Regional Economic Studies on Natural Resources and Their Economic Impact

By

Jinwon Bae

A Dissertation Submitted to the Faculty of the

SCHOOL OF GEOGRAPHY AND DEVELOPMENT

In Partial Fulfillment of the Requirements

For the Degree of

DOCTOR OF PHILOSOPHY
WITH A MAJOR IN GEOGRAPHY

In the Graduate College

THE UNIVERSITY OF ARIZONA

2017

THE UNIVERSITY OF ARIZONA
GRADUATE COLLEGE

As members of the Dissertation Committee, we certify that we have read the dissertation prepared by Jinwon Bae, titled “Regional Economic Studies on Natural Resources and Their Economic Impact” and recommend that it be accepted asfulfilling the dissertation requirement for the Degree of Doctor of Philosophy.

____ Date: 05/11/2017
Daoqin Tong

____ Date: 05/11/2017
Sandy Dall’erba

____ Date: 05/11/2017
David A. Plane

____ Date: 05/11/2017
George Frisvold

Final approval and acceptance of this dissertation is contingent upon the candidate’s submission of the final copies of the dissertation to the Graduate College.

I hereby certify that I have read this dissertation prepared under my direction and recommend that it be accepted as fulfilling the dissertation requirement.

____ Date: 05/11/2017
Dissertation Co-director: Daoqin Tong

____ Date: 05/11/2017
Dissertation Co-director: Sandy Dall’erba

STATEMENT BY AUTHOR

This dissertation has been submitted in partial fulfillment of the requirements for an advanced degree at the University of Arizona and is deposited in the University Library to be made available to borrowers under rules of the Library.

Brief quotations from this dissertation are allowable without special permission, provided that an accurate acknowledgement of the source is made. Requests for permission for extended quotation from or reproduction of this manuscript in whole or in part may be granted by the head of the major department or the Dean of the Graduate College when in his or her judgment the proposed use of the material is in the interests of scholarship. In all other instances, however, permission must be obtained from the author.

SIGNED: Jinwon Bae

ACKNOWLEDGEMENT

My gratefulness goes to many people that have encouraged me through the completion of my dissertation. I thank the brilliant, wonderful and dedicated cadre of professors, staff, colleagues of the School of Geography and Development at the University of Arizona. First and foremost my deepest gratitude goes to my academic advisor Prof. Sandy Dall'erba, for his support, guidance, understanding, and encouragement along the graduate school, even continued from Illinois remotely. Without his support and understanding, I would never have been able to finish my dissertation and reunite with my family. I thank him for providing me with sharp insight and expert perspective on the various topics and methodologies in regional science that I have benefitted enormously.

Tremendous thanks to my committee, Prof. David Plane, for his advice, expertise, and encouragement. I was so fortunate to serve him as a teaching assistant for 150B1 course, and inspired by his enthusiastic teaching and thoughtful advice. I am also wish to express my gratitude to Prof. Daoqin Tong who has provided me inevaluable support and feedback. My special thank goes to Prof. George Frisvold for admitting to serve on my committee and sharing me his intellectual knowledge on input-output and water management. I would also like to appreciate Prof. Francina Dominguez for her warmhearted encouragement, and guidance she provided me in my academic and personal life.

I want to express my gratitude to all my SGD friends, Dongwoo, Ran, Taehyun, Bokjin, Irving, Edna, Laurel, Carly, Yinan, Fang, Wangshu, Antonio, RJ, Casey, Niky, Laura, Sarah, Valente, Katherine, Bhuwan, Becky, Roy, Audra, Emma, Tom, Lily, and the list goes on.

I also send a huge thank you to my friends at University at Buffalo, Yoonhee, Susan, Weiyin, Jieun, Sonhyon, and Rosmary, as well as profs. Sara Metcalf and Joe Gardella who supported and guided me over the years I pursued my MA.

Finally, I could never have done this without the patience, love, understanding, and support of my husband, Kwangsu, and my daughter, Jia. Also I would like to thank all my family. Last of all, mom, I am so blessed to be your daughter.

DEDICATION

To my mother
for her love and devotion

To my husband, Kwangsu
who is my best friend and lifetime companion

To my daughter, Jia, my hope

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ABSTRACT

Various adaptation and mitigation strategies have been explored to cope with changes in the climate. Estimating these strategies impacts on the local economy is one of the growing and pressing issues for the management of natural resources. This thesis consists of three parts and aims to contribute to regional economic studies by analyzing: (1) the economic impact of solar energy facilities, (2) the level of virtual water flow and the effectiveness of scenarios to mitigate water resource shortage, and (3) the impact of climate change on agriculture through a Ricardian approach weighted by stream flow connectivity.

As an increasingly adopted renewable energy resource, solar power has a high potential for carbon emission reduction and economic development. In the first essay the impacts on jobs, income, and economic output of a new solar power plant are calculated in an input-output framework. The contribution is twofold. First, we compare the multipliers generated by the construction and operation/maintenance of a plant located in California with those that would pertain had it been built in Arizona. Second, we point out the differences in the results obtained with the popular IMPLAN software from those obtained with the solar photovoltaic model of JEDI.

The second essay focuses on water use in Arizona. As much as 73% of the state's scarce water is used by a single sector: crop production. Because 79% of Arizona's crop production is consumed outside the state, this means that, 67% of the water available in the state is being exported to the rest of the country and abroad. This should be of major concern for a state expected to see its population grow and its climate get drier. Using input-output techniques we explore three scenarios aimed at saving 19% of the water available. This

figure is based on the results of the first of the scenarios that explores how much can be saved through improving the efficiency of the current irrigation system. The second scenario shows that equivalent water savings could be reached by a twenty-seven-fold increase in the price of water. The third scenario shows that a 19.5% reduction in crop exports could conserve an equal amount of water. The model results suggest that the least costly solution is a more efficient irrigation system, while export reduction is the second best choice.

The third and final essay offers an extension of the well-known Ricardian model of agrarian economic rent. In spite of its popularity among studies of the impact of climate change on agriculture, there has been few attempts to examine the role of interregional spillovers in this framework. We remedy this gap by focusing on the spatial externalities of surface water flow used for irrigation purposes and demonstrate that farmland value—the usual dependent variable used in the Ricardian framework—is a function of the climate variables experienced locally and in upstream locations. This novel approach is tested empirically on a spatial panel model estimated across the counties of the Southwest USA for every five-year period from 1997 to 2012. This region is one of the driest in the country, hence its agriculture relies heavily on irrigation with the preponderance of the sources being surface water transported over long distances. The results highlight the significant role of irrigation spillovers and indicate that the actual impact of climate change on agriculture and subsequent adaptation policies can no longer overlook the streamflow network.

Chapter 1

INTRODUCTION

Accelerating climate change poses many risks on global and local economies including significant threats to ongoing agricultural productivity and current practices of managing natural resources. As proven in many previous studies, climate change is accompanied by more extreme events, such as floods (Kay et al., 2009; Kirshen et al., 2008; Kundzewicz et al., 2010; Madeley, 2007; Olsen, 2006; Wuebbles et al., 2013), storms (Knutson et al., 2013), droughts (Fu et al., 2012; Swain et al., 2014). These changes may be particularly harmful to some parts of the country. My work has mostly focused on Arizona and the US Southwest, as this is the driest and hottest region in the country. It is also a region facing ever higher demands for energy and water resources because of rapid population growth. Arizona's population has increased from 1.3 million in 1960 to 6.7 million today. Thus, Arizona and the Southwest constitute an interesting study area for exploring the impacts of climate change and for developing strategies to cope with a changing environment at a regional level. In general, strategies for dealing with climate change can be categorized into two groups: adaptation to reduce vulnerability (IPCC, 2014b) and mitigation to reduce greenhouse gas emission (IPCC, 2014a). This study performs an economic impact analysis that includes both adaptation and mitigation strategies through three topics related to natural resources in the US Southwest: (1) solar energy, (2) virtual water, and (3) the spatial externalities of stream flow.

One of the primary mitigation strategies has been an effort to promote the use of low-carbon energy resources (Storms et al., 2013) particularly at the municipal level in the US, with some proactive adaptation to support long term investment in energy supply (IPCC, 2014b). Progress in fighting climate change inevitably involves the shift to renewable energy sources because the energy supply sector is responsible for almost half (47%) of the increase in GHG emissions between 2000 and 2010 (IPCC, 2013). Beyond the environmental benefits they generate, the notable advantage of renewable energy sources is their socio-economic benefits on local economies. Most of the studies of the shirt to renewable energy have applied to European countries (Hillebrand et al., 2006; Lehr et al., 2008; Tourkolias & Mirasgedis, 2011; De Arce et al., 2012; Lambert & Silva, 2012; Lehr et al., 2012; Markaki et al., 2013), but there also has been an increasing body of research on renewable energy in the US (Huntington, 2009; Pollin et al., 2009; Carley et al., 2011, 2012). The measure of economic impact used here relies on the input-output (I/O) framework, which is capable of providing figures on overall job creation, income, and output in each economic category.

Among the various renewable energy sources, solar energy is seen as a major source to lead this trend. Its growing success is due, in part, to recent technical progress that has lowered the average price of solar silicon photovoltaic modules (IPCC, 2014). However, only a handful of economic impact analyses of solar energy have been conducted in the US (Schwer & Riddle, 2004; Frisvold et al., 2009; Evans & James, 2011; Hamilton & Berkman, 2011), with most of them focusing on the Southwest region: Arizona (Frisvold et al., 2009; Evans & James, 2011), California (Hamilton & Berkman, 2011), and Nevada (Schwer & Riddle, 2004). Arizona and California provide a good platform to measure these factors and for comparing the results obtained through the two main modeling packages: JEDI (Job and Economic Development Impact model) and IMPLAN (IMpact analysis for PLANning). Topaz Solar Farm (TSF), with a 550MW capacity, is the world's largest utility-scale solar farm. It was built in California over the period from November 2011 to November 2013 (Hamilton & Berkman, 2011). For the current study, it is assumed that the same solar farm (with a capacity of 550MW) is constructed in Arizona as a benchmark of the TSF case. It is thereby possible to analyze comparative advantage in the two regions through the economic multipliers generated by each JEDI and IMPLAN model.

Secondly, under severe climate conditions, agriculture can be viewed as the most vulnerable sector because it is highly water-elastic for production and thus extremely sensitive to the variation of temperature and precipitation. Arizona's local economies are particularly vulnerable because of its rapid population growth since 1950, desert environment and scarce water resources (Garfin et al., 2013; Dall'erba and Dominguez, 2016). Arizona has primarily relied on the Colorado River to meet its water demands, but the so-called Colorado River Crisis due to 'high demand and low supply' imposes more water risk for Arizona. To mitigate water stress in Arizona, we focus on a leakage of virtual water as embodied in crop exports. The problem emerges from crop production engulfing 75% of the water demand of the state (IMPLAN, 2010; USGS, 2010) but in-state consumption accounting for only 30% of the crops produced (IMPLAN, 2010). Allan used the term "virtual water" (1993, 1994) to refer to the water-intensive oranges and avocados that were being exported from water scarce regions in Israel (Fishelson, 1994). As such, Israel (Yegnes-Botzer, 2001) and Egypt (Wichelns, 2001) became leading case studies on the virtual water flow concept. The virtual water studies were further developed for studies conducted in Europe (Dietzenbacher and Velázquez, 2007; Van Hofwegen, 2004; Velázquez, 2006; Yu et al., 2010). There are increasing number of virtual water flow studies among the Chinese regions since the 2000s (Guan and Hubacek, 2007; Han et al., 2014; Wang and

Wang, 2009; Wang et al., 2013; Zhang et al., 2011). The concept has proven useful for studying an aspect of the recent drastic regional imbalance between the North and the South of China. Especially among the Chinese regions, Beijing has experienced a rapid population growth and urban sprawl that has resulted in water scarcity, so Beijing has become one of the most popular regions for conducting virtual water flow studies (Wang and Wang 2009; Zhang, Yang and Shi, 2011b; Wang et al., 2013; Han et al., 2014).

In the US, the similar concept with virtual water was explained as “An economy’s water-trade position” (Finster, 1971) that calculates the water trade balance embodied in the production of economic good exported and imported in Arizona. However, Finster’s study did not get much attention because he focused more on demand-oriented water policy and the virtual water discourse remained centered in Europe. Recently, the virtual water metaphor has been expanded to focus on agriculture and food security in the US, but only a handful of studies have, thus far, been published (Dang et al., 2015; Marston et al., 2015; Mubako et al., 2013). The findings of virtual water flow studies highlight two important facts. First, irrational patterns of virtual water flows, by which a water-scarce region is a net exporter of virtual water, are not uncommon (Finster, 1971; Dietzenbacher and Velazquez, 2007; Guan and Hubacek, 2007). We call such patterns “irrational” because they go against the fundamental Heckscher-Ohlin principles of economic trade theory according to which a place should specialize in and export goods of which production factors are locally abundant. Second, once all the rounds of transactions necessary for the production of a commodity have been accounted for, agriculture is always found to consume a greater amount of water than either the industry or the services sectors (Velázquez, 2006; Zhang et al., 2011; Zhao et al., 2010). Naturally, all such studies advocate for an improvement in the water use efficiency in agriculture.

Finster (1971) calculated a net export water-trade of 2.24 million acre-feet between Arizona and the rest of the US on the basis of its 1958 economic structure. His analysis, however, did not specify which industrial sectors were responsible for the imbalance while we will explicitly identify them in our analysis. In Chapter 3, we aim to examine two objectives. First, we elaborate the virtual water trade patterns of Arizona with respect to the US, by estimating virtual water multipliers and net trade balance for five aggregated economic sectors. Second, several mitigation scenarios, (1) water price increase, (2) irrigation system change, and (3) reduction of crop exports are proposed, and their impacts on the local economy measured.

