the thesis

This thesis is based on the five appended papers (see Figure 1). Since agriculture in transition countries is vulnerable but has the potential to supply a substantial share of the food demand through increased production and productivity, determining agriculture productivity is important because it provides an overall indication of the growth and adaptation of technical progress. Thus, Paper I attempts to examine the production and productivity growth of Macedonian agriculture, with emphasis on the origins and pace of such growth. Agricultural production in Macedonia is likely to be affected by the CAP because the country is a candidate for membership of the EU. In this regard, it is necessary to look deeper at the productivity features of the agriculture sector and examine the reasons behind its development over the last 10-15 years.

Although Macedonia is abundantly endowed with water, accurate quantification is still required given the water scarcity issue arising during the summer period. Paper II attempts to quantify and analyze the direct and indirect water requirements, combined with the economic interrelationships among sectors. By obtaining a comprehensive overview of the water flows, key water-consuming sectors can be identified. To understand better the issues within agriculture in terms of water consumption, in Paper II the sector, which is the major water consumer in the country, was disaggregated into several sub-sectors. The methodological approach used for this disaggregation procedure was comparable to that used for Sweden by Lindberg and Hansson (2009). The disaggregation was followed by an appropriate development of water accounts for Macedonia, using an approach proposed by the EU Commission (2002). These water accounts provided a detailed breakdown of water use by economic sectors in Macedonia, as well as an indication of the available water resources. Thus, the end result was a detailed and disaggregated IO table of Macedonia, with a special emphasis on agriculture.

Paper III investigated the effect of uncertainty inherent in the data, but considering agriculture as a single economic unit. The imprecision and uncertainty were studied in a fuzzy IO framework as introduced by Beynon *et al.* (2005). Volk *et al.* (2012) indicate that most comprehensive data analysis of agriculture and agricultural policy can be conducted in Macedonia, but that there are still some problems regarding data availability and quality.

The IO table developed in Paper II was used as background in Paper IV, where emphasis was placed on the concept of ‘virtual water’ and trade. Virtual water is the water component that is directly and indirectly consumed during the process of production. Through commercial trade, a quantity of water ‘embodied’ in products either exits or enters the country. Macedonia is rich in water resources at the moment, but intensive production of crops, which occupy the largest share of total irrigated land and are also among the major export commodities, combined with the already stressed water scarcity issue, may lead to even greater availability problems in the long run. Velazquez (2007) argues that trading virtual water may be an instrument to control and promote sustainable natural resource management and to reduce the pressure on the existing water resources.

Paper V again used the augmented IO table for Macedonia as background, but in that case direct impacts of climate change on agricultural crops were investigated. Given the fact that (semi)subsistence farming is important at national level and that farmers are facing inefficient use of water, a warming effect of temperature increases and precipitation decline will have a substantial effect on their production levels and subsequent wellbeing. The problem of having an uneven spatial, temporal, and quality distribution of water in Macedonia makes the climate change issue even more important. There will be output changes as a consequence of the direct influence on agriculture and on the inputs provided by the other economic sectors. There will also be indirect impacts of climate change upon agriculture. By specifying the direct and indirect changes in production as a result of the warming effect, water consumption was quantified in Paper V, assuming that the irrigation practices remain unchanged over the years.

Papers II, IV and V thus all used the disaggregated IO table of Macedonia. Given the uncertainty regarding the exact irrigated land area, as well as the data used on direct water consumption to construct the water accounts (explained in the next section), the fuzzy approach (Paper III) was deemed to be the most applicable conceptual framework to test whether agriculture is indeed the major water use sector in Macedonia.

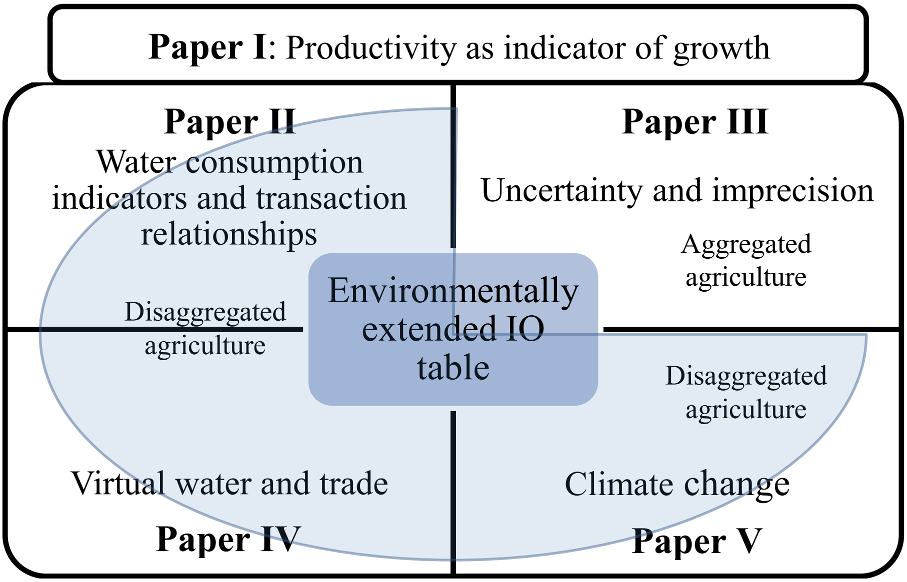

Figure 1. Papers I-V and topics researched in this thesis.

The results of the comprehensive research described in Papers I-V provide valuable information for decision makers that can support them in proposing and designing sustainable water consumption policies and implementing more effectively the objectives of the National Water Strategy. This thesis is also important because it is the first attempt to conduct such research at national level in the Western Balkans given the relevancy and extent of the study area.

Following this introductory part, Section 2 describes briefly the methods and data through the conceptual and empirical frameworks of each respective paper. The results presented in Papers I-V are then summarized in Section 3, while the final concluding remarks are provided in Section 4. The full papers are appended at the end of the thesis.

2 Methodology

2.1 Data and data issues

Paper I considered a period of over 10 years, using the Economic Accounts for Macedonian Agriculture from 1998 to the latest published in 2011, in the analysis. The official statistics were used as a basis in order to estimate the distribution of agricultural output and input volumes between family farms and agricultural companies (production per specific crop and livestock enterprises, input use, land use, *etc*.).

The empirical analysis in Papers II-V was based on an augmented version of the IO table for 2005, produced using data from the State Statistical Office (SSO, 2008a). The table was the first of its kind to be produced for Macedonia and was constructed in line with the harmonization system of the European statistical system, following the definitions and concepts recommended in the EUROSTAT Manual on Supply, Use and Input-Output Tables (EUROSTAT, 2008). To analyze the links between the economic sectors, a symmetric IO table that considered only domestic production was used. Such an approach using an environmentally extended IO table, as developed by Leontief (1970), was essential because in that way only the water used in producing commodities and services in the Macedonian economy was considered. Otherwise, the water that enters the country with products due to commercial trade would be incorrectly incorporated into the analysis (Velazquez, 2006). It is important to emphasize that the table used is classified as a product-by-product type, with a commodity technology assumption. The table describes the technological relations between products where the product mix is homogeneous, regardless of the industry in which they are produced (Miller and Blair, 2009). For instance, the products of agriculture are only produced by production units of the homogeneous branch agriculture. Hence, the total water consumed by the agriculture sector is allocated just for this product mix.

Product-by-product symmetric tables are generally more consistent in their description of the transactions and are favored more by the European system of accounts, since they are more suitable for many types of IO analysis (EUROSTAT, 2008).

In constructing the water accounts at sector level, a combination of two datasets was used: (1) sectoral water consumption data from the 2006 State Statistical Yearbook (SSO, 2007b) and (2) data from the EUROSTAT database. Physical data were introduced into the original conventional symmetric IO table for 2005 and considered consumption of both surface and underground water from the inland resource system[7]. The surface water is mainly supplied from reservoirs (71%), followed by lakes (24%) and water courses (5%) (SSO, 2008b). Underground water relative to the total water supply is small and accounts for about 2% (*ibid*). The interactions between the system of resources and the economic sectors which abstract water for consumption and production purposes directly from the water resource system, or indirectly from the infrastructure for storing, treating, and distributing water, are illustrated in Figure 2. Note, however, that some industrial sectors have the option to use recirculated water processed in the circulation system, but this water is not captured in the water accounts, because they refer only to the water resource used as an input for the first time (UN, 2012).

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[7] Inland water resource system considers all water resources such as lakes, artificial reservoirs, ground water and soil water within the territory of reference from which water can be abstracted (UN, 2012).

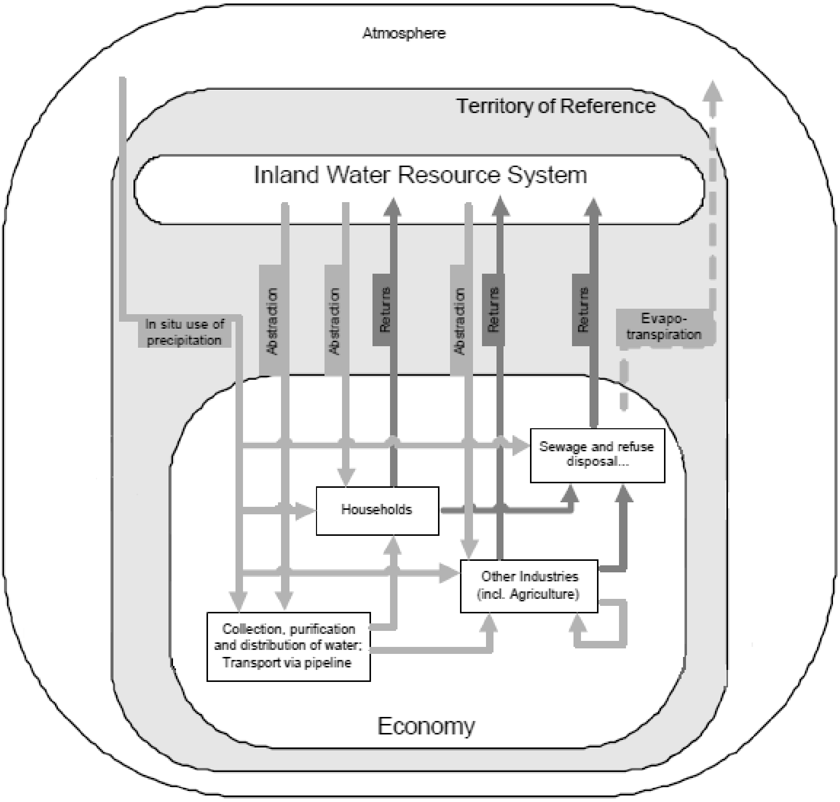

Figure 2. Main flows of water within the economy of Macedonia (adjusted from UN, 2012).

Recent studies have shown that both environmental and economic analyses are better disaggregated than aggregated, even if based on assumptions (Lenzen, 2011; Su *et al.,* 2010). A detailed description of the disaggregation procedure used for Macedonian agriculture as a major economic and water-consuming sector is provided in Papers II and V. The economic transactions allocated to each agricultural sub-sectoral production were based on sources such as: the Common Agricultural Policy Rationalised Impact (CAPRI)[8], the EUROSTAT data on Economic Accounts for Agriculture, and the Farm Monitoring Survey (FMS)[9] on farm performance, as well as data and the annual yearbooks and reports published by the Macedonian State Statistical

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[8] . More information about CAPRI may be found at: http://www.capri-model.org/dokuwiki/doku.php?id=start.

[9]. The Farm Monitoring System (FMS) is an annual survey carried out by the Macedonian National Extension Agency, gathering farm return data of around 300 farms, in line with the Farm Accountancy Date Network (FADN) principles.

Office (SSO). The agricultural water accounts were disaggregated using data on irrigated area from the 2008 Annual Agricultural Report (MAFWE, 2009), as well as the combined figures on crop water requirements (CWR) calculated specifically for Macedonia by Hoekstra and Hung (2003) and crop level estimates by Iljoski (1990). Concerning the livestock sectors, the water requirements reported in Galev and Arsovski (1990) were used. Although agriculture was disaggregated, several aggregations were considered due to the lack of water consumption data in either of the datasets for some specific sectors. Due to the absence of direct water consumption data for each service sector, the 26 public and market service sectors were aggregated to one economic unit. Continuing in the same manner, the four mining and quarrying sectors were aggregated. The last aggregation was done with the office and computer, electrical, radio, and TV equipment sectors.

An important aspect to be considered in constructing water accounts is the water used for production of electrical energy, *i.e.*, the hydroelectric power generation or the ‘Electrical energy’ sector. According to both datasets, the water quantity used in this sector in 2005 exceeded 1 000 million m^3, but this quantity only passes through the turbine generators and may be reused downstream by other economic agents. To avoid double counting, only the water used for cooling purposes was considered as input (ABS, 2010; UN, 2012). The same applies to the fish farming sector, where the water just flows through the fish ponds and is returned immediately to the environment and becomes available for the other sectors. Avoidance of double counting was also required in the ‘Collection, purification, and distribution of water’ sector. According to Figure 2 and the NACE class 41.00 (European Commission, 2002), this sector abstracts water from the environment, purifies it and distributes it to industries, households, and other sectors. Therefore, the water requirement as input in this sector was considered to be zero.

While comparing and combining the datasets to find an appropriate water demand quantities for some sectors, several inconsistencies in the data appeared, which might have resulted in misleading interpretation. For example, in the EUROSTAT database the total manufacturing sector water supply is 230.5 million m^3, which is the exact water abstraction for technical purposes in the 2006 State Statistical Yearbook. On the other hand, in the 2006 State Statistical Yearbook, the total supply of water for the manufacturing sector is 477.95 million m^3. This inconsistency can perhaps be explained by the huge water losses in the supply system. However, the issue of data availability for direct water consumption at sector level probably stems from the fact that there is a huge discrepancy over the years. AQUASTAT (FAO, 2014) estimated that the agricultural water withdrawal amounted to 1066 million m^3 in 1996, then 281 million m^3 in 2002 and 'only' 126 million m^3 in 2007, *i.e.* 69%, 47% and 12% of total water consumption, respectively. Sutton *et al.* (2013) reported and used as the basis for their models the water withdrawal in 1996. Such variations may also stem from the fact that over the years, different reports present different statistics regarding the area of irrigated land in Macedonia. According to the Agricultural Annual Reports 2006-2011 (MAFWE, 2007-2012), the constructed irrigation installation could potentially provide irrigation to 144 894 ha agricultural land. However, according to the 2011 Agricultural Annual Report (MAFWE, 2012), only 22 000 ha (15%) on average over the period of 2006-2011 were actually irrigated. On the other hand, in the official Agricultural Census (SSO, 2007a), the total area with possibilities for full control irrigation is 127 800 ha, whereas the actual irrigated area comprises 79 637 ha. The latest World Bank study (Sutton *et al.*, 2013, p.54) reports that: "In total, there are 87 590 hectares of irrigation across the country, with 31 750 hectares in the Crna Basin, 30 499 hectares in the Vardar Basin, 15 312 hectares in the Radika Basin, 7 585 hectares in the Pcinja Basin, and 2 444 hectares in the Bregalnica Basin". Hence, while there are comprehensive data available for the agriculture sector, as indicated by Volk *et al.* (2012), there is still some inconsistency in the quality over the years. As regards municipal water withdrawal, it remained stable, with around 212 million m^3 on average, whereas the industrial water withdrawal increased from 274 million m^3 in 1996 to 685 million m^3 in 2007 (FAO, 2014).

A detailed description of the inconsistencies in the data is important, because it provides justification for considering different reported irrigated area values in climate change analysis, as well as for conducting a fuzzy IO analysis to reconsider the uncertainty in the data regarding water consumption.

2.2 Productivity growth estimation

Although Paper I in this thesis differs from the others in dealing with model specification, it includes transactions on inputs and outputs. Productivity can be defined as the relationship between the volume of outputs and inputs, or the transformation of total input into output (Schreyer and Pilat, 2001). However, aggregation of the economic value of the associated inputs and outputs is necessary in order to determine total factor productivity (TFP) (Fuglie, 2010). The productivity measurement model of TFP and TFP growth considers constant returns to scale and it is based on the work by Kendrick and Sato (1963). Growth accounting is a deterministic non-frontier methodological approach that has been used as one of the most popular ways to estimate TFP at both aggregate and sector level (Del Gatto *et al*., 2011). This methodology has been extensively applied in productivity studies of French agriculture (Bureau *et al.*, 1992; Butault *et al.,* 1994; Boussemart *et al.,* 2012). The index number theory and methods of surplus accounting allow analysts to determine who is benefiting the most from improvements in productivity: consumers from lower prices, suppliers from increased factor prices or farmers from increased income. The productivity and surplus rate depend on volume and price indices between inputs and outputs, and the equality between them basically allows the surplus account to be presented as a breakdown of the productivity rate. The indices are based on the established Paasche and Laspeyres price or quantity index in Diewert and Nakamura (2003). The Paasche price index is the implicit counterpart of the Laspeyres quantity index and the Laspeyres price index is the implicit counterpart of the Paasche quantity index. In the surplus accounts in Paper I, the volume variations were weighted by the final period price (using Paasche index), while the price variations were weighted by the final period volume (Laspeyres index).