Thirdly, there have been numerous efforts to assess the impact of climate change on agriculture in a Ricardian framework (Schlenker et al., 2005, 2006; Deschênes and Greenstone, 2007; Dall'erba and Dominguez, 2016). (Mendelsohn et al., 1994) provided the framework to account for farmers' adaptation to climate change via shifting cropping pattern and irrigation technology. This idea is indirectly supported by other studies (Miao et al., 2016; Schimmelpfennig et al., 1996). Furthermore, more enhanced Ricardian models include various sources of spatial dependence, such as the ecological fallacy (Ezcuerra et al., 2008), communication between farmers (Polsky 2004; Munshi 2004; Kumar 2011), technology and investment spillovers (McCunn and Huffman 2000; Chatzopoulos and Lippert 2016), the water cycle (Dall'erba and Dominguez, 2016) and trade (Chen and Dall'erba, 2016). In Chapter 4, we incorporate another type of spatial externality, namely, surface water flows. The use of irrigation is one of the widely recognized strategies to compensate for the lack of local water sources and variability (Easterling, 1996; Tang et al., 2014; van der Velde et al., 2010). Securing a source of water for irrigation is more difficult in a semi-arid region (Frederick, 1991), so western counties are more irrigated than midwestern and eastern counties in the US (Grassini et al., 2009). Moreover, one should expect the share of irrigated water will increase due to increasingly irregular rainfalls as the climate gets hotter and dryer (Frederick and Major, 1997).

Some previous Ricardian studies reveal that if spillover effects are present and ignored, biased and inconsistent estimates result (Anselin, 1988; Le Sage and Pace, 2009). By accounting for stream flow externalities, this study aims to provide more accurate estimates and minimize the traditional standard errors. Although a growing number of spatial econometric studies with a Ricardian approach account for interregional spillovers (Polsky, 2004; Seo, 2008; Lippert et al., 2009; Schlenker et al., 2006), their spatial covariance matrix are based on Euclidean distance, which may not correctly reflect the spatial configuration, connectivity, and directionality of interregional dependence (Peterson et al., 2007). Several spatial econometric papers account for the idea of connectivity and directionality (Eliste and Fredriksson, 2004; Chen and Haynes, 2014; Kang and Dall'erba, 2015), but none has ever used the dendritic nature of the streamflow network.

In this sense, our spatial econometric study makes a main contribution that we build a novel spatial weight matrix that represents the identification, volume, distance, and directionality of the stream network in the Southwest region of the US. We follow the assumption that the climate condition in upstream places will affect the downstream places (Dall'erba and Dominguez, 2016) and elaborate the measurement of the upstream influence using the STARS (Spatial tools for the Analysis of River Systems) toolset in ArcGIS

(Peterson and Ver Hoef, 2014; Peterson; et al., 2013; Ver Hoef et al., 2006). Thus, our approach tends to provide new insights on the magnitude and precision level of the marginal effects of the climate variables usually used in the Ricardian literature. Further, we generate new estimates on the impact of climate conditions on agriculture, and we propose comprehensive adaptation strategies for flow-connected counties.

Given the aforementioned background, the remainder of this dissertation consists of three essays. Following three essays focus on exploring regional economic methodologies and tools to measure how the use of natural resources impact on local economy in the US southwest region.

The following chapter contains the first essay which examines the economic impact of solar farm installation in two different locations: Arizona and California. Beyond the deployment goal that 25% of electricity should be supplied from renewable energy source in Arizona, we measure how much of economic impact on local economy a 550MW solar farm could have using input-output analysis. Also, the differences in results generated by IMPLAN and JEDI photovoltaic models are compared. The next chapter traces the virtual water flow in Arizona with respect to the US and the rest of the world using input-output analysis. Furthermore, we also test three scenarios to attain a 19% of water saving in Arizona, and the most plausible scenario is suggested. The forth chapter provide an extension of Ricardian model of land profit throughout the US southwest. We develop a spatial panel model to explore the impact of climate change on agriculture, by capturing the role of interregional spillovers focusing on the spatial externalities of surface water flow. The final chapter summarizes the results and findings of the studies.

CHAPTER 2

THE ECONOMIC IMPACT OF A NEW SOLAR POWER PLANT IN ARIZONA: COMPARING THE INPUT-OUTPUT RESULTS GENERATED BY JEDI VS IMPLAN[1]

2.1 Introduction

Solar energy is increasingly seen as a major source of carbon emission and water consumption reduction and its potential on human health and air quality has already been demonstrated (Hernandez et al., 2014). Part of its growing success is technological progress that has allowed the average price of solar silicon photovoltaic modules to drastically decrease from 65 USD/Watt in 1976 to 1.4USD/Watt in 2010 (IPCC, 2014). The United States has arguably been a major player in this trend. As one of the largest emitters of greenhouse gas[2], the US has promoted the deployment of low-carbon energy resources over the most recent decades (Storms et al., 2013). For instance, more than 3.1 Gigawatts (GWs) of solar electricity generation facilities were installed in the US in 2012 (Lacey et al., 2013). It elevated the accumulated amount of solar photovoltaic facilities from 0.7% of the total renewable sources in the US in 2012 to 1.6% in 2013 (EIA 2013). These efforts are necessary to reduce greenhouse gas (GHG) emissions because the energy supply sector was responsible for almost a half (47%) of the increase in GHG emissions between 2000 and 2010, while the manufacturing sector produced around 30% of them (IPCC, 2014).

[1] This chapter is published as: Bae J. and Dall'erba S. (2016) The Economic Impact of a New Solar Power Plant in Arizona: Comparing the input-output Results generated by JEDI vs. IMPLAN, *Regional Science Policy and Practice*, 8, 1-2, 61-73.

[2] 6,135.03 $MtCO_2$ (i.e. 13.5% of the world's total) were emitted by the U.S. in 2011. It is the largest emitter after China (10,260.32 $MtCO_2$). However, in per capita terms, China produces 7.63 while the US produces 19.69 (WRI 2014).

Beyond the environmental benefits they generate, new solar power plants can also be seen as a facility of which construction and operation will stimulate the local economy. There is an increasing number of studies that compare the socio-economic impacts of multiple renewable energy sources (Hillebrand et al., 2006; Lehr et al. 2008; Huntington, 2009; Pollin et al., 2009; Carley et al., 2011, 2012; Tourkolias & Mirasgedis, 2011; De Arce et al., 2012; Lambert & Silva, 2012; Lehr et al., 2012; Markaki et al., 2013) including solar energy. Most of the latter studies are conducted in European countries, but increasing interest for renewable energy in the US has led to several contributions in this country too over the last few years (Huntington, 2009; Pollin et al., 2009; Carley et al., 2011, 2012). They conclude that, on average and depending on the energy source, the construction and operation of a renewable energy facility create between 5.65 and 17.4 jobs/$1 million of investment. According to Pollin et al. (2009) and Singh and Fehrs (2001), these figures are larger than the job creation expected from oil, natural gas and coal powered energy plants. However, it also means that traditional power plants produce energy at a cost per watt that is between 5-8 times lower than green energy plants and that the subsidies that support the latter could have stimulated job creation more efficiently elsewhere (Huntington, 2009). While measuring these types of externalities, including those that benefit the environment, are beyond the scope of this paper, the input-output framework we rely on provides us with a good understanding of the job creation that follow new investments in solar powered energy production.

As a leading source of renewable energy, solar energy has led to a handful of economic impact analyses in the US (Schwer & Riddle, 2004; Frisvold et al. 2009; Evans & James, 2011; Hamilton & Berkman, 2011) as well as outside of the US (Cladés et al., 2009;

Del Sol and Sauma, 2013). Among the US-focused studies, all the applications are performed on either Nevada (Schwer & Riddle, 2004), California (Hamilton & Berkman, 2011) or Arizona (Frisvold et al., 2009; Evans & James, 2011) due to the large number of sunny days they experience each year.

The latter two states are the focus of this paper. Arizona ranks second only to California in terms of solar energy generating potential in the country. Most areas in the state record more than 6.0 kwh/m2/day of solar radiation which is among the highest levels in the nation (NREL, 2011). Yet, many feel the solar potential of the state has been barely tapped. The solar electric capacity of Arizona was 1.8% of the state's total electric capacity in 2013 (Frisvold et al., 2009) and represents a cumulative capacity of 1093.5 MWs (Megawatts) according to (Lacey et al., 2013). In addition, in 2003 Arizona's state legislature set the goal that 15% of its electricity would come from renewable sources by 2025 (EIA, 2013) and at least 30% of them should come from distributed generation (DSIRE, 2014). Furthermore, up to 70% of the distributed generation could come from utility scale generation. This would represent a shift from Arizona's main current energy sources: coal (26.8%), petroleum (29.1%) and nuclear (19.0%) according to Brug (2013).

In order to examine further what would the economic impact of a new solar power plant in Arizona be, this paper provides an input-output (I/O) analysis applied to the characteristics of the Topaz Solar Farm, a 550MW facility built in California over Nov.2011-Nov.2013 and running at full capacity since then[3]. It is an interesting case study in that it is the world's largest solar farm and its utility scale generation is expected to grow more than

[3] According to EIA, Topaz Solar Farm has been generating utility scale electricity since Feb. 2013 (239 MWh of net generation) and the annual net generation was 1,053,373 MWh in 2014 (EIA, 2015 b), which corresponds to 121.9 MW. This amount is exactly 22.1% of 550MW installation and matches with the average annual system capacity of utility scale in Table 1.

commercial and residential solar panels. Indeed, it can improve cell grid reliability and stability and it already provides a predictable and affordable source of energy to utility customers (FirstSolar, 2014). According to Tucson Electric Power (TEP), the current unit cost per utility scale systems is as low as one-third of rooftop systems (Hughes, 2013).

In this paper, our analysis calculates the jobs, income and output multipliers that would be generated by a similar farm installed in Arizona and compares them with those that were generated in California, in the counties of San Luis Obispo and Kern that host it, according to the impact study produced by Hamilton (2011). This approach allows us to identify which of the two regions has a competitive advantage in terms of economic multipliers. Furthermore, the 550 MW case analyzed here can be seen as a benchmark against which the impact of future Arizona solar farms can be estimated. The second objective of this paper is to compare the returns generated by two different input-output software. The first one is IMPLAN (IMpact analysis for PLANning), the leading model for economic impact analysis, and the second one is JEDI (Job and Economic Development Impact model), a free and more recent model developed by NREL for the sole purpose of measuring the economic impact of power generation and biofuel plants.

The rest of this paper is structured as follows: the next section provides a review of the input-output literature applied to solar power generation as well as a description of the differences in the two software used for the analysis. Section 3 reports the details of the investments associated to the Topaz Solar Farm for both the construction and the operation/maintenance phases as they are used as final demand change in the I/O model that comes in Section 2.4. This section shows the direct, indirect and induced effects that result from such investments in California and in Arizona according to both JEDI and IMPLAN.

The effects are measured on job creation, labor income and output change. While the results the two software generate are comparable, some discrepancies are found and explained in this section. Finally, section 5 sums up the results and provides some concluding remarks.

2.2 Literature Review and Basics of JEDI vs. IMPLAN

2.2.1 Input-output applied to solar energy production

Pioneered by Leontief in the late 1930s, input-output analysis examines the effects of a change in final demand on the local economy. It relies on input-output tables that capture the market transactions between the selling sectors (the providers) and the purchasing sectors or final demand (the consumers). One of the advantages of input-output analysis is that it offers the capacity to measure overall changes to the economy due to intersectoral (supply and purchase) linkages (Miller and Blair, 2009), so that increasing demand for solar power in a locality will lead to changes in demand in a large number of additional sectors which are not necessarily directly related to electricity production. More precisely, a new solar farm creates a direct impact in the construction sector (for the foundation, erection, electrical system of the project) and in the services sector (for the permits, insurance) among others. It leads to an indirect impact when the latter sectors purchase inputs, such as concrete and electric wires, necessary to support their own activity. It also leads to an induced impact when the increased earnings generated in the previous sectors are spent on local goods and services, such as food and education. In an I/O framework, the sum of the direct, indirect and induced impacts constitutes the economic multipliers.

Based on this comprehensive framework, input-output analysis has been widely used to measure the economic impact of various renewable energy sources and compare their relative return. Their overall conclusion is that solar photovoltaics (PV) production provides larger returns than other renewable energy sources per unit of production but not per dollar of investment. For instance, Huntington (2009) finds that each MW of PV is between 4 and 11 times more effective than a MW of wind, biomass and natural gas at creating jobs in the US. However, wind and biomass are more effective than PV when measured in dollar amount of initial investment due to their lesser capital cost. Other studies do not provide both types of relative returns but confirm this difference. For instance, Tourkolias and Mirasgedis (Hillebrand et al., 2006; Tourkolias and Mirasgedis, 2011) use an integrated approach to quantify the employment benefits of renewable energy resources in the Greek economy in 2005. They find that it created an average of 265 job years/TWh for geothermal during 35 years of lifetime, and 1503 job years/TWh for solar photovoltaics (PV) during 20 years of lifetime. Moreno and Lopez (2008) conclude that in Spain the average job creation per MW installed is 37.3 for solar PV, 31 for biogas, 20 for hydro, and 13.2 for wind. On the other hand, Pollin et al. (2009) find that every $1 million of investment in biomass energy production creates more jobs (17.4) than investments in solar (13.7) or wind (13.3) in the US, thus confirming Huntington's (2009) ranking based on cost.

Previous studies compare the returns of different renewable energy sources because they rely on facilities located anywhere within a country and provide national-level impact estimates. However, we focus in this paper on one type of facility only and it is located in a specific region. The literature offers several regional I/O models applied to renewable energy sources. Among the ones that focus on solar energy, we find Schwer and Riddle (2004) who study the impact of a 100 megawatt (MW) Concentrating Solar Power (CSP) plant in Nevada. They report an employment multiplier of 2.9 during the 2004-2006 construction phase (817 direct jobs and 2,387 total jobs per year). They find a slightly larger employment multiplier equal to 3.1 over the 2007-2035 O/M phase (45 direct jobs and 140 total jobs per year). Their work relies on the REMI model, a multivariate, multi-equation model of the Nevada economy developed by the Regional Economic Models Inc.

Hamilton and Berkman (Hamilton and Berkman, 2011) start their input-output analysis by aggregating IMPLAN's 440 economic sectors to a scheme that matches JEDI solar PV model. Their model is applied to a solar farm in California and constitutes the benchmark against which our results on Arizona will be compared. More details about their work appear in the next section. Another example is Frisvold et al. (2009) who analyze the economic impact of the solar market growth in Arizona. The state legislature is committed to have solar generation gradually increase from 32,300 MWh in 2010 to 9,544,100 MWh in 2030. In their work, estimates on the future cost of energy, annual cash flow of solar technologies, capital cost, payback and net present value are generated by Sandia National Laboratory in collaboration with NREL. Based on this information, they use IMPLAN to quantify that opening the needed solar power plants should have large economic and environmental benefits for the state: the cumulative amount of new jobs is 277,759 during the construction period and 1,198 for the O/M period corresponding to an employment multiplier of 1.95 and 1.48 respectively.