2.3 Input-output modeling and water consumption

The increasing awareness at national, regional, and global level that water resources are limited and need to be protected and managed in a sustainable manner has brought about an increase in scientific research on water development and management over the last decade (Duarte and Yang, 2011). The relevance of an environmental extended IO table to study such relationships between the economy and the environment was first noted in the 1950s (Velazquez, 2006), but factors such as lack of data regarding water consumption, the abundance of water resources in many developed countries, and the lack of data on water quality have resulted in increased use of environmental extended IO tables (Duarte and Yang, 2011). Given that fact that in recent years water statistics are far more improved and there has been a drastic shift in concerns about the quality and availability of water resources, there has been increasing recognition that water resource management can be analyzed using an IO table. Some recent studies on water use applying an IO framework are summarized in Table 1. For example, Chen (2000) used such a framework to study the water supply and demand balance in Shanxi Province in China. On the basis on the IO table, by using translog production function and a linear programming model, he was able to allocate an economic value to the water and propose a water resource-saving budget for Shanxai Province. Lenzen and Foran (2001) analyzed water use in Australia and showed that the predominantly urban population is responsible for the entire water consumption. Duarte *et al.* (2002) studied the effect of Spanish water consumption in a Hypothetical Extraction framework using I-O methodology. Okadera *et al.* (2006) performed an analysis of the water demand and pollution discharge for the Three Gorges Dam in China. Velazquez (2006) studied the intersectoral water relationship in Andalusia. In addition, the methodology used by Velazquez (*ibid*) was adapted by Wang *et al.* (2009) to analyze regional water consumption in Zhangye City. Another recent study was that by Yu *et al.* (2010), who attempted to identify the key water-consuming sectors in the north and south of the UK using regional extended IO methodology.

Table 1. *Summary of recent water consumption input-output studies*

Country	Author/s	Topic/s
Australia	Lenzen and Foran (2001)	Intersectoral consumption relationships
	Lenzen (2009)	Regional trade and virtual water flows
China	Chen (2000)	Supply and demand balance
	Guan and Hubacek (2008)	Integrated hydro-economic accounting of water resources
	Huang *et al.* (2005), Guan and Hubacek (2007), Ip *et al.* (2007), Zhang *et al.* (2011)	Regional trade and virtual water flows
	Okadera *et al.* (2006)	Demand and pollution discharge
	Wang *et al.* (2005)	Resource management
	Wang *et al.* (2009), Liu (2012)	Intersectoral consumption relationships
	Zhao *et al.* (2009)	Water footprint
	Zhao *et al.* (2010)	Water footprint and virtual water trade
Iran	Yousefi (2012)	Consumption of industrial sectors
Korea	Yoo and Yang (1999)	The role of water utility
Spain	Cazcarro *et al.* (2012),Velazquez (2006)	Intersectoral consumption relationships
	Dietzenbacher and Velazquez (2007), Velazquez (2007)	Regional trade and virtual water flows
	Gonzalez (2011)	Macroeconomic impact of water supply restrictions
	Llop (2008)	Economic impact of water policy scenarios
UK	Yu *et al.* (2010)	Regional and global water footprints
World	Arto *et al.* (2012)	Water use, water footprint and virtual water flows

All the studies cited above make use of the well-known conventional IO table developed by Leontief (1936) and extend it in terms of water consumption. The basic framework of the Leontief IO analysis concerns the "flow of products from each sector, considered as producer, to each of the sectors, itself and others, considered as consumers" (Miller and Blair, 2009, p.2). It is generated from observed data for a particular time period and a given geographical region. The mathematical structure behind the IO tables consists of a set of linear equations in a matrix representation, where rows represent the distribution of producer output and columns represent the inputs required by a particular sector to produce its output:

$$x_i = \sum_{j=1}^{n} z_{ij} + f_i \tag{1}$$

where z_{ij} represents the values of the transactions from each sector i to sector j and f_i is the final demand for goods by each sector. Final demand is created by consumers in the economy who are exogenous to the industrial sectors and this column vector displays the intermediate output spending by households and government, as well as changes in capital investment and exports.

Table 2. *Environmental extended IO table*

Producer sector	**Consumer sector**			**Final demand**			**Total output**
	Agriculture	Mining	*etc.*	Consumption	Investment	Exports	
Agriculture							
Mining		Z_{ij}			F_i		X_i
etc.							
Value added		V_j					V_i
Imports		M_j			M^F_j		M_i
Total inputs		X_j			F_j		
Total water use		W_j					

Note: Capital letters indicate matrix notation.

Source: Miller and Blair, 2009.

Equation (1) can be rewritten to include the technical coefficients of production (a_{ij}), which are defined as the purchases that sector j makes from sector i per total effective production unit of sector j and which represent the direct input required by that sector, *i.e.,* $a_{ij} = z_{ij} / x_j$. These coefficients are assumed to be constant, *i.e.*, when the output of sector j doubles, the input from i to j doubles as well. Therefore, it is assumed there are constant returns to scale. In matrix notation it becomes $X = AX + F$ and solving for X, the total production delivered to final demand is $X = (I - A)^{-1} F$. The element $(I - A)^{-1}$ is known as the Leontief inverse matrix or the total requirement matrix representing the total production that every sector must generate to satisfy the final demand of the economy (*ibid*). This relationship is the essence of this doctoral thesis and many other applied IO studies in terms of water, since the elements are used for evaluating the linkages between economic consumption activities and environmental impacts. They also describe an increase in production generated by an increase of one unit in the demand. Thus, with a better understanding of the relationship between the economy and the environment, awareness of sustainable water consumption and management can be increased.

Before discussing further the particularities of the model outlined above, a property that is considered in all papers dealing with IO analysis is that the IO model of the Macedonian economy is *open*. This means that the output produced may also be sold to other final purchasers, including households, government, and other countries, by trade. Furthermore, the producing sectors may use primary inputs such as labor and capital to produce their own output. By making household consumption and the wages earned by households endogenous or included in the intersectoral relationships, the induced effect can be captured. Through closing the economy with respect to households, the induced effect determines how an increase in the level of household income influences the demand for local goods and services (ten Raa, 2005). However the necessary condition of an IO table, that all corresponding endogenous row and column totals must be equal, is not satisfied in such a situation. West (1999, p.19) stresses that "this restriction is not satisfied since the household row typically only includes wages and salaries and not other forms of income, and therefore the income row total is generally less than the consumption column total. In such cases, technically the results of impact analyses are invalid". In Macedonia, the remittances in 2012 from abroad through bank transfers were estimated to be about US$400 million (Utrinski Vesnik, 2013). When the money brought personally when travelling or sent through the post is considered, the amount is even greater. In addition, the magnitude of the underground (grey) economy in Macedonia is argued to be around 40% (Nenovski, 2012). Therefore, the effect of household expenditure on the demand for commodities and services related to water as an input in the production process is probably underestimated in this case.

Although IO analysis is the most widely used method for assessing the environmental impacts of economic production (Wang *et al.*, 2009), an important limitation of the methodology needs to be recognized. The main disadvantage of IO analysis is that the analysis is static, *i.e.*, in the present case it was just a ‘snapshot’ of the Macedonian economy in 2005. Over the years the economic structure and water consumption might change, so the results presented here are intended to be only indicative for that earlier period. Changes in the composition or proportion of input use over time can be analyzed using the new, recently published IO table. Other limitations of the IO methodology are the linearity assumption of the model structure and the fixed proportion production technology with constant prices (Miller and Blair, 2009).

Despite the disadvantages of the chosen framework, the challenges in terms of water management that Macedonia faces or, more specifically, sustainable use of water by the agriculture sector, while also responding to increasing demand by the industrial and service group of sectors, can be assessed using an environmentally extended IO table (see Table 2). Paper II made use of such a model where proper quantification and identification in terms of water consumption were essential to understanding and creating equitable and effective use of water. The extension of the traditional IO model consisted of introducing water inputs (W_j) as a production factor (measured in physical units), which according to Velazquez (2006) enables the structural relationship between a production activity and its physical relationship with the environment to be analyzed. The water consumption indicators necessary to conduct the analysis and determine the direct and indirect relationships are developed and discussed further in Paper II. Intersectoral linkage analysis (backward and forward) was also employed to identify the key sectors with a greater influence on the whole water consumption process. Although there are several other measurement methods for interindustry interdependencies, a Rasmussen (1956) linkage analysis was applied due to its simplicity. In order to obtain information on the sectors that have the greatest impact on the whole water consumption process through the effect of their purchases (backward) and sales (forward), the technical coefficients matrix was adjusted to water consumption equivalence. A simple normalization was used to obtain the indices of the backward and forward linkages, where indices showing a value greater than unity were taken as indicators of key water-consuming sectors.

Paper IV again made use of the previously defined Leontief inverse matrix. However, the matrix was adjusted to water multipliers by combining with a vector of direct water coefficients (W^*), defined in the same way as the conventional technical coefficients. The virtual water multipliers obtained were combined with both exports (F_e) and imports (M) in order to investigate how much water (by volume) exits or enters the country due commercial trade, *i.e.*, $VW_e = \hat{W}^*(I - A)^{-1} F_e$ or $VW_m = \hat{W}^*(I - A)^{-1} M$. These multipliers are also essential because by applying the Dietzenbacher and Velazquez (2007) methodology, it is possible to investigate how price sensitive the products are, resulting from a cost-push in water prices as input. By setting the price of water per m^3 at the same level as the other input prices, it was possible to identify how much the cost of production for a specific good increased when the price of 1 m^3 water increased by one unit. In addition, by considering a policy aspect of export nullification of the most water-consuming sectors at national level, it was possible to assess and propose water-saving policies or achieve more rational use of water. This is important because although Macedonia is abundant in water at the moment, it is characterized by a high Water Exploitation Index (WEI) of 34%[10], similar to that in Spain and Italy (EEA, 2009).

In recent years the issue of climate change has become an important aspect that has a potential impact on water resources availability, and consequently upon agricultural production as the key input in production, and thus the national economy. In order to investigate such direct and indirect relationships, an environmentally extended version of an IO table was used in Paper IV with a combination of a mixed model approach and water accounts. The advantage of this modified mixed-variable Leontief model is that it permitted investigation of the so-called "backward linkage" effect from a supply side perspective, where a reduction in an agricultural output due to climate change reduces the demand for farm inputs, thus triggering a whole series of indirect effects on the other economic sectors, which must adjust their output to the new lower level of activity (Roberts, 1994). The ability to explain the relationships of climate-sensitive sectors in a disaggregated environment is another advantage regarding the choice of model (Rose *et al.*, 2000). From a demand side perspective, capital investment in the development, reconstruction, and maintenance of irrigation schemes is essential in order to mitigate the change in output production in the long run and ensure a sufficient supply of water as input, reduce the substantial water losses and fully utilize the potential of irrigation infrastructure. Thus, a change in the exogenous final demand (ΔF) affects the change in total output (ΔX) through the elements $(I-A)^{-1}$ of the Leontief inverse matrix, *i.e.* $\Delta X = (I-A)^{-1}\Delta F$.

2.4 Fuzzy IO approach

Given the existing issues in terms of data availability and quality, the results obtained in this thesis might have been compromised. In addition, as was pointed out above, several aggregations had to be conducted due to the absence

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[10] WEI has a threshold value of 20% indicating a transition from non-stressed to water scarce region. A severe situation occurs when the index is greater than 40%.

of data regarding sectoral direct water consumption. Beynon and Munday (2008) argue that aggregation of sectoral primary factor returns is among the numerous sources of uncertainty and imprecision in IO analysis. Hence, beside uncertainty in the data used to construct the water accounts, another source of uncertainty may stem from aggregation bias. Thus, Paper III attempted to minimize the uncertainty and imprecision by investigating the water consumption in a fuzzy IO environment developed by Beynon *et al.* (2005). The advantage of this approach is that there is no sharp boundary or value for the observed object in the IO matrix and it depends entirely on the defined membership function. In Paper III we adopted a triangular membership function for each object in the matrix of technical coefficients. The membership function depends on two parameters, *i.e.* an α-cut parameter, which closes the triangular number to an lower and upper bound; and a β parameter, which represents the level of imprecision (Beynon and Munday, 2008). Both parameters range from 0 to 1, with $\alpha = 1$ indicating the real value of the observed object and $\beta = 1$ indicating the worst imprecision case (*ibid*).

Recent work by Diaz and Morillas (2010) argues that a more appropriate way to capture the fuzziness of each element is by assigning a Beta probability distribution. However, such an approach requires the primary information that is used to construct the IO table, which we did not have at our disposal. Therefore, instead of using Monte Carlo simulation with Beta probability distribution as the best fit, we used the fuzzy approach as the most appropriate method at the given moment. Following the work of Beynon *et al.* (2005), a general symmetry condition was introduced to define the bounds, *i.e.*, 0 as lower bound and twice the observed value as upper bound. To investigate the imprecision in the observed data, the fuzzy numbers had to be ranked. The most appropriate method of ranking fuzzy numbers that was consistent with the change in the fuzziness rate of the technical coefficient matrix was by using centroids, calculated with formulae presented by Wang *et al.* (2006). In addition, to reduce the uncertainty in identification of the key water-consuming sectors even more, the Dietzenbacher (1992) method was applied because it has been shown to provide a better indicator of interindustry linkages than the Rasmussen (1956) methodology. This is because Rasmussen analysis is based on the technical coefficient matrix *A,* whereas Dietzenbacher is based on the Leontief inverse matrix $(I - A)^{-1}$, making it more appropriate in an environmental IO analysis. As indicated above, agriculture, fish farming and forestry were considered here to be one economic unit and not disaggregated.

3 Results from Papers I-V

After providing a brief explanation of each methodology, this section summarizes the results presented in Papers I-V in terms of methodologies and dimensions. For more detail on the actual methodologies, results, and discussions, see the individual papers.

3.1 Paper I

Assessment of the Macedonian agriculture sector through productivity analysis

The difficulties that the Macedonian economy has experienced during the transition period to a market economy in the last decade or two were mentioned in Section 1 of this thesis, which also indicated how important the agriculture sector is for Macedonia and how vulnerable its production may be, especially to external factors such as water shortages. Such impediments have resulted in yield levels for most agricultural sub-sectors that are still far below the EU average (Mizik, 2012). However, the analysis of production and productivity growth of Macedonian agriculture in the period 1998-2011 presented in Paper I revealed that the country had experienced an increase in terms of output volume, with an average annual rate of 1.52%, and a productivity or growth rate of 1.36% per annum. The results were calculated as averages smoothed over three years, and hence the reference period was fixed as 1999-2010. Two sub-periods were clearly defined, *i.e.*, sub-period 1999-2004 with the worst performance due to the internal ethnic conflict in 2001, adverse weather conditions in the early 2000s, and the ongoing privatization and transformation of the state-owned '*agrokombinats*'[11], resulting in an

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[11] Agrokombinat was state owned vertically integrated agro-business with large areas of available arable land. They were diversified in the primary production, food processing industry, commercial storing as well as market services. Often they were major suppliers of raw materials

volume increase of only 0.20% and a productivity decline of -2.17% per annum; and sub-period 2005-2010, marked by considerable efforts to rejuvenate agricultural production with an average annual increase in volume of 2.63% and a 4.40% increase in productivity.

Two-thirds of the country's agricultural output value comprises crop production, and the remainder livestock production. The major crops are vegetables, cereals, grapes, and forage crops, while within livestock production dairy farming and sheep and pig rearing are the most important enterprises (Figure 3).

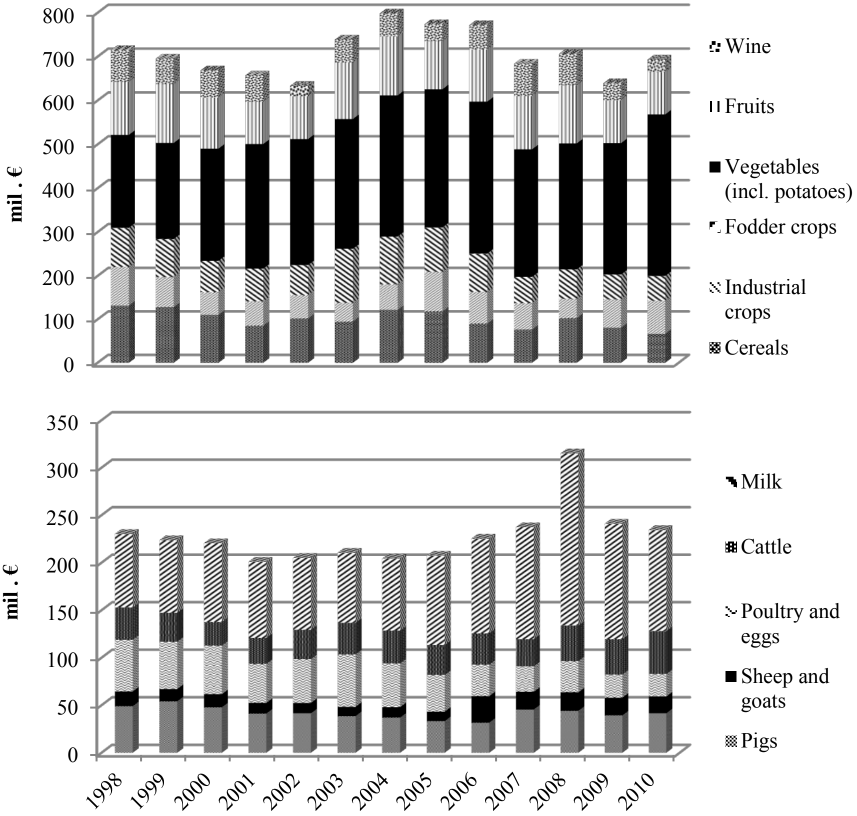

Figure 3. Crop and livestock output, 2005= 100.