2.2.2 JEDI vs. IMPLAN

IMPLAN is one of the most-widely used tools for input-output analysis. It provides an extensive, annually-updated data set dating back to 1977 (LLC, 2013). IMPLAN provides a complete commodity tracking using proprietary gravity model which estimates the intersectoral trade linkages and regional purchase coefficients (LLC, 2013). The version of IMPLAN we rely on in this paper is 3.0 and the transactions among the 440 industrial sectors it encompasses are measured in 2010. In contrast, JEDI is a free software that has been specifically designed by the National Renewable Energy Laboratory (NREL) for analyzing the economic impact of new renewable energy facilities. It allows the user to develop a model for 9 types of renewable energy sources: Wind, Biofuels, Solar, Natural Gas, Coal, Marine/hydrokinetic Power, Geothermal, Petroleum and Transmission Line Model. The solar model of interest to us allows the user to distribute the electricity generated by residential, commercial and utility consumers. Additional choices include the concentrated solar panel trough, the project photovoltaics and the scenario photovoltaics (PV) in addition to user-input on the solar cell/module material, the average system size, and the specified installation costs per materials and equipment vs. labor. Furthermore, JEDI offers the possibility to separate the impact generated by the construction phase from that due to the O/M phase.

The multipliers that JEDI generate are calculated at the state level[4] and rely on IMPLAN's input-output tables. However, JEDI claims that the direct input coefficients have been modified to reflect the actual intersectoral purchases made by the renewable energy sectors. These are derived from extensive interviews JEDI has conducted with industry experts and professionals alike (NREL, 2013). Another example of the degree of proficiency of JEDI is that the system capacity is automatically set to a value between 18.9-22.1% of its full-time capacity to reflect that solar power plants do not produce electricity at night and under certain weather conditions, or shut down for maintenance. By comparison, a coal power plant generally operates 80% of the time (Wei et al., 2010). Table 2.1 below reports

[4] Analysis of a specific region other than the state level can be only performed through the "User Add-in Location" feature in JEDI that requires inputting local multipliers and other necessary information.

some of the attributes of JEDI these interviews and experience with the renewable energy sectors have led to. JEDI still offers the users the capacity to modify the default values below, but we decide to keep them in this study. In contrast, IMPLAN does not have a sector that is specifically for power plants, so that the "construction" sector (NAICS 34-38) and the "maintenance" sector (NAICS 39) are the ones that will be used in the rest of the analysis by IMPLAN.

Table 2.1 Defaults in JEDI solar PV by energy use

	residential retrofit	residential new construction	small commercial	large commercial	Utility
Average annual system capacity factor (percentage):	18.9%	18.9%	18.9%	20.4%	22.1%
Average system size– Direct Current Nameplate Capacity (kW)	5.7	3.5	20	150	1000
Annual direct O/M cost ($/kW)	< $25.22	< $25.22	< $20.25	< $18.34	< $17.84

It is important to note that, in spite of its many useful features, JEDI presents the same shortcomings as any other input-output model such as the lack of consideration for "technological improvements, import substitution, changes in consumption patterns, or relative price variations over time" (Lambert and Silva, 2012, p.4668)

2.3 Topaz Solar Farm, our 550 MW Case study

In the absence of data specific to an existing or planned solar plant in Arizona, this study uses the features of the Topaz Solar Farm (TSF) that was built in 2013 in San Luis Obispo County, California. It was constructed for 3500 acres of utility-scale solar farming with a proposed photovoltaic capacity of 550 MW. It provides power for 160,000 average homes and meets 65% of the 1.7GWh of energy annually consumed in San Luis Obispo County. The cost of the plant is as follows: $175 million are spent during the three years of the construction period (2011-2013) whereas $2.475 million are expected to be spent annually during the next 25 years for the plant's operation and maintenance ($61.875 million in total). All costs are for labor, materials and supplies. In addition, it is assumed during the operating period that the spending on material and supplies is 10% of the spending on labor. Another assumption is that the modules/inverters are imported from outside the county. All the above figures are in 2011 dollar value and a discount rate of 2% is used to actualize future revenues. The economic impact analysis of TSF that we use as a benchmark in this paper was performed by Hamilton and Berkman (2011) using IMPLAN v3. The impact they calculate takes place over two neighboring counties, San Luis Obispo and Kern county, that constitute the area where the solar energy is sold and from which the workers are drawn. The model assumes that at least 60% of the money is spent in the former county.

The impacts and multipliers estimated by Hamilton and Berkman (2011) will be discussed throughout the rest of this paper and will be compared with the impacts of a similar investment in the state of Arizona. However, several adjustments are necessary to apply the figures of TSF to JEDI. First, all the dollar values are expressed in 2012 because it is the first year for which the IO model can run in our version of JEDI. They appear in table 2.2 below. The 3-year construction period is thus 2012-2014 and the following 25 years of O/M cover 2015-2039. Since both IMPLAN and the JEDI solar PV model can estimate returns until 2030 only (i.e. 16 years of O/M) we extend the O/M period by adopting an annual depreciation rate of 1.257% for 2030-2039. It corresponds to the rate observed over the last three years (2027-2030). In that situation, the spending for O/M increases from $39.6 million to $61.875 million in 2012 dollar. Finally, just like in the TSF case, we assume that the modules and inverter are not locally purchased while 100% of the mounting and the electrical components are manufactured and purchased locally. In the absence of better information[5], this assumption allows us to compare the results across all four models. Many studies have used a similar approach (Frisvold et al., 2009; Hamilton & Berkman, 2011; Tourkolias and Mirasgedis, 2011) which assumes the maximum economic impact for the locality. In our case, the choice is driven by the settings of TSF IMPLAN and our desire to make the figures generated by JEDI and for Arizona comparable. Calculation of the right LPCs for Arizona is left for future research.

Table 2.2 Fiscal Inputs from the Topaz Solar Farm case

Category		Materials & Supplies		Labor	Locally purchased percentage	Total
Economic sector		Fabricated Metals	Electrical Equipment			
Annual	Construction	1,458,333	1,458,333	55,416,666	100%	58,333,333
	O/M	112,500	112,500	2,250,000	100%	2,475,000
Total	Construction (3 years)	4,375,000	4,375,000	166,250,000	100%	175,000,000
	O/M (25 years)	2,812,500	2,812,500	56,250,000	100%	61,875,000
	Total	7,187,500	7,187,500	222,500,000	100%	236,875,000

While the dollar amounts that correspond to the construction of this solar power plant are the same whether one uses JEDI or IMPLAN, there are some important differences in the way some input data are set across software. In JEDI, we assume that the entirety of the energy produced will be sold to the utility market sector, which is consistent with the TSF case. A share or the totality of other market sectors could be selected but this would depart

[5] IMPLAN does not have a sector for each of the above four components. Instead, the local purchase percentages (LPC) of fabricated metals and electrical equipment are 26.54% and 7.70% respectively based on the SAM model values found in the Arizona 2010 IMPLAN dataset during the whole period of construction and O/M.

our measurements from the benchmark. In addition, a choice between thin film and crystalline silicon needs to be made with regards to the type of solar cell/module material. IMPLAN disregards these options. By default the cost of the installed system declines at an annual rate of 0.928% while the cost of O/M declines at a rate of 0.954 in JEDI's solar PV model. These values are based on NREL's interactions with the US Department of Energy, Photon consulting, the Lawrence National Laboratory and various companies in the renewable energy sector. As for the input costs, JEDI offers a preset allocation by expenditure type that we adjust to reflect TSF's scenario. More precisely, we allocate 10% of the labor cost to mounting and electrical equipment each year. By default JEDI allocates 27.7% of the total costs to the category "other costs" which encompasses permitting (1.7%), business overhead (20.6%) and other miscellaneous costs (5.4%). Changing these inputs manually affects the role of 'professional services' and 'other services' in the final economic impact. Therefore, we modify the allocation of the installation costs to match our case study and keep the default value of 'other costs' in JEDI. Then the rest (72.3%) is allocated for labor (68.7%), mounting (1.8%), and electrical equipment (1.8%)

In order to guarantee the primary data in IMPLAN match the ones of JEDI, we aggregate the economic sectors of IMPLAN based on the sectoral scheme used by NREL (2008) for the solar industry so that construction, electric services and the manufacturing sectors are subdivided into detailed sectors whereas other sectors are aggregated at a higher level in JEDI. As a result, the 440 industries of IMPLAN are aggregated into the following 22 sectors: 1) Agriculture, Forestry, Fish & Hunting, 2) Mining, 3) Construction, 4) Construction/Installations - Non Residential, 5) Construction/Installation Residential, 6) Manufacturing, 7) Fabricated Metals, 8) Machinery, 9) Electrical Equip, 10) Battery

Manufacturing, 11) Energy Wire Manufacturing, 12) Wholesale Trade, 13) Retail trade, 14) TCPU, 15) Insurance and Real Estate, 16) Finance, 17) Other Professional Services, 18) Office Services, 19) Architectural and Engineering Services, 20) Other services, 21) Government, and 22) Semiconductor (solar cell/module) manufacturing. Note that the "Electric power generation, solar" sector, which is associated with O/M of a solar farm belongs to "Other services" (sector 20) according to the North American Industry Classification System (NAICS) classification (see Appendix A1). Although there is a one-one match in *the name* of the sectors, JEDI's direct input coefficients have been adjusted from IMPLAN's in order to reflect the greater experience/knowledge it has developed with the energy sectors.

2.4 Results

Table 2.3 reports the results of the four models under study: 1) those calculated for TSF by Hamilton and Berkman (2010) with IMPLAN; 2) those we generate for California with the JEDI model; while 3) and 4) are the results we obtain for Arizona based on IMPLAN and JEDI respectively. Our calculations indicate, first, that all four cases lead to roughly the same number of total jobs and total output created by the end of the project. The total number of job years created ranges from 11.56 to 11.84 per $ million of investment. These results are slightly lower than those found in Pollin et al.'s (13.7), but higher than those of Huntington (7.80 for 20% capacity and 11.12 for 80% capacity). In this paper, we rely on an annual capacity of 22.1% in the JEDI models, which is the default value for utility scale.

All models indicate also that more than 80% of the job years created take place during the construction period[6]. The total outputs are estimated to be $1.76-1.78 million in California and $1.54-1.57 million in Arizona for every $1 million of spending. Overall, the installation of a solar farm in Arizona would create less labor income and output than in California with the bulk of the difference coming from the construction phase. The largest source of the difference between JEDI and IMPLAN can be seen in the changes in labor income. JEDI calculates a lower direct impact in both the CA and AZ cases. This difference propagates to the indirect and induced effects, although in Arizona they are relatively greater in IMPLAN than in JEDI per unit of direct effect. As a result, the overall income created is nearly twice as large in JEDI than in IMPLAN. The difference could come from JEDI allocating 27.7% of spending to high value-added activities such as permitting, business overhead and "other services" by default. In contrast, IMPLAN does not reveal the direct input coefficients allocated to any of the previous three activities. Another source of the difference with the benchmark is that labor in the direct sectors is cheaper in Arizona than in California. Indeed, the mean annual wage of solar photovoltaic installers is $35,760 in Arizona, i.e. $7,520 less than in California as of May 2014 (USDOL, 2014).

[6] It is not surprising that the large bulk of job creation is concentrated during the construction phase given that 74.7% of the funding for labor is allocated to that phase. Other recent studies focusing on various types of electricity production facilities find somewhat similar figures (Schwer and Riddle 2004; Williams et al., 2008; Frisvold et al., 2009).

Table 2.3 Economic impacts of TSF / $1 million of spending

Local economic impacts	TSF IMPLAN model – benchmark			California JEDI model		
	Job years[7]	Labor Income ($)	Output ($)	Job years	Labor Income ($)	Output ($)
Construction						
Direct Effect	5.07	710,593.72	738,786.28	4.33	571,577.63	613,311.23
Indirect Effect	0.95	51,716.64	161,763.78	2.29	149,990.75	408,000.45
Induced Effect	3.15	156,735.32	467,436.65	3.31	181,984.13	514,914.85
Construction total	9.17	919,045.69	1,367,986.71	9.93	903,552.52	1,536,226.53
O/M						
Direct Effect	1.58	99,971.48	261,213.72	0.99	135,965.93	135,965.93
Indirect Effect	0.33	18,238.72	57,227.29	0.26	16,981.29	49,064.72
Induced Effect	0.49	24,302.67	72,452.80	0.40	22,918.03	64,830.89
O/M total	2.41	142,512.87	390,893.80	1.65	175,865.39	249,861.66
Total Effect	11.57	1,061,558.56	1,758,880.52	11.59	1,079,417.91	1,786,088.19
	Arizona IMPLAN model			Arizona JEDI model		
	Job years	Labor Income ($)	Output ($)	Job years	Labor Income ($)	Output ($)
Construction						
Direct Effect	4.79	240,873.39	682,285.56	4.64	571,372.90	613,311.23
Indirect Effect	1.81	93,833.34	230,254.72	2.43	126,957.00	339,125.74
Induced Effect	2.68	112,264.25	328,105.36	3.11	137,546.30	388,390.92
Construction total	9.29	446,970.98	1,240,645.64	10.18	835,876.20	1,340,827.89
O/M						
Direct Effect	1.22	62,777.89	171,501.80	0.99	136,045.66	136,045.66
Indirect Effect	0.39	20,694.61	50,636.14	0.27	13,504.26	41,230.62
Induced Effect	0.67	27,967.69	81,648.44	0.40	18,276.74	51,657.02
O/M total	2.28	111,440.73	303,786.40	1.66	167,826.66	228,933.30
Total Effect	11.56	558,411.71	1,544,432.04	11.84	1,003,702.86	1,569,761.18

Note: Dollar year value for all models is 2011. "TSF IMPLAN" was calculated by Hamilton and Berkman (2011). The O/M period in the TSF JEDI, Arizona IMPLAN and JEDI models is extended to the year 2039 to match the TSF case.

[7] Job years refer to full time equivalent (FTE) employment for a year (1 FTE equals to 2080 hours)

The difference with the Arizona JEDI model is much less obvious probably because the latter is more familiar with the type of skills required in the renewable energy sector. For example, the mean annual wage of a construction worker is much lower ($30,470) than that of a solar photovoltaic installers mentioned above (USDOL, 2014). However, by default JEDI sets the labor cost to $450/kW during the construction period and to $10.70/kW during the O/M period in Arizona or California.