The production itself was the most important factor, leading to a positive surplus amounting to 1.34% annually. As Table 3 shows, the economic surplus

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to the farmers as well as the major buyers of their production, but indirectly through the state owned agricultural cooperatives (MAFWE, 2007).

for the whole period originated mostly from the productivity gains (1.66% on annual level), but also from government payments (0.40% annually), paid labor (0.28% annually), and the suppliers of intermediate inputs such as seeds, fertilizers, pesticides, energy, and animal feed (0.09% annually). The main beneficiaries of the economic surplus that led to growth were consumers, who benefited from a decrease in output prices, and farmers, through an increase in net farm income per family annual working unit, receiving on average an annual 1.35% and 0.75% of the surplus, respectively.

Table 3. *Formation and distribution of the economic surplus*

		1999-2011		1999-2004		2005-2011	
		Source	Distribution	Source	Distribution	Source	Distribution
Formation	Production.	1.66		0.39		2.72	
	IC	0.04			0.76	0.71	
	Capital		0.03		0.01		0.04
	Land	0.00		0.00		0.00	
	Labor		0.34		1.78	0.87	
	Surplus		1.34		-2.16		4.26
	Total	1.71	1.71	0.39	0.39	4.30	4.30
Distribution	Surplus	1.34		-2.16		4.26	
	Agricultural prices		1.36	1.35			3.61
	Government	0.40		0.03		0.71	
	Suppliers	0.09			0.18	0.31	
	Capital				0.02	0.02	
	Land						
	Paid labor	0.28		0.44		0.14	
	Family labor		0.75	0.54			1.82
	Total	2.11	2.11	0.20	0.20	5.43	5.43

The distinctive dual structure of Macedonian agriculture, with family farms on one hand and agricultural companies on the other, was evident during the whole study period (Paper I). Although the family farms are highly diverse in their production, using small fragmented plots, their volume of agricultural production showed an increase at an average annual rate of 2.72%. In contrast, the production levels of the agricultural companies followed a decreasing trend of -5.86% annually, even though the privatization process for this sub-sector had finished and market-oriented production strategies had been adopted (see Figure 4). As regards agricultural productivity, there was an increase of around 1.93% annually on family farms and a decrease of -1.63% annually in agricultural companies. Production itself was the major generator of the growth on family farms, while the opposite was observed for the agricultural companies. A significant boost to growth was achieved through increases in subsidies and tax reductions, but paid labor also actually served as a contributor through price disadvantages. It may be argued that the global financial crisis in 2008 had a greater impact on the agricultural companies, in which case the results in Paper I show that the production diversification characteristic of Macedonian small-scale (semi)subsistence farming provides greater flexibility to market shocks than agricultural enterprises which make use of returns to scale.

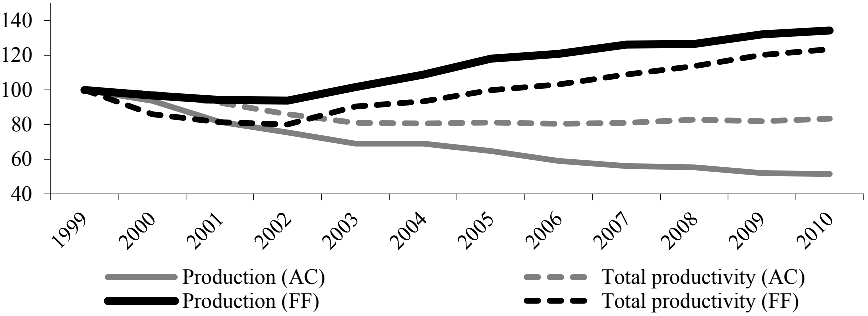

Figure 4. Production and productivity at family farms and agricultural companies (1999-2010, 2009=100).

3.2 Paper II

The economic role of water in Macedonia: an input-output analysis

Paper II explored water consumption and associated relationships with Macedonian water use sectors in 2005, based on an environmentally extended input-output analysis. Emphasis was given to agriculture by disaggregating it into 11 sub-sectors (see Table 4). The direct and indirect water consumption was investigated throughout several indicators. In general, the results confirmed that Macedonian agriculture is characterized by a water-intensive structure, mainly centered on rice, fruit, and grape production. In 2005, agriculture as the major water-consuming sector at national level consumed around 38% of total water use. The indicator of direct water use obtained revealed that if the rice, grapes, and ‘other crops’ sub-sectors (the latter dominated by alfalfa and other forage production) increase their production by 1 million MKD [12], annual water consumption will increase by around 28 855, 9 048 and 13 177 m^3, respectively. Macedonia is currently very rich in

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[12] 61.5 MKD (Macedonian Denar) = 1 €; National Bank of R. Macedonia

water, but given the water scarcity issues during the summer months, such use would impose significant pressure on this natural resource. Regarding livestock, the cattle and sheep sectors had the largest indicators of direct water use, but also displayed significant indirect consumption. This may be explained by the very high indicator of direct water use in other crop production sectors from which the products are used as feed input in livestock production. This was also characteristic of the pig production sub-sector, but to a smaller extent, mainly because pigs are fed with concentrated grain-based feed.

Although Table 4 only shows the results for the agricultural sub-sectors, it must be stated that the secondary raw materials and the electrical energy production sectors displayed high levels of indirect consumption (about 98 and 69 m^3 per cubic meter of directly consumed water) compared with the other sectors. This means that large amounts of water were consumed directly somewhere else to produce the inputs for these sectors. For the sector responsible for the production of electrical energy, the consumption was mainly driven by the mining and electrical equipment production sectors. Hence, if the electrical energy sector increases its output, the indicator of direct use of 27 778 m^3 by the mining industry and 8 301 m^3 by the electrical equipment production sector would increase even more (Table 5).

Table 4. *Water consumption in Macedonian agriculture in 2005*

No.	Designation	Direct total water consumption million m^3	Direct total water consumption %	Indicator of direct water use (m^3/1 mill MKD)	Indicator of total water use (m^3/1 mill MKD)	Linkage analysis U_{BL}	Linkage analysis U_{FL}
1	Cereals	26.11	3.82	**4090.35**	**4588.99**	0.44	**1.28**
2	Rice	14.07	2.06	**28854.80**	**31986.19**	**2.95**	**1.71**
3	Raw tobacco production	11.27	1.65	2709.74	2971.23	0.25	0.16
4	Vegetables	41.98	6.14	2467.01	**3525.80**	0.77	0.74
5	Fruits	23.65	3.46	**6343.31**	**7988.57**	**1.58**	**1.04**
6	Grapes and wine production	49.82	7.29	**9048.36**	**12595.49**	**3.19**	**2.09**
7	Other crops	43.73	6.40	**13177.28**	**13956.73**	0.85	**1.94**
8	Cattle	25.59	3.74	**3387.56**	**8917.93**	**4.90**	0.78
9	Pigs	5.02	0.73	1863.27	**3878.17**	**1.35**	0.63
10	Sheep/lamb	11.05	1.62	**5509.17**	**9776.16**	**4.50**	0.36
11	Other livestock	2.81	0.41	1000.29	2079.90	0.67	0.23
	Total water use	255.10	37.52				

Note: Indicators that show intensive water use within the economy and indices in the linkage analysis that are larger than 1 are marked in bold type.

The different values of the indices of backward (U_{BL}) and forward (U_{FL}) linkages provide information on the sectors that have the greatest impact on the whole water consumption process through the effect of their purchases and sales. Thus, the indices (greater than 1) show that rice, fruit, and grapes are key water-using sub-sectors (see Table 4). In addition, Table 5 shows that within the manufacturing group sector, mining and food and beverage production, followed by the production of electrical energy, are key water users. Therefore, policy makers should take into account the need to introduce changes in production technology and to encourage specialization in less water-intensive production sectors in this region, in order to ease the pressure upon this natural resource. Taking into account the projected impacts of climate change, this issue deserves even greater attention. In addition, reconsidering the existing water pricing policy based on comprehensive research that would capture the economic, social, and environmental aspects should be a priority.