On the other hand, the TSF models lead to a much greater labor income (about $1.08 million per $1million of spending) and output level (about $1.79 million per $1million spending) than the Arizona models. It is mainly due to the greater feedback in the indirect and induced effects that emanate from the local economy of California. In addition, the California JEDI model leads to more labor income and output than the California IMPLAN model. The larger return is partially due to the difference in labor costs but also to the options specified in JEDI such as the average annual system capacity factor, the procurement of materials and equipment, the allocation by final consumers (residential, commercial and utility scale) and the solar cell/module material. However, it is important to note that the difference is to be expected as the California JEDI model is performed over the state as a whole while the TSF IMPLAN model is for two counties only.

Table 2.4 reports the indirect and induced employment effects of a $1 million of investment for each of our four models. The results appear for six sectors aggregated as in the sectoral scheme available in JEDI. Unfortunately JEDI does not report the figures by sector for the O/M period. All the models report an induced effect that is much larger than the indirect effect and that most of the employment creation takes place during the construction period. In the TSF IMPLAN model, the sector experiencing the largest indirect effect is 'wholesale trade and retail' (0.32) while 'other services' (1.61) experiences the largest induced effect – the bulk of it is taking place during the construction period. On the other hand, the Arizona IMPLAN model estimates the largest indirect and induced effect in 'other services' (0.59 and 1.34), again during the construction period. For the JEDI models which rely on a different set of assumptions (see section 2.2), the largest number of jobs created is in 'other sectors' and its value is more than 10 times the matching figure from IMPLAN (1.29 for TSF JEDI and 1.39 for Arizona JEDI).

Table 2.4 Employment effect by sectors based on spending of $1 million

Employment effect	TSF IMPLAN		TSF JEDI		Arizona IMPLAN		Arizona JEDI	
	Construction	O/M	Construction	O/M	Construction	O/M	Construction	O/M
Indirect Effect	0.95	0.33	2.26	0.26	1.81	0.41	2.4	0.26
Manufacturing Impacts	0.04	0.01	0.19	0	0.08	0.02	0.20	-
Trade (Wholesale & Retail)	0.32	0.11	0.24	0	0.39	0.08	0.25	-
Finance, Insurance & Real Estate	0.08	0.03	0.00	-	0.15	0.03	0.00	-
Professional Services	0.23	0.08	0.14	-	0.50	0.11	0.16	-
Other Services	0.20	0.07	0.39	-	0.59	0.14	0.40	-
Other Sectors	0.07	0.02	1.29	-	0.11	0.03	1.39	-
Induced Effect	3.16	0.49	3.26	0.40	2.68	0.67	3.06	0.40
Manufacturing Impacts	0.03	0.00	-	-	0.03	0.01	-	-
Trade (Wholesale & Retail)	0.80	0.12	-	-	0.58	0.15	-	-
Finance, Insurance & Real Estate	0.50	0.08	-	-	0.50	0.13	-	-
Professional Services	0.11	0.02	-	-	0.09	0.03	-	-
Other Services	1.61	0.25	-	-	1.34	0.33	-	-
Other Sectors	0.11	0.02	-	-	0.15	0.04	-	-

'-' means no information

We report in table 2.5 the multipliers that correspond to the figures displayed in table 2.3. We focus on job, labor income and output type I and type SAM Multipliers. The difference between the latter two is that Type I multipliers account for the indirect effects only whereas Type SAM multipliers consider both indirect and induced effects. The multipliers range from 1.07 to 1.85 in the TSF IMPLAN model, 1.12 to 2.50 in the California JEDI model, 1.32 to 1.94 in the Arizona IMPLAN[8] model and from 1.10 to 2.19 in the Arizona JEDI model. As a result and according to JEDI, a new facility leads to a larger multiplier effect in terms of jobs, labor income and output in California than in Arizona. They come from the comparatively larger indirect and induced effects as well as from the larger size of the study area (California is 1.4 and 5.7 times bigger and more populated than Arizona). Comparison based on the two IMPLAN models is not appropriate since they are not dealing with the same territory (two counties in CA vs. AZ as a whole).

Table 2.5 Multipliers of TSF and solar farm in Arizona based on spending

Multipliers		TSF IMPLAN			California JEDI		
		Job years	Labor Income	Output	Job years	Labor Income	Output
Construction	Type 1	1.19	1.07	1.22	**1.53**	1.26	**1.67**
	Type SAM	1.81	1.29	1.85	**2.29**	1.58	**2.50**
O/M	Type 1	1.21	1.18	1.22	1.26	1.12	1.36
	Type SAM	1.53	1.43	1.50	1.67	1.29	1.84
Total	Type 1	1.19	1.09	1.22	**1.48**	1.24	1.61
	Type SAM	1.74	1.31	1.76	**2.18**	1.53	**2.38**
Multipliers		Arizona IMPLAN			Arizona JEDI		
		Job years	Labor Income	Output	Job years	Labor Income	Output
Construction	Type 1	1.38	**1.39**	1.34	1.52	1.22	1.55
	Type SAM	1.94	**1.86**	1.82	2.19	1.46	2.19
O/M	Type 1	**1.32**	**1.33**	1.30	1.27	1.10	1.30
	Type SAM	1.87	1.78	1.77	1.68	1.23	1.68
Total	Type 1	1.37	1.38	1.33	1.48	1.20	1.51
	Type SAM	1.92	**1.84**	1.81	2.10	1.42	2.09

1) Type I Multiplier = (Direct Effect + Indirect Effect) / (Direct Effect)
2) Type SAM Multiplier= (Direct Effect + Indirect Effect + Induced Effect) / (Direct Effect)

[8] Our results by Arizona IMPLAN are in tune with those of Frisvold et al. (2009) as they find an employment multiplier of 1.95 and 1.48 for the construction and O/M periods respectively.

2.5 Conclusions

The benefits of a new solar power plant with large utility scale go beyond the environmental advantages of replacing fossil fuel energy sources with low carbon emission sources. New power plants have a large impact on the economy of the area that hosts them. This paper focuses on Arizona where solar radiation is abundant and takes place all year long. The economic impacts of the world's largest solar plant called Topaz recently built in California serves as a benchmark against which we measure the impact of the same investment but in Arizona. In that purpose, we use the popular IMPLAN model, as in the economic impact study performed by Hamilton (2001) for the Topaz case, and compare the results it generates with those of the JEDI Solar module, a free software developed by the NREL. It allows us to compare how the differences in the input characteristics lead the two models to generate slightly different overall impacts. Indeed, while IMPLAN provides detailed information about a very large number of sectors, it does not have a sector specific to the construction of a solar plant. On the other hand, JEDI counts few sectors but it is specifically designed for economic impact analyses of renewable energy facilities. It offers a large set of options on the average annual system capacity factor, the procurement of materials and equipment, the detailed market sector share (residential, commercial and utility scale) and the solar cell/module material. Its creators claim that these options derive from numerous interactions with companies in the renewable energy sector, the U.S. Department of Energy, Photon consulting and Lawrence Berkeley National Laboratory.

One consequence of this difference is that during the construction period the direct labor income is nearly twice larger in the JEDI Arizona model than in the IMPLAN Arizona model. We believe that it is because IMPLAN uses the average income of a worker in the construction sector no matter what type of facility is being built. Instead, JEDI accounts for the costs specific to a solar plant and automatically allocates 27.4% of the construction costs to high value-added sectors such as permitting and business overheads.

In spite of these differences, our economic impact analysis shows that all four models - TSF IMPLAN, California JEDI, Arizona IMPLAN and Arizona JEDI model - generate reasonable results that are fairly similar in terms of total job and output creation. For instance, all models indicate that about 80% of the total job creation takes place during the construction period. In addition, the total number of job years is similar across models at about 11.5 per $1 million of spending and the JEDI models calculate a labor income multiplier (resp. output multiplier) that is only 1.08 times (resp. 1.14 times) larger in California than in Arizona. The slightly greater overall return that California displays over Arizona comes from its larger indirect and induced income effects. Indeed, the same of solar photovoltaic installer would make $7,520 more a year in California than in Arizona (USDOL, 2014).

Our results indicate also that the JEDI solar PV model is very efficient at generating an economic impact analysis by input-output. First of all, the input options available to the JEDI user are very specific to the solar energy industry, which means that JEDI relies on direct input coefficients that are more realistic. For example, the latter vary with the user's choice of energy use (residential, commercial, and utility) and cost per kW allocated to materials and equipment, labor, permitting and business overhead. Second, the 22 industrial sectors integrated in JEDI keep the sectors related to solar energy very detailed, while the others are aggregated. IMPLAN will always have an advantage in terms of the number of industrial sectors it offers (440), but JEDI's aggregation scheme allows the user to focus on the most relevant sectors for his/her study. These two advantages, combined with its free access, make JEDI a very appealing software for economic impact analysts focusing on renewable energy sources. One possible shortcoming of JEDI is its intrinsic focus on state level analysis – because the transaction table it relies on is as such – but it can easily be overcome by combining JEDI with a local I/O table from IMPLAN. In this case, the direct job multipliers of the region of interest can be transferred from IMPLAN to JEDI using its user add-in function. As for setting the appropriate LPC in JEDI, the SAM model values that are offered in IMPLAN can help improve the accuracy of local estimates generated by JEDI.

In this paper, we have estimated the local economic impact following a new solar plant. Our choice was driven by the inputs used in the analysis of the TSF built in California. However, we would like to investigate in the future whether a change in the LPCs would affect our results and whether other energy producing facilities, such as coal or natural gas fired power plants, would lose jobs as a result of an expansion in solar energy. In this regard, the contributions of Singh and Fehrs (2001), Kammen et al. (2004) and Pollin et al. (2009) suggest that the net effect on job creation would still be positive as solar power plants create more jobs/$1 of investment than plants relying on coal or natural gas. Huntington (2009) finds this difference in terms of jobs/MW as well. At the same time, the higher cost of the energy generated by solar PV compared to more traditional sources (Huntington, 2009) can increase utility prices in the area and hurt the local economy. Calculating the net effect is left for future research. Another extension of interest for the state of Arizona consists in investigating whether facilities built for other types of renewable energy sources, such as wind, geothermal or biomass, could lead to greater multiplier effects on the economy and identify the ones that add the least stress to the environment in terms of water-consumption or disturbance to wildlife when they are produced and operated. These results could help state and local policy-makers justify their spending for more renewable energy facilities and figure out their "right" mix based on their relative multipliers and the state's current and future natural resources endowment.

CHAPTER 3

CROP PRODUCTION, EXPORT OF VIRTUAL WATER AND WATER-SAVING STRATEGIES IN ARIZONA[9]

3.1 Introduction

Many dry regions in China, Europe, and the US are suffering from insufficient water sources, and it has been pointed out that some water scarce regions are even exporting a bulk of their scarce water as a hidden flow of water embodied in trade (Cazcarro et al., 2013; Dietzenbacher and Velázquez, 2007; Guan and Hubacek, 2007; Velázquez, 2006). Under the increasing impact of climate change and population growth, arid and many semiarid regions will face more stresses of absolute water scarcity globally (Vörösmarty et al., 2000) including Colorado river basin (Christensen et al., 2004). While Arizona (AZ) is one of the driest states in the country, its water demand has never been as high as it is today. It is driven by a recent and rapid population growth (from 1.3 million in 1960 to 6.7 million today) and, more importantly, its well-developed agriculture (its export ranked 33rd in the nation in terms of value in 2012 (USDA, 2012) and it uses 35% of AZ's land). The lack of local rainfall and groundwater is compensated by artificial reservoirs and the Central Arizona Project which have been diverting water from the Colorado River for decades. However, these heavy irrigation requirements impose huge water demand stresses on the ecological system of the

[9] Financial support from USDA NIFA Hatch (grant 1006816) and from the Renewable Energy Network, Water, Environmental and Energy Solutions Initiatives is gratefully acknowledged.

state to the point where one has to wonder for how long crop production can keep engulfing 75% of the water used in the state (IMPLAN, 2010; USGS, 2010). This figure is disproportionally high since only 30% of the crops produced in AZ are consumed locally (IMPLAN, 2010), which implies that AZ exports a significant amount of much-needed water. In addition, agriculture represented only 0.55% of the state's employment in 2015 (USDOL, 2015).

Several virtual water flow analyses have been performed on regions suffering from an imbalance between water use and water availability. Such studies have focused on regions within China (Guan and Hubacek, 2007; Han et al., 2014; Wang and Wang, 2009; Wang et al., 2013; Zhang et al., 2011), Europe (Dietzenbacher and Velázquez, 2007; Van Hofwegen, 2004; Velázquez, 2006; Yu et al., 2010) or the US (Dang et al., 2015; Finster, 1971; Marston et al., 2015; Mubako et al., 2013).

The most significant findings in previous studies are some water-scarce regions sell more water-intensive goods to water-abundant regions than vice-versa (Cazcarro et al., 2013; Dietzenbacher and Velázquez, 2007; Guan and Hubacek, 2007; Velázquez, 2006). Based on a Social Accounting Matrix for Spain Cazcarro *et al*. (2012) conclude that the country as a whole is a net importer of water, although it is clear from Cazcarro *et al.* (2013) and Dietzenbacher and Velázquez (2007) that some Spanish regions are net exporter vis-à-vis foreign trade partners. The paradox of water-scarce regions exporting water through their production and trade is not unique to the US. Mubako et al. (2013) have analyzed the bilateral virtual water trade between California and Illinois across 8 sectors. These two states have very different water endowments yet the water volume that each of the two states exports virtually is more than 50% of the water they actually use. Moreover, CA has larger direct water input coefficients than IL in aquaculture, livestock, mining, services, and domestic usages. While based on 2008 trade flow data, their article echoes the concerns expressed about California's water shortages, (e.g., Bêche et al., 2009; Harou et al., 2010) and the even more dramatic drought of 2013-2014 (Howitt et al., 2014; Swain et al., 2014). Another recent contribution is Marston et al. (2015) who focus on groundwater originating from three aquifers (the High Plains, the Mississippi Embayment and the Central Valley) of which (over)exploitation for irrigation purposes may threaten national food security and be challenged by future droughts. While the large majority of the food this water helps produce stays with the country (91%), the authors are concerned that even a small part of currently diminishing resources are devoted to foreign markets. They suggest that they should be more valued and saved as the future may bring more drought and extreme events. Dang et al. (2015) take on a different approach by examining the virtual water content (VWC) for each food commodity group provided in the US Commodity Flow Survey. When they compare it to the values at the international level, their results indicate that the VWC in the US alone is as much as 51% of the international flows. It is much higher than the mass or value share of the US market. The difference comes from the disproportionate amount of water-intensive meat commodities that are traded in the country.

Through a so-called virtual water flow analysis (Allan, 1993, 1994; Allan, 1998) our aim is, first, to uncover how much water is embedded in the products and services made in Arizona and is "virtually" traded with its U.S. and foreign partners. Arizona is an interesting case in that it receives less media coverage than its drought-prone neighbor California; yet its water export was already pointed out as a critical issue more than three decades ago (Finster, 1971). He focuses on the 1958 structure of Arizona's economy and on its trade pattern with the rest of the country. The author finds that, at that time, Arizona was a net exporter of 2.24 million acre-feet of water with respect to the rest of the US but he does not highlight which sector(s) is responsible for it. We will not only discover such sectors and, in addition, we determine whether significant water savings could be achieved through 1) a more efficient irrigation system, 2) an increase in the price of water, and 3) a reduction in crop exports. Beyond the logic of avoiding specialization and trade of goods of which production factors are not locally abundant (Heckscher and Ohlin, 1991), this exercise is motivated by the fact that Arizona’s population is expected to double by 2050 (AZDOA, 2012), various climate models anticipate more droughts in the state in the future (Dominguez et al., 2010) and the heavy reliance on the Colorado River for irrigation surface water even when its source is located beyond the state’s borders.

3.2 Methodology

3.2.1 The concept of virtual water flow and economic input-output Model

Virtual water flows derive naturally from the input-output framework developed decades ago by Leontief (1953, 1956, 1970) in that it allows consideration of both traded final goods (e.g., cattle) and also all intermediate goods (e.g., water and hay fed to cattle) used in the production process of the former, thereby avoiding the risk of double counting. This approach permits accurate measurement of the total amount of water embodied in trade. Virtual water is defined as the volume of water embodied in the production process of a good (Hoekstra and Hung, 2002). It is analogous to the ‘water footprint’ idea introduced later on by Hoekstra and Hung (Hoekstra and Chapagain, 2007), except that their study focuses on freshwater sources only and the national level.

By summing over the rows, we could obtain x_i which is the total output of sector *i* that satisfies intermediate demand of the sectors j (z_{ij}) and final demand (f_{ij}):

$$x_i = \sum_j z_{ij} + \sum_j f_{ij} \qquad (3.1)$$

Then we can denote the technical coefficients of production (a_{ij}) as z_{ij}/x_j. They correspond to the dollar value of z_{ij} needed for the production of \$1 of x_j. Equation (1) can therefore be rewritten as:

$$x_i = \sum_j a_{ij}\, x_j + \sum_j f_{ij} \qquad (3.2)$$

The economy as a whole could be written in matrix notation, and be solved for X as:

$$X = AX + f$$

$$X = (I\text{-}A)^{-1} f = Lf \qquad (3.3)$$

where A is the coefficient matrix, and $L = (I\text{-}A)^{-1}$ is known as the Leontief inverse matrix. The element of l_{ij} represents the output in sector i that is required to satisfy for \$1 of final demand in sector j, and L takes both direct and indirect effects into consideration.

In the input-output terminology, the amount of water used in the production process of a sector, noted $y_j = w_j/x_j$, is a direct water input coefficient. It allows us to calculate the quantity of water consumed by sector *i* to satisfy \$1 of final demand in sector *j*. The latter is called total (direct + indirect) water input coefficient or virtual water multiplier $\varepsilon_i = \sum_i y_i l_{ij}$.

3.2.2 Virtual water input-output model and price elasticity

In order to calculate the virtual water flows associated to AZ's (net) trade, we first define the direct water input coefficients of AZ's imports as the technology, regulations and industry-mix of its trade partners may differ from its own. Let $\tilde{y}_j = \tilde{w}_j/\tilde{x}_j$ be the rest-of-the-US (RofUS) and rest-of-the-world (RoW) direct water input coefficients that we both approximate by the measurements on the US as a whole. Since we have access to the list of imports of intermediate goods and of final goods (or institutional goods), we decide to report them separately. The net virtual water flows are thus $\sum_i y_j\, l_{ij} e_j - \sum_i \tilde{y}_j\, \tilde{l}_{ij} m_j$, where e_j is the amount of exports in sector *j*, m_j is the amount of imports in sector *j* and $\tilde{l}_{ij}$ is the Leontief inverse of the US matrix. If we define the direct value added coefficient as $va_i = v_i/x_j$ and the direct employment coefficient as $emp_i = s_i/x_j$ then an decrease in crop exports leads to the following decreases in value added (equation 3.4) and in employment (equation 3.5):

$$\sum_i va_i l_{ij}\ (\Delta f_i^{RoUS} + \Delta f_i^{RoW}) \qquad (3.4)$$

$$\sum_i emp_i l_{ij}\ (\Delta f_i^{RoUS} + \Delta f_i^{RoW}) \qquad (3.5)$$

Note that value added in equation (3.4) does not include employment compensation.

Ultimately, a lesser local production requires less imports. If we define the direct import coefficient as $imp_i = m_i/x_j$, then AZ's regional trade balance can be define as:

$$(1-\sum_i imp_i l_{ij})\ (\Delta f_i^{RoUS} + \Delta f_i^{RoW}) \qquad (3.6)$$

Additionally, we develop below a set of equations based on a theoretical \$1/m3 increase in the price of water as in an input-output framework the underlying assumption is that the physical unit of measurement of a good corresponds to the amount that can be bought for \$1 (Dietzenbacher and Velázquez, 2007). The equation indicating that the price (\$1) of one physical unit of product *j* is equal to the cost of all the inputs necessary in its production is equation (3.8) below. It derives from equation (3.7) that reports the basic relationship implied in the column of the input-output table (with v_j the value-added in sector *j*).

$$x_j = \sum_i z_{ij} + \sum_i m_{ij} + v_j \qquad (3.7)$$

$$\$1 = \sum_i a_{ij} + \sum_i (m_{ij}/x_j) + (v_j/x_j) \qquad (3.8)$$

If we now introduce a cost $\widehat{w}_j$ associated to the use of water in sector *j*, it will increase the price per unit of product *j* from its current level ($1) to a new level noted p_j. The same idea holds true for the input sectors *i* which are experiencing a new price per unit p_i. Assuming that imports and value-added are not modified by this local price increase, the (new) price still equals the costs per physical units:

$$p_j = \sum_i p_i a_{ij} + \sum_i (m_{ij}/x_j) + (v_j/x_j) + (\widehat{w}_j/x_j) \qquad (3.9)$$

If we subtract the new price p_j (equation 3.9) with its former price (equation 3.8), the price change of product *j* corresponds to:

$$p_j - 1 = \sum_i p_i a_{ij} - \sum_i a_{ij} + (\widehat{w}_j/x_j)$$

$$\sum_i (p_i - 1)\, I_{ij} = \sum_i (p_i - 1)\, a_{ij} + (\widehat{w}_j/x_j)$$

$$\sum_i (p_i - 1)\, (I_{ij} - a_{ij}) = (\widehat{w}_j/x_j)$$

using matrix notation and solving the linear equation using the relation of $(I - A)^{-1} = L$, we obtain equation (3.10). e' is the summation vector composed of 1's, and p' denotes the matrix of new price of one physical unit of product *j*.

$$(p' - e')\,(I - A) = \widetilde{w}\hat{x}^{-1}$$

$$p' - e' = \widetilde{w}\hat{x}^{-1}(I - A)^{-1}$$

$$p' - e' = \tilde{w}\hat{x}^{-1}L$$

$$p_j = \sum_i (\hat{w}_j / x_j)\, l_{ij} + 1 \qquad (3.10)$$

3.3 Economic structure and water use by sector

Our input-output dataset comes from the Minnesota IMPLAN group and reports the transactions among 440 economic sectors defined in the North American Trade and Industrial Classification System (NAICS). Data on their exact amount of water used for consumption and/or production does not exist. Instead, we rely on the most recent USGS data (US Geological Survey). They correspond to the year 2010 and they became available in December 2014 (USGS, 2010). These water use data are estimated and published every 5 years and are not available at a finer level than the 8 sectors. They measure the amount of water withdrawal i.e., the quantity removed from the water source for a particular use regardless of how much of that total is consumptively used (USGS, 2010). Although USGS covers 8 types of water users, we aggregate some of them and work with 5 economic sectors because the "public supply" sector of USGS covers "users for domestic, commercial, and industrial purposes". The final matching and aggregating scheme is reported in table A2 in the Appendix 2.

For the state of AZ, the total amount of water withdrawn in 2010 was m^3 8,407 million and its entirety was made of fresh water. Table 3.1 below reports the share of each type of user in total withdrawals. When it comes to the sources of water, Arizona is relatively more dependent on groundwater than the country as a whole. However, when it comes to water used for irrigation, AZ consumes a larger than national share of surface water. The latter comes almost exclusively from the Colorado River and access to it has been facilitated over the years by a series of large-scale water projects such as artificial reservoirs (dams) and the Central Arizona Project (CAP).

Table 3.1 Water withdrawals by water-use category per year and by source (2010) (million m^3 per year and % of total in parenthesis)

Water use	Arizona			US			
	Fresh water			Fresh		(Saline)	Total
	Surface water	Ground water	Total	Surface water	Ground water		
Crop	2,235 (26.58)	3,918 (46.60)	6,153 (73.19)	61,120 (12.38)	90,398 (18.32)	-	151,517 (30.70)
Livestock/aquaculture	92 (1.09)	11 (0.13)	103 (1.22)	4,173 (0.85)	11,616 (2.35)	-	15,788 (3.20)
Mining	120 (1.42)	-	120 (1.42)	5,402 (1.09)	1,561 (0.32)	4,242 (0.86)	11,205 (2.27)
Thermoelectric	107 (1.27)	37 (0.45)	144 (1.72)	996 (0.20)	160,274 (32.48)	60,656 (12.29)	221,926 (44.97)
Industry/services/ domestic	969 (11.53)	923 (10.97)	1,888 (22.45)	37,930 (7.69)	53,799 (10.90)	1,362 (0.28)	93,092 (18.86)
Total	3,522 (41.90)	4,889 (58.15)	8,407 (100.00)	109,621 (22.21)	317,648 (64.36)	66,260 (13.43)	493,529 (100.00)

Note: All water sources in Arizona are from fresh water. Only small amounts of water in other states in the US come from saline water for the use of industrial, mining and power generation. However, it is not verified whether those saline waters are withdrawn from surface or ground on the USGS data (2010). It is notified that 'figures might not sum to totals because of independent routing' in the original USGS water use data (2010).

We rely on a closed input-output framework and the IMPLAN data of 2010 to capture the economic structure of AZ's economy. Table 3.2 reports the direct and indirect input coefficients for each of the 5 sectors. They indicate the $ amount needed from each sector (by row) for the production of $1 of the sector of interest (by column) either directly or once all the rounds of transactions have been accounted for (i.e. indirectly). From this table, we note that crop production, like all the other sectors, depends primarily on the sector industry/services/domestic as it provides the necessary inputs such as fertilizers, machinery and workforce.

Table 3.2 Direct and indirect input coefficients

Direct requirement matrix (Direct +Indirect requirement matrix)	Crop	Livestock/ aquaculture	Mining	Thermo-electric power	Industry/ services /domestic
Crop	0.054 (1.071)	0.127 (0.175)	0.001 (0.009)	0 (0.006)	0.004 (0.017)
Livestock/aquaculture	0.002 (0.015)	0.172 (1.222)	0 (0.008)	0 (0.006)	0.004 (0.018)
Mining	0.003 (0.057)	0.003 (0.064)	0.075 (1.114)	0.066 (0.095)	0.020 (0.075)
Thermoelectric power generation	0.015 (0.042)	0.016 (0.051)	0.009 (0.026)	2×10^{-6} (1.013)	0.011 (0.038)
Industry/services/domestic/wages	0.654 (2.367)	0.539 (2.587)	0.392 (1.448)	0.288 (1.070)	0.686 (3.381)
Sum	0.729 (3.552)	0.856 (4.099)	0.478 (2.605)	0.354 (2.189)	0.725 (3.530)

Source: IMPLAN (2010)

Table 3.3 reports the economic structure and water use in AZ with respect to the USA. As expected, crop production is only a very small share of the state's output (0.6%) and it is a sector that is well connected to the rest of the economy: \$1 spent in crop output generates \$3.552 in the economy due to the direct, indirect and induced inputs (e.g., machinery, labor, fertilizer) needed in the production process (Miller. and Peter D. Blair, 2009) (see table 3.1). These figures are in line with the national level. However, when it comes to water use, the difference is important: each dollar of crop produced in AZ consumes 2.47 and 2.32 times more direct and total water than its national counterpart. The matching between the output of these economic sectors and the USGS water use data is described in Table A2 in Appendix. The amount of water withdrawals for crop production was m^3 6,152 million in Arizona in 2010. It represents 51,532 gallons of water per second. Columns 3.5 of table 3.3 indicate that Arizona crops consume a share (73.13%) that is more than twice larger than its equivalent at the national level (30.7%) or nearly m^3 2.5/\$1 of crop produced vs. $\mathrm{m}^3$1/\$1 for the nation. The difference increases when the water-content of the inputs is also accounted for (m^3

2.671 vs. $m^3$1.151 per $1 produced). Every $1 of crop produced in AZ requires nearly 43 times the amount of water needed for $1 of production in the industry/services/domestic sector. Contrary to general belief, the amounts of water used to maintain golf courses (3% of the state's total and embedded in services) and for mining activities (1.42%) represent very small shares in comparison.

3.4 Location of overall final demand and net trade balance of AZ

An analysis of the location of the consumers of goods and services made in AZ reveals that the two most water-intensive sectors, crops and livestock/aquaculture, lag behind mining only in terms of the share of their output that is exported (79% and 45% respectively). Table 3.3 shows the amount and percentage of exports of both output and virtual water from AZ. The exports of crops represent only 0.47% of all goods made in AZ, but the direct virtual water these exports carry with them is as much as 57.86% of the overall water available in AZ (47.56% go to the rest of the US and 11.30% to the rest of the world). Among the former sector, the top 4 agricultural products exported by AZ in 2012 were cotton (40%), fruits & vegetables (fresh and processed, 34%), dairy (16%) and beef (10%) (Murphree, 2014). It means that even if agriculture consumes directly up to 73.13% of the water available in the state, only a mere 15.28% of that water stays in Arizona for final and intermediate consumption.