Table 5. *Water consumption by the Macedonian manufacturing and service sectors in 2005*

No.	Designation	Direct total water consumption		Indicator of direct water use (m^3/1 mill MKD	Indicator of total water use (m^3/1 mill MKD	Linkage analysis	
		million m^3	%			U_{BL}	U_{FL}
12	Forestry	0.00	0.00	0.00	199.79	0.08	0.24
13	Fishing	0.00	0.00	0.00	1125.04	0.60	0.00
14	Mining and quarrying	161.33	23.59	**27778.39**	**28461.38**	0.56	0.50
15	Other mining	26.43	3.87	**7262.74**	**8896.20**	**1.53**	**1.01**
16	Food and beverages	103.37	15.12	**3339.88**	**6292.08**	**2.38**	**2.06**
17	Tobacco products	0.40	0.06	44.46	1413.84	**1.29**	0.01
18	Textiles	0.45	0.07	151.66	495.99	0.06	0.00
19	Wearing apparel	0.97	0.14	36.00	134.43	0.02	0.00
20	Leather products	0.04	0.01	15.29	202.19	0.02	0.00
21	Wood products	2.20	0.32	1311.96	1649.25	0.10	0.07
22	Pulp and paper products	0.08	0.01	16.10	230.40	0.02	0.06
23	Printed matter	0.29	0.04	273.20	342.83	0.03	0.05
24	Coke, refined petroleum	0.28	0.04	12.77	98.94	0.07	**7.90**
25	Chemicals	4.71	0.69	814.73	1345.31	0.39	0.78
26	Rubber and plastic	0.08	0.01	17.41	274.16	0.10	0.10
27	Other mineral products	1.46	0.21	222.09	1321.57	0.90	0.12
28	Basic metals	68.13	9.96	**2260.65**	**5260.18**	**3.06**	0.43
29	Fabricated metal products	0.09	0.01	21.75	286.56	0.14	0.02
30	Machinery and equipment	4.52	0.66	2133.18	2491.89	0.16	0.39
31	Office, computers; Electrical machinery	42.81	6.26	**8301.59**	**8727.21**	0.25	0.09
32	Medical and optical instruments	0.01	0.00	25.02	145.99	0.03	0.00
33	Motor vehicles	0.17	0.03	95.30	486.18	0.18	0.00
34	Other transport equipment	0.13	0.02	201.80	514.06	0.13	0.00
35	Furniture	0.31	0.05	173.98	405.58	0.09	0.03
36	Secondary raw materials	0.00	0.00	2.92	288.78	0.16	0.04
37	Electrical energy	1.00	0.15	68.79	**4830.42**	**5.47**	**3.41**
38	Collected and purified water	0.00	0.00	0.00	614.62	0.36	0.03
39	Construction work	1.00	0.15	23.58	474.27	0.24	0.04
40	Services	8.40	1.23	33.10	342.56	0.16	**11.66**
	Total water use	428.68	62.48				

Note: Indicators that show intensive water use within the economy and indices in the linkage analysis that are larger than 1 are marked in bold type.

3.3 Paper III

The effect of uncertainty in a fuzzy input-output analysis of water consumption applied to Macedonia

Paper III reassessed the reliability of the results in Hristov *et al.* (2012) from the input-output analysis of water consumption, by taking into account the effect of uncertainty inherent in the data. Beside the uncertainty of the selected data in terms of water use, the aggregation of sectoral primary factor returns was an additional source of uncertainty and imprecision in the input-output analysis. Application of the fuzzy approach to the technical coefficients matrix of the aggregated 28-sector input-output matrix revealed a variation in the level of fuzziness for some output multipliers. This meant that when the sectors were ranked in a fuzzy environment, due to the aggregation there were changes in the ranking order given the proportional imprecision, *i.e.*, rank reversal.

As outlined before, the method for identification of key sectors using Rasmussen linkage analysis depends entirely on the direct IO technical coefficient matrix. Given that the output multipliers are derived from this matrix, changes in the degree of fuzzification of the output multipliers indicate that the Rasmussen linkage analysis is risked. As a consequence, some sectors were identified as key water users, but were not considered as such to any great extent during the IO analysis of the Macedonian water consumption in Hristov *et al.* (2012). Dietzenbacher (1992) linkage analysis provided better insights of the linkages and identified the sectors that displayed the most water-intensive structure (Table 6). For instance, the mining sector was omitted in the Rasmussen linkage analysis, whereas in the Dietzenbacher linkage analysis it was identified as a key sector with a significant influence on water consumption in Macedonia. The same applied for the sector responsible for production of electrical equipment and the reverse for the energy production sector.

Table 6. *Key sectors in Macedonia in terms of water consumption in 2005*

No.	Sectors	Indicator of total water use (m^3/1 mill MKD)	Linkage indicator			
			Rasmussen		Dietzenbacher	
			U_{BL}	U_{FL}	U_{BL}	U_{FL}
1	Agriculture, forestry, and fisheries	5833.81	**1.97**	**5.59**	**5.31**	**1.75**
2	Mining and quarrying	5821.57	0.06	0.52	**4.98**	**12.30**
3	Other mining products	8168.99	**2.16**	**3.89**	**8.12**	**9.35**
4	Food and beverages	4109.67	**2.40**	0.86	**2.86**	0.31
12	Coke, refined petroleum	3937.40	**7.56**	**2.24**	0.01	0.01
16	Basic metals	2838.12	**1.63**	**2.60**	**1.88**	**1.12**
19	Office, computers; Electrical machinery	3328.22	0.43	0.19	**2.90**	**2.14**
25	Electrical energy,	1497.27	**2.41**	**1.56**	0.07	0.06

Note: Indices larger than 1, identified as key water use sectors, are marked in bold type.

Given the new key water use sectors identified based on the Dietzenbacher linkage analysis and the uncertainty in the data used to construct the water accounts, the fuzzy methodological framework was applied to the indicators of total water consumption. As can be seen in Figure 5, there were changes in the level of fuzziness for some of the sectors. The basic metals (16) and electrical energy (19) sectors showed changes in their upper bound of water consumption when the level of imprecision (β) was around 0.3. As the imprecision increased to a level that ensured solution of the fuzzy system (β went from 0 to 0.412), the lower and upper bounds of consumption did not increase at the same rate. The larger the value of the indicator, the greater the uncertainty. However, it should be pointed out that this occurrence should be viewed as a result of the general symmetry condition. On ranking each fuzzy triangular water indicator, rank reversal was observed for these two sectors around the value of 0.35. However, there was no incidence of rank reversal for the agriculture sector. Given these considerations, it can be argued that in a fuzzy environment, agriculture remains the key water-consuming sector. Consequently, due to the high indicator of direct and total water consumption (around 5834 m^3 of water per unit of output produced), increases in the production of this sector and the other major water-intensive sectors will impose significant pressure on the natural freshwater resources and the environment.

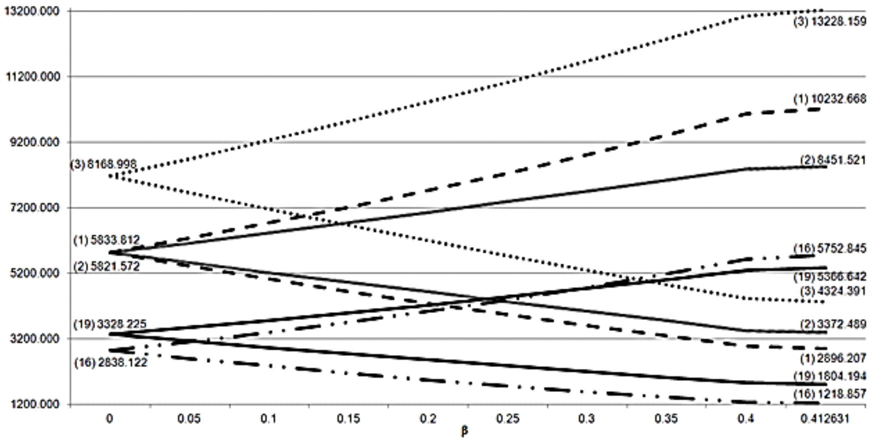

Figure 5. Bounds of the triangular fuzzy indicators of total water consumption[13].