Table 3.3 Water use at the sectoral level in Arizona and the US (2010)

Sectors		Output in $ million/yr (% in parenthesis)	Sum of direct input coefficients	Sales multipliers (per $1)	Water use (ω_j) (million m^3/yr) (%)	Direct water input coefficient y_j (m^3/$1)	Virtual water multipliers ε_i (m^3/$1)
AZ	Crop	2,480.21 (0.60)	0.729	3.552	6,152.89 (73.13)	2.481	2.671
	Livestock/aquaculture	778.45 (0.19)	0.856	4.099	102.63 (1.22)	0.132	0.610
	Mining	7,320.99 (1.77)	0.478	2.605	119.77 (1.42)	0.016	0.048
	Thermoelectric	5,672.31 (1.37)	0.354	2.189	144.32 (1.72)	0.025	0.047
	Industry/services /domestic	397,429.06 (96.07)	0.725	3.530	1,893.54 (22.51)	0.004	0.064
	Total	413,681.02 (100.00)			8,413.14 (100.00)		
USA	Crop	150,947 (0.58)	0.745	4.963	151,517.17 (30.70)	1.004	1.151
	Livestock/aquaculture	147,111 (0.56)	0.668	4.407	15,788.40 (3.20)	0.107	0.247
	Mining	435,087 (1.66)	0.469	3.272	11,205.38 (2.27)	0.026	0.064
	Thermoelectric	325,099 (1.24)	0.606	4.087	221,925.96 (44.97)	0.683	0.733
	Industry/services /domestic/wages	25,093,057 (95.95)	0.824	5.407	93,091.61 (18.86)	0.004	0.078
	Total	26,151,301 (100.00)			493,528.52 (100.00)		

Table 3.4 Location of overall final demand for AZ's products and for AZ's water

(Unit: \$ million, m^3 million)

sectors	Total		Consumption in AZ		Exports to RoUS		Exports to RoW		Total Exports	
	Output	water use	output	water use	Output	water use	output	water use	output	water use
Crop	2,480.21	6,152.89	518.06	1,285.20	1,578.86	3,916.84	383.28	950.85	2,480.21	6,152.89
% by each sector	100.00	100.00	20.89	20.89	63.66	63.66	15.45	15.45	79.11	79.11
(% w.r.t the state)	(0.60)	(73.13)	(0.13)	(15.28)	(0.38)	(46.56)	(0.09)	(11.30)	(0.47)	(57.86)
Livestock/aquaculture	778.45	102.63	427.29	56.33	347.55	45.82	3.61	0.48	778.45	102.63
% by each sector	100.00	100.00	54.89	54.89	44.65	44.65	0.46	0.46	45.11	45.11
(% w.r.t the state)	(0.19)	(1.22)	(0.10)	(0.67)	(0.08)	(0.54)	(0.00)	(0.01)	(0.08)	(0.55)
Mining	7,320.99	119.77	1,386.28	22.68	4,560.99	74.62	1,373.73	22.47	7,320.99	119.77
% by each sector	100.00	100.00	18.94	18.94	62.30	62.30	18.76	18.76	81.06	81.06
(% w.r.t the state)	(1.77)	(1.42)	(0.34)	(0.27)	(1.10)	(0.89)	(0.33)	(0.27)	(1.43)	(1.15)
Thermoelectric	5,672.31	144.32	4,361.17	110.96	1,294.52	32.94	16.62	0.42	5,672.31	144.32
% by each sector	100.00	100.00	76.89	76.89	22.82	22.82	0.29	0.29	23.11	23.11
(% w.r.t the state)	(1.37)	(1.72)	(1.05)	(1.32)	(0.31)	(0.39)	(0.00)	(0.01)	(0.32)	(0.40)
Industry/services /domestic/wages	397,429.06	1,893.54	282,203.18	1,344.55	89,657.21	427.17	25,568.67	121.82	397,429.06	1,893.54
% by each sector	100.00	100.00	71.01	71.01	22.56	22.56	6.43	6.43	28.99	28.99
(% w.r.t the state)	(96.07)	(22.51)	(68.22)	(15.98)	(21.67)	(5.08)	(6.18)	(1.45)	(27.85)	(6.53)
Total	413,681.02	8,413.14	288,895.98	2,819.72	97,439.14	4,497.38	27,345.90	1,096.04	413,681.02	8,413.14
% by each sector	100.00	100.00	69.84	33.52	23.55	53.46	6.61	13.03	30.16	66.48
(% w.r.t the state)	(100.00)	(100.00)	(69.84)	(33.52)	(23.55)	(53.46)	(6.61)	(13.03)	(30.16)	(66.48)

Note: % is by each sector, and (%) is with respect to the state.
Source: IMPLAN (2010)

The virtual water coefficient for livestock/aquaculture increases to 0.610. Crop is therefore the most water intensive sectors by far; but it is obvious that, unlike livestock/aquaculture, its overall consumption is almost entirely driven by direct water use. Neither of the latter two sectors generate an output multiplier (total $ of output needed to satisfy an additional $1 of final demand) above the one of the much less water intensive industry/services/domestic sector.

Power generation (45%) and industry/services/domestic (17%) are the next main consumers of water at the national level whereas only the latter represent a large share in AZ (20%). One thing could be questioned is the low share of thermoelectric water use in AZ (1.72%) with respect to US total (44.97). Thermoelectric water use is mostly to turn turbines for hydropower, to condense and cool the steam at thermoelectric power plants (Fleischli and Hayat, 2014), and the largest total water withdrawals are in TX, IL, CA, FL, TN for cooling purposes. The water withdrawals in the eastern states take more than 80% of total (USGS, 2010). Another reason of low water withdrawals in AZ could be using closed-loop cooling systems which is mostly adapted in water scarce states to manage water strictly.

Table 3.5 reports the quantity of water associated to exports (see equations 3-6). Similar figures are reported for imports so that one can notice that, overall, Arizona has a net trade deficit but it is a net exporter of virtual water by around m^3 775 million. The average water content of $1 of its import ($m^3$0.023) is less than the water content of $1 of its export ($m^3$0.045). A deficit in trade and virtual water flow is observed for every single sector of the economy except crop where the greater water content of export (m^3 2.48/$1 vs. $m^3$1.00/$1 for import) leads to the m^3 5.6 billion virtual water trade surplus. This gap could come from several factors such as differences in the mix of imported and exported crops, a less efficient use of water or higher level of evapotranspiration in Arizona than elsewhere. Therefore, we focus the next section on identifying a set of strategies that would lead to significant water savings in the state.

Table 3.5 Direct and indirect AZ trade flows and balances ($ million value and m^3 million in parenthesis)

Trade flows (Virtual water flows)	Crop	Livestock/ aquaculture	Mining	Thermo-electric	Industry/ services/ domestic/ wages	Total
Direct exports (Direct virtual water exports)	1,962.15 (4,867.69)	351.16 (46.29)	5,934.71 (97.09)	1,311.14 (33.36)	115,225.88 (548.99)	124,785.04 (5,593.42)
Total exports (Total virtual water exports)	4,234.28 (10,504.40)	2,573.77 (339.31)	15,572.50 (254.77)	5,945.88 (151.28)	405,122.68 (1,930.19)	433,449.11 (13,179.94)
Direct imports (Direct virtual water imports)	2,139.95 (2148.03)	1,593.97 (171.07)	7,994.48 (205.89)	-	116,126.70 (430.81)	127,855.10 (2,955.81)
Total imports (Total virtual water imports)	4873.78 (4,892.19)	4,659.61 (500.08)	20,470.54 (527.21)	6,045.84 (4,127.14)	635,688.46 (2,358.31)	671,738.3 (12,404.93)
Net trade balance: total exports –imports (Net virtual water trade balance)	-639.50 (5,612.20)	-2,085.85 (-160.77)	-4,898.04 (-272.44)	-99.96 (-3,975.86)	-230,565.78 (-428.12)	-238,289.12 (775.01)

3.5. Defining and selecting water saving strategies

3.5.1 Scenario 1: Irrigation technology shifts to less water intensive irrigation

In light of the above results, one may wonder for how long the current levels and types of water use will last. Indeed, demand for water should increase as the forecasts predict around 5 million additional inhabitants in the state by 2050 (AZDOA, 2012), while, at the same time, the supply of water may be lesser and more uncertain than in the past due to the expected changes in the climate of the Southwest (Dominguez et al., 2010; Garfin et al., 2013). As such, we suggest three mitigation scenarios and measure their impact on the local economy. Our first water-saving scenario consists in switching from a gravity system to a pressure system that is more efficient and can be made of a low-flow or sprinkler system. In Arizona, 83.85% of the irrigated water is delivered through a gravity system (USDA, 2008) which is less costly and technologically advanced than a pressure system. However, it is also less efficient as it leads to water runoffs (USGS, 2016). A sprinkler system is not problem-free either as up to 35% of the water can be wasted because of evaporation and wind (USGS, 2000). When switching the irrigation system currently in use to the more efficient one for each type of crop and for the entirety of that crop, we find that a 19.17% decrease in the amount of irrigated water used can be achieved. This figure is based on the average irrigation water use data reported in USDA's Census of agriculture (2008) for each crop in the state of AZ. Mathematically, it can be formulated as $\sum_{k=1}^{n}(\rho_{k,s_g} - \rho_{k,s_l}) \cdot r_k$, where ρ_k is the water use amount (m^3) per acre for crop k, s_g and s_l means gravity and low-flow system respectively, and r_k represents the area devoted to crop k's cultivation.

As shown in table 3.6, most of the savings come from switching from a gravity system to a pressure system (18.25%) among the most water-intensive crops: alfalfa, cotton and wheat. Together they account for nearly 70% of the irrigated water use, hence even small gains in efficiency in the irrigation systems of these crops leads to large water savings in the state. The total water saving amounts to $\mathrm{m}^3$1,018.05 million or \$40.7 million based on the \$0.04/m^3 rate used for agriculture that year (CAP, 2009). Based on the \$158.04 per acre figure (USDA, 2008) for the state of AZ, the pumping cost associated to a pressure system is estimated at \$151.2 million in 2010 values, hence the cost of this scenario is estimated at \$110.5 million. Our figure does not include additional costs related to the purchase of pipes, motors, electricity and other materials. However, the latter are relatively marginal and do not modify the overall difference with the magnitude of the cost calculated in the other two scenarios.

This irrigation technology shift is consistent with on-farm water saving strategies seen in other arid and semi-arid areas (e.g. Deng et al., 2006) because the expected gains in water use efficiency have already been documented in the literature. For instance, Dasberg and Or (1999) estimate that, in general, the water use efficiency of sprinklers is at 60-80%, the one of surface irrigation is at 50-60% while the one of drip systems (low-flow) is at 90%. Beyond technology switch, some contributions have emphasized the use of plastic mulch to prevent soil-evaporation (Zhang and Cai, 2001), to limit irrigation water supplement during the flowering and budding stages for cotton (Hu et al., 2001), and to rely on enforcement, regulation, and education to support farm-level water savings (Zhou, 2003).

None of the above options is easy to implement. For instance, Alcon et al. (2011) find that, in Spain, it took on average 20 years for farmers to shift from other types of irrigation to a low-flow (especially drip) irrigation system. Furthermore, the question of where the funding would come from is not obvious. Farmers already pay very little for water; hence they do not have strong incentives to fund new irrigation systems themselves. Should the government subsidize them (tax everyone) in the name of protecting the environment and guaranteeing water availability to future generations? Should city-dwellers be charged for on-farm water savings as additional supply should reduce the price of water for domestic usage? Answering these questions is beyond the scope of this paper and the rest of this section will limit itself to comparing the cost of the switch proposed so far with the cost of two other water saving strategies.

Table 3.6 Water use by crop types and reduction by irrigation system improvement (m^3 million value and % in parenthesis)

Crop types	Irrigated area (acre)	Water use efficiency (m^3 per acre)				Current irrigation water use					Water use saving***		
		Gravity	Pressure	Low-flow	Sprinkler	Gravity	Pressure	Low-flow	Sprinkler	Total water use	Gravity to pressure	Sprinkler to low-flow	Total saving
corn	44,578	5,489	3,392	-	-	152.74	60.02	-	-	212.76 (4.01)	58.48	-	58.48 (1.10)
wheat	138,472	4,440	3,947	-	-	572.21	37.94	-	-	610.15 (11.49)	63.58	-	63.58 (1.20)
alfalfa	280,741	7,894	6,044	-	-	1,942.28	209.75	-	-	2,152.04 (40.51)	455.22	-	455.22 (8.57)
cotton	142,163	5,920	-	4,687	5,550	744.04	-	31.36	54.43	829.82 (15.62)	155.01	8.47	163.47 (3.08)
sorghum	24,328	4,317	4,070	-	-	87.09	16.91	-	-	104.00 (1.96)	4.98	-	4.98 (0.09)
vegetables	102,471	3,700	-	2,960	4,317	178.69	-	79.97	117.29	375.95 (7.08)	35.74	36.86	72.60 (1.37)
orchards, vineyards, nut trees	30,745	8,017	-	5,551	7,031	159.99	-	46.66	16.76	223.41 (4.21)	49.23	3.53	52.76 (0.99)
other small grains*	6,595	4,194	5,797	-	-	21.62	8.35	-	-	29.97 (0.56)	-	-	0 (0.00)
all other crops**	193,528	4,410	3,084	-	-	595.22	127.64	-	42.56	773.78 (14.57)	146.96	-	146.96 (2.77)
total	963,621	5,877	4,157	3,752	4,576	4,453.87	460.62	157.99	231.04	5,311.88 (100.00)	969.19 (18.25%)	48.86 (0.89%)	1,018.05 (19.17)

Data from USDA (2008) Census of Agriculture, 2008 FRIS – General Data 91, Table 28. Estimated Quantity of Water Applied and Primary Method of Distribution by Selected Crops Harvested: 2008 and 2003.

* A gravity system is more efficient for other small grains so we left it as such.

** Lettuce & romaine, and potatoes are missing data of each irrigation system, so removed in the calculation of water savings.