3.4 Paper IV

Virtual water and input-output framework: an alternative method for assessing trade and water consumption in Macedonia

Paper IV investigated the direct and indirect relationships in water consumption by Macedonian economic sectors by means of the notion of virtual water in the context of an IO framework. The monetary transactions were translated into virtual water multipliers and used to analyze Macedonian commercial trade strategies in terms of Heckscher-Ohlin (HO) theory. The essence of this theory is that traded commodities are a bundle of factors (Leamer, 1995), and thus due to commercial trade such factors become mobile and provide service to regions where they are scarce. Macedonia as an abundantly endowed water region has a comparative advantage and should practice the paradigm of HO theory. However, such trade strategies, combined with the water-intensive production and the uneven spatial, temporal, and quality distribution of the resource and mismanagement, emphasize the water scarcity issue even more. Hence, virtual water multipliers were used to quantify the virtual water exports and imports. In general, the results showed that the trade balance in Macedonia in terms of virtual water was in line with the stated HO theory, *i.e.*, for the water-intensive sectors the exports exceeded the imports in terms of virtual water they make use of. As a consequence of the

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[13] The left hand side of the figure is the observed real value in input-output model, whereas the right hand side indicates the limits of the upper and lower bound of the triangle given the level of imprecision for which solution is observed.

significant exports and virtual water content of the agricultural sub-sectors (vegetable, fruit, grapes, as well as sheep and lamb products), and the food and basic metal products from the manufacturing group of sectors, Macedonia proved to be a net exporter of virtual water and lost around 124 million m^3 water at 2005 level or 18% of total water consumption. Such a trade strategy is definitely not sustainable in the long run given the water issues that the economic agents, especially the agricultural producers, are facing in their production.

The policy option of export reduction of the most water-intensive products with significant net exports as an alternative way of saving water would yield substantial water savings of about 291 million m^3 or 42.53% of total water consumption. If the exports were reduced, the trade balance and the Macedonian economy would shrink by only 3.26% from the total output in 2005. From an economic perspective this practise would be reasonable, because the economic returns would not decrease much compared with the environmental benefits. Although this policy analysis is rather hypothetical, these results may serve to help policy makers propose specialization in production enterprises with an environmental sustainability path.

By implementing the Dietzenbacher and Velazquez (2007) methodology[14], it was found that the most price-sensitive products, given a cost-push in the price of water, will be the sectors rice, fruit, grapes, other crops, cattle and sheep, by 31.98, 7.98, 12.5, 13.9, 8.91, and 9.77 %, respectively. Such sensitivity in the cost of agricultural production indicates that the water pricing policy to the agriculture sector, as the major consumer, may be used as a tool to promote water savings policies to enhance rational use of water.

3.5 Paper V

An exploratory analysis of the impact of climate change on Macedonian agriculture

Paper V again employed the augmented IO table used in Papers II and IV and investigated two approaches. First, from a supply side perspective by using the mixed input-output framework, it investigated the potential changes in output and in the water requirements at national level due to climate change. Second,

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[14] By setting the price of water per m^3 at same level with the other product prices, *i.e.,* one unit of output produced it is possible to identify how much the cost of production for a specific good is increased if the price for 1 m^3 is increases by one unit. Meaning, the price of the new product (*wi*) is calculated by dividing the virtual water multipliers (*vwmi*) divided by 1000, *i.e.,* $w_i = vwm_i/1000$.

from a demand side perspective it investigated the output and water use changes due to capital investment in reconstructing, maintaining, and improving irrigation systems in Macedonia. The analysis was performed using two different datasets on irrigated land, in order to make use of the two different values for irrigated area reported in the Agricultural Census (SSO, 2007a) and the 2011 Agricultural Annual Report (MAFWE, 2012). A broad range of studies have investigated the climate change impact as a significant feature of the national economy and agricultural production in Macedonia (Bergant, 2006; MOEPP, 2008b; World Bank, 2010; Callaway *et al.*, 2011; Sutton *et al.*, 2013). All of these came to the same conclusion, namely that climate change will negatively affect agricultural crop production, especially grape, tomato, apple, wheat, corn, and alfalfa production. Sutton *et al.* (2013) identified climate change impact scenarios with respect to aridity (low, medium, and high), *i.e.*, changes in temperature and precipitation. They combined these in an IO framework by using the output changes in the Mediterranean and Continental climate zones in Macedonia. On analyzing the exogenous shock of climate change effects from a supply side perspective, it was found that it mattered most for the agriculture sector in terms of yield reduction and the associated water requirements. It mattered especially for grape, fruit, cereal, and other crop production (the latter mainly dominated by forage). As can be seen from Table 7, in the most severe scenario, up to 47.38% reduction in grape production was possible even with the use of irrigation. In the medium and high impact scenarios, all crops were affected negatively both directly and indirectly. In contrast, in the low impact scenario the forage production sector benefited the most (38.12% change in output), by making use of the increased cropping period accompanied by moderate changes in temperature and precipitation. However, in all scenarios the indirect effect was not a major potential consideration for policy makers in creating adaptation measures to mitigate the climate change impact. According to the results, water consumption varies depending on the scenario, *i.e.*, increasing in the low impact scenario by 15.58 million m^3 and decreasing in the medium and high impact scenario by 21.27 and 41.17 million of m^3 water, respectively.

Table 7. *Output and water consumption variation in Macedonia under different future climate change scenarios*

2005			Output change (%)			Change in water consumption (million m^3)		
Sector	Output (million MKD)	Water use (million m^3)	Low	Medium	High	Low	Medium	High
Cereals	6 383	26.11	**-3.41**	**-10.65**	**-20.49**	**-1.25**	**-3.90**	**-7.50**
Rice	487	14.07	0.01	-0.11	-0.21	0.03	0.00	-0.06
Raw tobacco	4 159	11.27	0.00	0.00	0.00	0.00	0.00	0.00
Vegetables	17 016	41.98	**0.25**	**-1.34**	**-3.47**	**0.08**	**-0.40**	**-1.04**
Fruits	3 728	23.65	**0.33**	**-11.28**	**-16.34**	**0.05**	**-1.86**	**-2.70**
Grapes and wine	5 505	49.82	**-0.69**	**-26.49**	**-47.38**	**-0.36**	**-13.72**	**-24.55**
Other crops	3 318	43.73	**38.12**	**-2.22**	**-10.28**	**16.96**	**-0.98**	**-4.57**
Cattle	7 554	25.59	0.01	-0.05	-0.09	0.00	-0.01	-0.02
Pigs	2 696	5.02	0.00	-0.06	-0.10	0.00	0.00	0.00
Sheep/lamb	2 004	11.04	0.00	-0.03	-0.05	0.00	0.00	-0.01
Other livestock	2 811	2.81	0.00	-0.04	-0.08	0.00	0.00	0.00
Coke, refined petroleum	22 243	0.28	0.40	-1.16	-2.18	0.00	0.00	-0.01
Chemicals	5 785	4.71	0.03	-0.95	-1.78	0.00	-0.04	-0.08
Total						15.58	-21.27	-41.17

Note: Bold type indicates exogenous sectors in the mixed model approach.

The output and water consumption changes from the exogenous shock of climate change based on the Agricultural Census data (SSO, 2007a) across the scenarios followed the same pattern for all directly and indirectly affected sectors. The magnitude was different, of course, because of the higher proportion of irrigated land, which mitigated to a greater extent the negative impact of climate change, *i.e.*, with a less severe negative effect in the medium and high impact scenarios and a moderate increase in the low impact scenario. Therefore, this led to greater water use for all climate change scenarios compared with the 2005 case.

All previous studies that have investigated climate change effects in Macedonia have taken into consideration the water shortages for irrigated crops given the current water supply. As indicated in Section 1 of this thesis, the irrigation schemes in Macedonia are already old and insufficiently maintained and managed. If this trend continues until 2050, the projected impact might be even more severe. Thus, from a demand side perspective, the analysis of capital investment in irrigation equipment, *i.e.*, €204 million estimated at the 2005 level for building dams and reconstruction and development of new irrigation schemes, provided indications that cereal, grape, and forage producers will benefit the most from such a policy if the irrigated land maintains the same distribution. From Table 8 it can be seen that the output for these crops increased by a range of 52.57-77.11%. Concerning the indirect effect of such a demand-driven change, the same inference appears as in the supply-driven aspect: Investment in irrigation structure will utilize the full potential of irrigation systems, as well as ensuring a sufficient water flow followed by a reduction in the already significant water losses. However, although this will mitigate the effects of future climate change, at the same time it will impose an additional stress on the existing limited water resources of 97.52 million m^3 annually, which in the long run is not sustainable.

Table 8. *Direct and indirect impacts of capital investment in irrigation infrastructure in Macedonia*

	2005	
Sector	Output change (%)	Change in water consumption (million m^3)
Cereals	**52.57**	**13.73**
Rice	**77.11**	**10.85**
Raw tobacco	**18.93**	**2.13**
Vegetables	**9.96**	**4.18**
Fruits	**25.54**	**6.04**
Grapes and wine	**55.43**	**27.61**
Other crops	**70.14**	**30.67**
Cattle	0.25	0.06
Pigs	0.28	0.01
Sheep/lamb	0.14	0.02
Other livestock	0.21	0.01
Coke, refined petroleum	5.89	0.02
Chemicals	4.68	0.22
Total		97.52

Note: Bold type indicates exogenous sectors in the demand-driven approach.