*** Water saving of each crop is calculated by multiplying the irrigated area with the reduction of water use per m^3 switching from gravity to pressure/low flow or from sprinkler to low flow.

3.5.2 Scenario 2: Effect of a water price increase on output prices

We use the 19.17% water-saving figure found in the previous scenario as the benchmark for our second scenario. Its driving force is an increase in the price of water which should lead to an increase in the price of the final agricultural goods and reduce their demand and output. According to CAP (CAP, 2009), the 2009/2010 delivery rates for water services were $0.1/$m^3$ for municipal, industrial and federal usages, $0.04/$m^3$ for agriculture and $0.11/$m^3$ for all other usages in Arizona. Based on the traditional input-output assumption that the physical unit of measurement of a good corresponds to the amount that can be bought for $1 (Dietzenbacher and Velázquez, 2007), we find that doubling the price of water used in agriculture would lead to a mere 10.8% increase in the price of locally-produced crops. But how much water would be saved? The literature finds that demand for irrigation water is generally inelastic to water prices in the short-run (Scheierling et al., 2006). However, water price elasticities have been reported in Moore et al. (1994) and Schoengold et al. (2006) for the long run. The first study calculates such elasticities across several types of crops in the Southwestern US: -0.3 for alfalfa, -0.38 for corn, 0.17 for cotton, 0.02 for wheat, and -0.2 for sorghum. Based on these measurements, we calculate that doubling the price of water to $0.08/$m^3$ for these crops would lead to saving only 0.45% of the water devoted to crops each year (m^3 24 million). On the other hand, if we were to assume an average water demand elasticity of -0.184 for all types of crops as found in the latter study (Schoengold et al., 2006), we would conclude that a mere 0.74% water saving would occur. As a consequence, a 19% water saving would require the price of water to increase to 1.08 $/$m^3$. It corresponds to about 27 times the current price. Such an increase in the price of water would cause the output price to be multiplied by 3.74 times (see equation 3-10). Overall, this scenario corresponds to a cost worth $ 8,205.3 million for the crop sector, even when accounting for the water saving.

Even though it is clear that the expected magnitude of the cost associated to scenario 1 is lesser than that of scenario 2, we are aware that our latter measurement may be overstated. Indeed, since the production quantities are unitary price elastic in our approach, then the revenues are constant. As a result, when prices change, the quantities change in direct proportion. A computable general equilibrium model would be needed to circumvent this shortcoming and to consider indirect effects such as the possible substitution between local and foreign goods, a reduction in exports, the possible allocation of farm subsidies, and whether a change in the crop mix and/or in the efficiency of the irrigation system could happen. However, the full quantification of such effects would require the calculation of the associated elasticities for which data are non-existent. As a result, the scope of this paper does not include a CGE model.

3.5.3 Scenario 3: Direct and indirect AZ trade flows and trade balance due to a decrease in agricultural exports

Before we conclude, we investigate a third scenario which is based on the idea of conserving water by reducing the export of crop production (79%). In our input-output framework, a 19.17% water-use reduction in crop can be achieved by decreasing the current level of crop export by 19.5% ($383 million) only. The negative effect on the state's output and value added would be relatively small at around 0.33% and 0.32%, which corresponds to $1,362 million and $389 million, respectively. In terms of employment, it would represent a mere 0.31% decrease (Table 3.7). Furthermore, the trade balance with the rest of the US and of the world would be little impacted with a 0.36% ($ 1,506 million) decrease only (See equation 3-6 and table 3.5). These figures indicate that crop production is a very small share of the state's economy; yet, as seen earlier, it consumes a very large part of its water. We note also from table 3.5 that the majority of these changes would not come from the crop sector itself but from the “industry/services/domestic” sector. The reason is that the crop sector needs more inputs from the latter sector than from any other sector to produce (see table 3.2).

We should note that the effect on the net trade balance may be underestimated due to the partial equilibrium approach we have adopted here. In a CGE framework, one would see that a decrease in crop production would lead to an increase in local prices which could lead to a decrease in local crop consumption and/or an increase in crop imports from the rest of the US or beyond. However, such an exercise, and the demand elasticities it relies on, are left for future research.

Table 3.7 Impact of a 19.5% decrease in crop export

Impact of export decrease	Water use		Output		Value added*		Employment		Trade balance	
	m^3 million	% change	$ million	% change	$ million	% change	Number	% change	$ million	% change
Crop	-1,018.05	-12.10	-410.37	-0.10	-111.36	-0.09	-2,488	-0.08	-193.24	-0.05
Livestock/ aquaculture	-0.76	-0.01	-5.80	-1.40^{-3}	-0.83	-0.69^{-3}	-62	-1.95^{-3}	-379.42	-0.09
Mining	-0.36	-4.27^{-3}	-21.95	-5.31^{-3}	-11.46	-0.96^{-3}	-55	-1.73^{-3}	-371.86	-0.09
Thermoelectric	-0.41	-4.87^{-3}	-16.09	-3.89^{-3}	-10.39	-0.87^{-3}	-26	-0.83^{-3}	-383.31	-0.09
Industry/services domestic/wages	-4.32	-0.05	-907.37	-0.22	-254.94	-0.21	-7,134	-0.22	-178.13	-0.04
Total	-1.023.90	-12.17	-1,361.58	-0.33	-388.98	-0.32	-9,765	-0.31	-1,505.96	-0.36

*Value added does not include employment

3.6 Conclusions

A virtual water flow analysis of the economic and trade structures of the state of Arizona allows us to uncover that crop production consumes as much as 73% of all the water used in the state. It is more than twice the national share. Furthermore, it turns out that the water embedded in crop production does not stay in AZ for long: 79% of the crop is exported to the rest of the nation and abroad. It corresponds to exporting 67% of the state's water. Overall, AZ is a net exporter of virtual water because the water content of the crops it exports surpasses the one of the crops it imports. This apparent contradiction with well-established economic theory of specialization and trade motivates us to investigate three mitigation strategies aimed at preserving this scarce resource while harming the local economy little. All of them have figures set on saving 19% of the state's water as it is the upper threshold that can be reached in the first scenario. It consists in switching the current irrigation system from a gravity system or sprinklers to a pressure system or a low-flow system respectively. Such increase in water use efficiency is estimated to be much less costly than the other two water saving policies we investigate. Furthermore, some parts of Arizona have already completed significant steps to raise the water efficiency of their irrigation system (YAWC, 2015), but our findings indicate that there is still room for improvement. The other two, costlier, scenarios aim at achieving the same percentage of water saving but by increasing the price of irrigated water or by reducing the export of crops. The former is very unlikely as it requires a 27-fold increase in the price of water used for irrigation, which would put it above the price of any other usage. The latter scenario is more plausible considering that the 19.5% reduction in crop export it entails would still allow AZ to export up to 59.6% of its crop production and the impact on each of the major macroeconomic variables (output, employment, value added and trade balance) would be around 0.3% only.

While our results clearly favor the approach of improving water use efficiency, we do not disregard the possibility that combining these three scenarios or complementing them with other approaches such as switching to less water-intensive crops (e.g., millet and sorghum that are well adapted to dry climate and erratic rains) could lead to an affordable solution as well. In either case the questions of who would pay for the change (farmers or customers), how (tax or subsidy) and for how long are important but are left for future research. Furthermore, water rights negotiated long ago (Dunning, 1977; Phare, 2009) and a well-developed network of lobbying are known to present various challenges to any of the scenarios offered here. However, one has to wonder how long it will take Arizona to value the risk mitigating potential of its water given its expected population growth, the low level of the Colorado River of which source is beyond the state's boundaries and the simplicity with which most crops grown in Arizona can be imported from well-rainfed US states.

CHAPTER 4

THE ROLE OF THE SPATIAL EXTERNALITIES OF IRRIGATION ON THE RICARDIAN MODEL OF CLIMATE CHANGE: APPLICATION TO THE SOUTHWESTERN U.S. COUNTIES

4.1 Introduction

A growing number of contributions use the Ricardian framework to assess the impact of climate change on agriculture (Schlenker et al., 2005, 2006; Deschênes and Greenstone, 2007; Dall'erba and Dominguez, 2016). This concept, initiated by Mendelsohn et al. in 1994, offers the advantage to account explicitly for farmers' adaptation to climate change. Other studies provide indirect evidence of the potential for adaptation by showing that crop yields respond to market price changes; suggesting that as crop prices increase due to adverse climatic conditions in the future, farmers are likely to respond by changing production practices and increasing yields (Miao et al., 2016). Significance evidence indicates that adaptation is already taking place among U.S. farmers and that it is not only limited to crop-producers (see, for instance, Schimmelpfennig et al., 1996). Examples of climate change adaptation mechanisms are, for instance, when farmers modify their quantity and mix of inputs and outputs, their tillage and management techniques, their crop-rotation, reduce their herd in dry years, shift to heat- and drought-resistant varieties, etc.

However, in its basic version the model assumes that changes in climate conditions in other localities do not affect local production techniques and choices. This assumption has become impossible to defend considering that the literature has highlighted several sources of spatial dependence by now. They are, among others, ecological fallacy (Ezcuerra et al., 2008), communication between farmers (Polsky 2004, Munshi 2004, Kumar 2011), technology and investment spillovers (McCunn and Huffman 2000, Chatzopoulos and Lippert 2016), the cycle of water (Dall'erba and Dominguez, 2016) and trade (Chen and Dall'erba, 2016). This manuscript focuses on another type, namely surface water flows.

Surface water is well known for the spatial externalities it generates due to its common resource properties. Surface water creates both stock externalities and pumping cost externalities. The former take place when the water pumped by a farmer in period *t* reduces the stock of water available in period *t+1* to all the other farmers located downstream. The latter arise when pumping in one location increases the cost of pumping in any other location due to the lower level of water available, more especially during the dry seasons (Gichuki, 2004). The same phenomena have been highlighted for groundwater (Provencher and Burt, 1993). The presence and enforcement of water rights may modify the allocation of water across farmers (e.g. An and Eheart, 2006; Colby et al., 1993; Foran et al., 1995; Ghimire and Griffin, 2014; Wollmuth and Eheart, 2000) but it does not remove the presence of the above externalities.

Our contribution distinguishes itself from the previous Ricardian literature for various reasons. First, our approach provides us with more appropriate estimates and standard errors as the spatial econometric literature has now provided ample evidence that ignoring spillover effects present in a model leads to biased and inconsistent estimates (Anselin, 1988; Le Sage and Pace, 2009) even when traditional spatial fixed effects are included in the model (Baltagi et al., 2007; Kapoor et al., 2007; Anselin and Arribas-Bel, 2013). Second, while a growing number of Ricardian studies adopt a spatial econometric approach to account for interregional spillovers (Polsky, 2004; Seo, 2008; Lippert et al., 2009; Schlenker et al., 2006), all of these studies define the spatial weight matrix based on geographical proximity only. To our knowledge, the only exception is Dall'erba and Dominguez (2016) where proximity is weighted by the origin-destination relative level of Gross Value Added in agriculture to reflect the spatial differences in the capacity to adopt innovation generated elsewhere (Jaffe, 1993). Here, we push the idea further by creating a spatial weighting scheme based on actual flow data that we consider more appropriate theoretically and empirically as they change over time, they are non-symmetric and they provide a clear idea of directionality. Spatial econometric contributions that have used this approach, although in a very different context, are Eliste and Fredriksson (2004), Chen and Haynes (2015) who use trade flows and Kang and Dall'erba (2015) who rely on actual flows of patent creation-citation. Third, only a handful of Ricardian studies (Deschênes and Greenstone, 2007; Fezzi and Bateman, 2012; Massetti and Mendelhson, 2012) use a panel approach and benefit from its advantages in terms of estimate accuracy and control of omitted variables

Last, but not least, our sample is also different from the traditional water externality literature that has often focused on a specific basin (such as Brozović et al., 2010) or a set of wells (e.g., (Pfeiffer and Lin, 2012)). In the current paper, we focus on the counties of the Southwestern part of the U.S. because recent evidence indicates future climate conditions will very likely challenge their agriculture (Garfin et al., 2013; Dall'erba and Dominguez, 2016). Indeed, this region is not only the hottest and driest part of the country, it is also expected to become warmer in the future. As noted in Dall'erba and Dominguez (2016, p. 47), "the projected climate conditions […] offer a future with more frequent heat waves in summer, decreasing precipitation, more frequent precipitation extremes in winter, a decline in river flows and soil moisture and more severe extremes (droughts and/or floods) in parts of the Southwest." The sector that is the most likely to be affected by such changes is obviously agriculture because it represents a fairly large part of the land of each of the Southwestern states (35% of Arizona's land, 47% of Colorado's, 20% of Utahs' and 55% of New Mexico's) and because it is supported by a well-developed irrigation system composed of canals, reservoirs, dams and the well-known Central Arizona Project. These infrastructures allocate water across its many users but it does not change the facts that surface water originates mainly in the Colorado Rockies and that agriculture (mostly crop production) consumes around 80% of the water available (Bae and Dall'erba, 2016). As a result, changes in the climate conditions in the Rockies is expected to impact more than the local agriculture.

In this paper, we do not use surface water flows for the purpose of highlighting negative externalities in water availability (Gichuki, 2004; Brozovich et al., 2010) or for advocating for irrigation's capacity to mitigate climate variation (Easterling, 1996; van der Velde et al., 2010; Tang et al., 2014). Instead, we use the identification, volume and directionality of these flows to demonstrate that changes in climate conditions in upstream places will affect water access, hence agriculture, downstream (Dall'erba and Dominguez, 2016). As a result, our approach has the potential to provide new insights on the magnitude and precision level of the marginal effects of the climate variables usually used in the Ricardian literature, to generate new estimates on the expected impact of future climate conditions and to suggest adaptation strategies that encompass the counties that share the same streamflow.

In order to tackle these issues, the following section offers a theoretical model of the expected impact of upstream climate conditions on downstream farmland value. The model separates clearly the marginal effects in the low- and the high-irrigated counties as it is well-known irrigation acts as a substitute for local (lack of) rainfall (Schlenker et al., 2005). The following section, section 3, starts with the description of the data and moves on to the surface water flow weighting scheme that will be used in section 4 for econometric purposes. The latter section reports and interprets the estimation results while section 5 provides some concluding remarks.