The demand-driven analysis based on the Census information yielded the same configuration for the direct and indirect effects, with differences in the magnitude again due to discrepancies in the data. However, on aggregate level the water consumption was similar for the entire economy of Macedonia.

4 Concluding remarks

The aim of this thesis was to provide relevant information necessary to understand the role of water from an economic perspective regarding agricultural water demand and that of other sectors in Macedonia. The work provides an analysis of interactions between water use in agriculture and other sectors at the macroeconomic level by including different dimensions such as uncertainty and imprecision inherited in the data, climate change, virtual water, and commercial trade (Papers II-IV), as well as an overall indication of the growth in agricultural productivity at aggregated level which is necessary for adaptation of technological progress, especially in irrigation practices (Paper I). One of the most relevant aspects of this research is that it is the first attempt to quantify and investigate water relationships not just in Macedonia, but also in the wider region of the Western Balkans. The models used and findings presented can act as a basis for promoting and developing sustainable management of water resources at national and regional level. Irrespective of the limitations and assumptions associated with the IO model framework, it is still the most appropriate tool for such analysis, providing meaningful and reliable results. Therefore, several conclusions can be drawn from the work described in this thesis.

Paper I contributes to the overall picture of the agriculture sector by enabling a better understanding of the factors responsible for productivity growth. In the period 1998-2011, the Macedonian agriculture sector displayed a noticeable increase in output volume and productivity, with an average annual increase of 1.52% and 1.34%, respectively. The increase in volume for the whole period led to an economic surplus, which originated mostly from the productivity gains, but also from the government (subsidies and tax compliance) and paid labor. The sub-period 1999-2003 was not favorable, but production and productivity both distinctly improved in the following sub-period, 2004-2010. Family farms, which dominate the agriculture sector in

Macedonia, proved to be more resilient and consistent in terms of production and productivity growth over the study period, despite their small size and heterogeneous nature. The production and productivity levels in agricultural companies during the study period followed a decreasing trend. However, an important question is whether the resilience of the family farms and the less positive outcome for the agricultural companies will continue once these farms have to compete on a single EU market. Decision makers should shape their policy measures accordingly, increase support through national programs, and facilitate use of the Instrument for Pre-Accession Assistance for Rural Development (IPARD) with emphasis on agricultural investments, modernization, and improved competitiveness.

Paper II confirmed that the Macedonian economy is characterized by a water-intensive structure, mainly centered on agriculture and some other industrial sectors (other mining, food and beverages, and energy production). Agriculture confirmed its reputation of being a major water use sector, with around 38% of total consumption. More importantly, the indicators derived in Paper II allowed us to observe and draw a distinction between direct and indirect water consumption, with agricultural sub-sectors such as rice, fruit, and grape production accounting for a high proportion of direct water use. The highest levels of indirect water consumption were displayed by the cattle and sheep agricultural sub-sectors and by electrical equipment and electrical energy production in the manufacturing sector. Overall, the transaction coefficient matrix revealed that the indirect water consumption was largely driven by the mining and electrical energy sectors.

By making use of fuzzy modeling, Paper III achieved greater transparency in terms of aggregation and used data linked with the identification of the key water use sectors. This reduced the effects of uncertainty in the analysis, but the results still suggested that agriculture and some industrial sectors practice intensive exploitation of the water resources in Macedonia. However, special attention should nevertheless be given to data quality in Macedonia if the existing data are to be used in research activities necessary for the management of water. An aspect that policy makers should strongly focus on in the future is the development of detailed water accounts similar in spirit and scope to those published in *e.g.*, Australia. Sound policy decisions cannot be based solely on national average, and thus any future water accounts of Macedonia should present information on both physical and monetary supply and use of water flows in the Macedonian economy and the environment, but also take into consideration the yearly, seasonal, and spatial variation in terms of availability and use because sound policy decisions are not sufficient based on national averages (UN, 2012).

Paper IV provides a deeper analysis of the relationships between production processes and commercial trade in terms of virtual water at the disaggregated level. The findings reveal that in general, Macedonia follows the HO theory paradigm. More specifically, as a water abundant country, it has a comparative advantage in trade strategies, which is evident from its significant net exports by agricultural sub-sectors such as vegetables, fruits, grapes, and sheep and lamb production. Due to water-intensive consumption by these sectors followed by large exports, a significant amount of water exits the country. Even with imports taken into account, the country is still a net exporter of virtual water. If such intensive use domestically and the current export structure persist over the years, combined with the climate change effect and the evident scarcity issue over the summer months, there will be significant impact on the environment and on water availability. Thus, virtual water multipliers provide the opportunity to investigate and confirm how price-sensitive agricultural products are given a cost-push in water prices in order to promote sustainable water use. Applying the policy option of restricting exports as a policy for enhancement of rational use of water would result in a substantial reduction in water demand, but only small reduction in the trade balance. Thus, the environmental benefits in the long-run would exceed the economic losses.

Paper V shows that the exogenously defined direct effect of climate change can be expected to have varying impacts on agricultural output, but should not be considered a major concern for other sectors in the Macedonian economy. The varying direct effects on agricultural production in scenarios with different levels of climate change impact will also alter water consumption, since agriculture is the major water-consuming sector in the Macedonian economy. The policy shock of capital investment in development, reconstruction, and maintenance of irrigation infrastructure in order to fully exploit the potential for irrigation would support the necessary water consumption, considerably reduce water losses, and result in a substantial increase in the output of the agriculture sector, but also increase water demand quantity. Therefore, over the years there will most likely be an additional stress on the existing water resource due to intensive water consumption by the agriculture sector (Papers II and III).

Given these results, any increase in the production level or importance of the agriculture sector as a major water user, showing indicators of high direct water consumption, would impose significant pressure on the natural freshwater resources of Macedonia and the environment. Considering the projected impacts of climate change, this issue deserves even greater attention. It may be necessary to introduce changes in production technology, to promote a change in agricultural specialization in the country, or revise the existing water pricing policy based on comprehensive research. Water pricing in Macedonia was historically based on full cost pricing, but nowadays direct volumetric charges are also in use. However, installing water meters is not very popular among farmers because of the excessive installation costs and the fact that most farmers only operate very small holdings. Improvement of national water pricing schemes, in particular with regard to improving the low collection efficiency for water bills, must be embedded in a structural and institutional reform process. The establishment in the past of the Water User Associations (WUAs), a project financed by the World Bank, improved the cost recovery dramatically, but only for a short period of time due to the lack of trust in senior management and an inability to exclude non-payers. Hence, identification and implementation in the water management sector of organizational structures that are able to react in an appropriate manner to internal and external modifications is necessary. Before introduction of the WUAs the governance was centralized, but even when the governance was transferred locally to the associations there was still a marked lack of proper management. What may succeed in the future is a form of public-private partnership where the government remains responsible for the infrastructure and the WUAs are responsible for providing the water services. Such a strategy has already been applied with some success in some WB countries, but its success will ultimately depend on the local social capital and the willingness of the public-private management to provide detailed responsibilities and maximize transparency in their work.

The most realistic future policy option with a significant impact upon water consumption is capital investment in reconstruction and development of the existing irrigation systems in Macedonia, combined with technological improvement in irrigation practices. However, modern irrigation techniques such as drip irrigation require smaller distances between the supply networks, a constant supply, higher pressure in the distribution channels, and a sufficient quality of the water. Given that the water quality in Macedonia has already deteriorated, combined with the scarcity issue over the summer period when irrigation is most important, much needs to be done if efficient modern irrigation techniques are to be applied. In the final analysis, the reconstruction and development of irrigation schemes ought to be conducted according to farmers' demands and needs, because they are the final users who will benefit from the investments.

In conclusion, all the findings in this thesis will hopefully support decision makers in Macedonia to propose and design sustainable water consumption policies at national level, and implement more effectively the objectives of the National Water Strategy.

The findings also have important implications for other countries in the Western Balkans region, because of the transboundary nature of river basins. The actual results presented here are specific to Macedonia, but the models may be applied to any other WB country. The harmonization reforms toward EU accession have resulted in acquisition of a substantial amount of statistical data of satisfactory quality. Transfer of this knowledge to conduct similar studies at national level in the other WB countries can result in cooperative water management of transboundary basins and reduce potential conflicts arising from stakeholders within the region not managing the resource in a sustainable manner, leading to its depletion. The WB region has a history of conflicts, and the ecosocial features of water, the projected climate change impacts, the intensive consumption accompanied by resource mismanagement, and the increasing demand for food and water due to population growth could otherwise lead to new disputes in the future. Consumption-based accounting in a multi-regional IO model framework is an option that should be considered in the future. High availability of economic and environmental accounts of sufficient quality will be necessary for such modeling to be implemented on a wider scale.

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