4.2 Theory and reduced-form model

Following Schlenker et al. (2005), we can approximate the farmland value as the discounted sum of future profits in the equilibrium, i.e., $V = \sigma\pi^*$, where σ is the capitalization ratio and π^* is the maximized profits in the equilibrium. For a representative farmland in irrigated county *i*, we model profit π as a quadratic function of the inputs as in many standard agricultural economic studies, with the index *i* omitted for simplicity:

$$\pi = [\boldsymbol{x}' \quad \boldsymbol{z}' \quad y]\begin{pmatrix} A_{xx} & A_{xz} & A_{xy} \\ A_{zx} & A_{zz} & A_{zy} \\ A_{yx} & A_{yz} & a_{yy} \end{pmatrix}\begin{bmatrix} \boldsymbol{x} \\ \boldsymbol{z} \\ y \end{bmatrix} - \boldsymbol{p}_{\boldsymbol{z}}'\boldsymbol{z} - p_y y - C \qquad (4.1)$$

where $\boldsymbol{x}$ is a n × 1 vector of exogeneous inputs (say precipitation), $\boldsymbol{z}$ is a m × 1 vector of endogenous inputs (fertilizers) and *y* is endogenous irrigation water demand. A is a matrix of production coefficients that characterize the technology. $\boldsymbol{p}_{\boldsymbol{z}}$ is a m × 1 vector of input prices of fertilizers and p_y is the input price of irrigation water. Since the input prices of fertilizers are very similar across different areas of the country (Schlenker et al., 2005) and we are interested solely in the water price, we assume that $\boldsymbol{p}_{\boldsymbol{z}}$ is given and is independent from the variation of water price. Following Mendelsohn et al. (1994) and Schlenker et al. (2005), we also assume that the price of inputs $\boldsymbol{x}$ is constant and is normalized to 1. The variables $\boldsymbol{x}$, $\boldsymbol{z}$ and y are measured in per acre unit, therefore π represents the profits per acre.

The first order condition of profit-maximization assumes that the farmer will find how much fertilizer and water is to be used as follows:

$$z^* = A_{zz}^{-1}\left(\frac{\boldsymbol{p_z}}{2} - A_{zx}\boldsymbol{x} - A_{zy}y^*\right) \tag{4.2}$$

$$y^* = a_{yy}^{-1}\left(\frac{p_y}{2} - A_{yx}\boldsymbol{x} - A_{yz}z^*\right) \tag{4.3}$$

The second-order condition requires that the Hessian matrix of π is negative semidefinite at the optimal point, which implies: $a_{yy} - A_{yz}A_{zz}^{-1}A_{zy} \leq 0$ (4.4)

Combining (4.2) and (4.3), we find the optimal demand of y and z as:

$$y^*(p_y, \boldsymbol{p_z}, \boldsymbol{x}) = \Gamma_y^{-1}\left[\frac{p_y}{2} - \left(A_{yx} - A_{yz}A_{zz}^{-1}A_{zx}\right)\boldsymbol{x} - A_{yz}A_{zz}^{-1}\frac{\boldsymbol{p_z}}{2}\right] \tag{4.5}$$

$$z^*(p_y, \boldsymbol{p_z}, \boldsymbol{x}) = \Gamma_z^{-1}\left[\frac{\boldsymbol{p_z}}{2} - \left(A_{zx} - A_{zy}a_{yy}^{-1}A_{yx}\right)\boldsymbol{x} - A_{zy}a_{yy}^{-1}\frac{p_y}{2}\right] \tag{4.6}$$

where $\Gamma_y = a_{yy} - A_{yz}A_{zz}^{-1}A_{zy}$ and $\Gamma_z = A_{zz} - A_{zy}a_{yy}^{-1}A_{yz}$.

Differentiating y^* with respect to p_y, we have: $\frac{\partial y^*(p_y, \boldsymbol{p_z}, \boldsymbol{x})}{\partial p_y} = \frac{1}{2}\Gamma_y^{-1} \leq 0$

because the second order condition in (4.4) implies $\Gamma_y^{-1} \leq 0$. It corresponds to the fact that π^* is convex. According to (4.5) and (4.6), we can re-write π^*as:

$$\pi^* = \boldsymbol{x}'A_{xx}\boldsymbol{x} - \boldsymbol{x}'\left(A_{xz}\Gamma_z^{-1}A_{zx} + A_{xy}\Gamma_y^{-1}A_{yx} - A_{xy}A_1A_{zx} - A_{xz}A_2A_{yx}\right)\boldsymbol{x} + \boldsymbol{p_z'}\left(\Gamma_z^{-1}A_{zx} - A_2A_{yx}\right)\boldsymbol{x} + p_y\left(\Gamma_y^{-1}A_{yx} - A_1A_{zx}\right)\boldsymbol{x} - \frac{1}{4}\left(\boldsymbol{p_z'}\Gamma_z^{-1}\boldsymbol{p_z} + \Gamma_y^{-1}p_y^2 - p_yA_1\boldsymbol{p_z} - \boldsymbol{p_z'}A_2p_y\right) - C \tag{4.7}$$

where $A_1 = \Gamma_y^{-1}A_{yz}A_{zz}^{-1}$; $A_2 = \Gamma_z^{-1}A_{zy}a_{yy}^{-1}$.

The Envelope Theorem implies that $\frac{\partial \pi^*}{\partial p_y} = -y^*$, which implies that the marginal effect of an increase in p_y increases the costs of agricultural production after taking the substitution effect into account as shown by A_y, but it also influences the profits by altering the marginal effect of the climatic variables on agricultural production. For example, rainfall becomes more important to crop growth when the cost of irrigated water rises while the lack of precipitation is less harmful to the farmers with access to cheap water.

While the water needed for agricultural production purposes in a county is rather inelastic, the supply of surface stream water varies from year to year because, for most counties, the stream originates in an upstream county and relies heavily on its local climate conditions. For instance, about 95 percent of the water needed for cotton production in California is obtained from either groundwater or from surface water of which source is more than 500 miles away (Schlenker et al., 2005). As such, we define the irrigation surface water available in county *i* as:

$$Y_i = g_i(q_o, q_i) \tag{4.8}$$

where $q_o = q(\sum_{j \neq i}^{n} w_{ij} x_j)$ defines the surface water originating from outside county *i*. x_j stands for the climatic variables of counties *j* identified as being located upstream of county *i* by the interregional stream flow weight matrix w_{ij} . $q_i = q(x_i)$ stands for the surface water supply that originates from county *i* itself, hence it is a function of local climate conditions. Even though water is provided from the surface water system, restrictions on the quantity of water that can be pumped are often imposed on farmers (Schlenker et al., 2005), therefore a function $g_i(.)$ is used to characterize the contractual and legal water rights as well as any specific water policies that may vary across different regions. We assume that the water available in county *i* increases with the outside water supply:

$q_o = \frac{\partial Y_i}{\partial q_o} > 0.$

In the equilibrium, the input price of irrigation water is determined by equating demand and supply:

$$Ny_i^*(p_{y_i}, \boldsymbol{p_z}, x_i) = Y_i \qquad (4.9)$$

where N stands for the quantity of farmland within county i that requires irrigation.

By solving (9), we obtain the equilibrium price of water for county i represented by $p_{y_i}^*$:

$$p_{y_i}^* = 2(\Gamma_y \frac{Y_i}{N} + \left(A_{yx} - A_{yz}A_{zz}^{-1}A_{zx}\right)\boldsymbol{x} + A_{yz}A_{zz}^{-1}\frac{\boldsymbol{p_z}}{2}) \qquad (4.10)$$

From (4.10), it can be observed that $\frac{\partial p_{y_i}^*}{\partial Y_i} = \frac{\partial \Gamma_y}{N}$ <0 , indicating that the price of water rises as water availability decreases. This corresponds to the expected water pricing mechanism as a water district must raise the water price in years of short supply so that it can cover the fixed costs of operating and maintaining the irrigation system (Wichelns, 2010).

In order to illustrate the role of the spatial externalities of irrigated surface water q_o on farmland value, we investigate how a change in the former affects the equilibrium profits and thus the farmland value of county i :

$$\frac{\partial V_i}{\partial q_o} = \sigma\left(\left.\frac{\partial \pi_i^*}{\partial p_{y_i}}\right|_{p_{y_i}=p_{y_i}^*} \frac{\partial p_{y_i}^*}{\partial Y_i}\frac{\partial Y_i}{\partial q_o}\right) \geq 0 \qquad (4.11)$$

The first term of (4.11) results from the Envelope Theorem where $\frac{\partial \pi^*}{\partial p_{y_i}} = -y_i^*$ is negative. The second partial derivative has the form $\frac{2\Gamma_y}{N}$ that is non-positive according to (4.4). The last term is positive by assumption (4.8). Since q_o is a function of the upstream climate conditions $\sum_{j\neq i}^{n} w_{ij}x_j$, then whenever the climate variables in $j \neq i$ increase q_o in county i, the farmland value of county i rises.

4.3. Data and streamflow weight matrix

4.3.1 Data

We apply our approach to the 138 counties of Arizona, New Mexico, Colorado and Utah. Thirteen of the counties that compose this group need to be removed for different reasons: five of them have no or very little agricultural activity as indicated by the absence of employment in agriculture[10]. In addition, we remove eight urban counties[11] because the literature has shown that their farmland value is not necessarily driven by agricultural productivity but by the option of developing land for further urban uses (Plantinga et al., 2002; Schlenker et al., 2006). They are identified as counties where the population density is above 400 inhabitants per square mile in 2007. This sample was used by Dall'erba and Dominguez (2016) but in a cross-section setting. We revisit it in our panel data model to provide more efficient estimates, include spatial fixed-effects that control for omitted variables, and model the spatial externalities of irrigation in a structure that is closer to the actual interregional flows of surface water.

Our dependent variable is farmland value per acre from the Census of Agriculture, USDA every five years from 1993 to 2012. Our independent variables are composed of three groups: a set of socioeconomic variables, a set of climate conditions and a couple of soil conditions. All the economic variables are converted to constant 2012 US dollars using the corresponding Consumer Price Index. Human intervention takes the form, first, of the level of demand and of the potential effect of development upon farmland value. As such, we capture these effects through per capita income and population density. We also include

[10] San Juan, Gilpin, Clear Creek and Lake in Colorado as well as Los Alamos in New Mexico.
[11] Davis, Salt Lake in Utah; Maricopa in Arizona; Bernalillo in New Mexico; Boulder, Jefferson, Denver and Arapahoe in Colorado.

elements representing the production process. They are irrigation (% of irrigated farmland) from USDA's National Resources Inventory and the use of fertilizers from USDA.

The climate variables are obtained from NARR (North American Regional Reanalysis), which is used as the proxy for observations as it assimilates observed precipitation and temperature. These additional variables are also available in the downscaled climate simulations. NARR data are available for the conterminous US and are at a 32-km spatial resolution. We use standard interpolation techniques and area-weighted averaging (available in, for example, ArcGIS software) to obtain unique values over each county. The high spatial resolution of these data allows us to obtain accurate estimates of climate variables within each county for all the US counties. Because of the high degree of multicollinearity among the climate variables, we are not able to include all the seasons in our analysis. As a result, we include the summer and winter precipitation and temperature. As indicated in Dall'erba and Dominguez (2016), most of the precipitation takes place during these two seasons in the Southwest. Furthermore, most crops available in that part of the country grow during summer. We also include the squared value of precipitation as a way of testing the nonlinearity of its marginal effect. We do not do the same with temperature because of a high level of multicollinearity.

Finally, we include an index of soil erodibility (K-factor in the Universal Soil Loss Equation) and of permeability from USDA's General Soil Map (STATSGO2) National Resource Inventory. These two factors have been chosen among other soil characteristics because erosion is common in the Southwest due to low annual rainfall and the poor soil water storage capacity. The latter element is captured through the permeability measure.

The basic statistics associated to all these variables are reported in Table 4.1 below. More precisely, we report these values for the groups above and below the median elevation value (1.87 km). Following Dall'erba and Dominguez (2016), our idea is to verify if the marginal effects of the lowland counties (in southern Arizona, southern New Mexico and the eastern part of Colorado) differ from the ones of the highland counties (in western Colorado, northern New Mexico, northern Arizona and the Northeastern part of Utah).

Table 4.1 Basic statistics of climate and soil variables

	High elevation counties (>1.87km)				Low elevation counties(<1.87km)			
Variable	Mean	Std. Dev	Min	Max	Mean	Std. Dev	Min	Max
Farmland value ($/acre)	1,937	1,435.7	145.8	1,1520	1,256	1,649.5	197.8	1,2680
Per capita Income ($)	29,478	11,688.5	11,859	88,163	26,337	8,433.6	12,539	63,434
Density (person/square mile)	25.238	54.456	0.455	354.049	24.365	59.155	0.329	388.594
Share of irrigated land in farm	0.654	0.267	0.045	0.9857	0.371	0.255	0.004	1
Fertilizers ($/acre)	5.072	9.829	0.006	62.778	12.255	51.8	0.005	607.176
Summer precipitation (mm/day)	1.160	0.541	0.224	2.721	1.295	0.728	0.071	3.297
Winter precipitation (mm/day)	0.832	0.525	0.069	2.384	0.571	0.400	0.031	2.022
Summer temperature(°C)	21.48	4.219	11.68	29.77	29.43	2.765	19.20	36.14
Winter temperature(°C)	-6.256	3.133	-11.533	2.492	0.626	4.513	-7.103	12.096
Squared summer precipitation	1.638	1.463	0.050	7.402	2.204	2.315	0.005	10.869
Squared winter precipitation	0.966	1.097	0.005	5.682	0.486	0.683	0.001	4.087
K-ratio (erodibility)	0.190	0.049	0.093	0.300	0.231	0.048	0.119	0.327
Awc-ratio (permeability)	0.119	0.018	0.075	0.152	0.125	0.032	0.049	0.187

4.3.2 Stream flow weight matrix using STARS toolset

We use the spatial tools for the Analysis of River Systems (STARS) ArcGIS custom toolset developed by Peterson et al. (2007) to generate the spatial weight matrix in conjunction with the linkage of river streams. In the STARs toolset, a series of geoprocessing tools are provided to build the spatial data required for spatial modeling: the Watershed attributes, the Segment PI, the Additive Function and Upstream distance (Peterson and Hoef, 2010; Peterson and Ver Hoef, 2014). Figure 1 shows the dendric system of natural stream lines and more downstream edges are expressed with thicker lines based on the Strahler's stream order. Man-made canals are also considered to build our weight matrix, as shown in Figure 4.1.

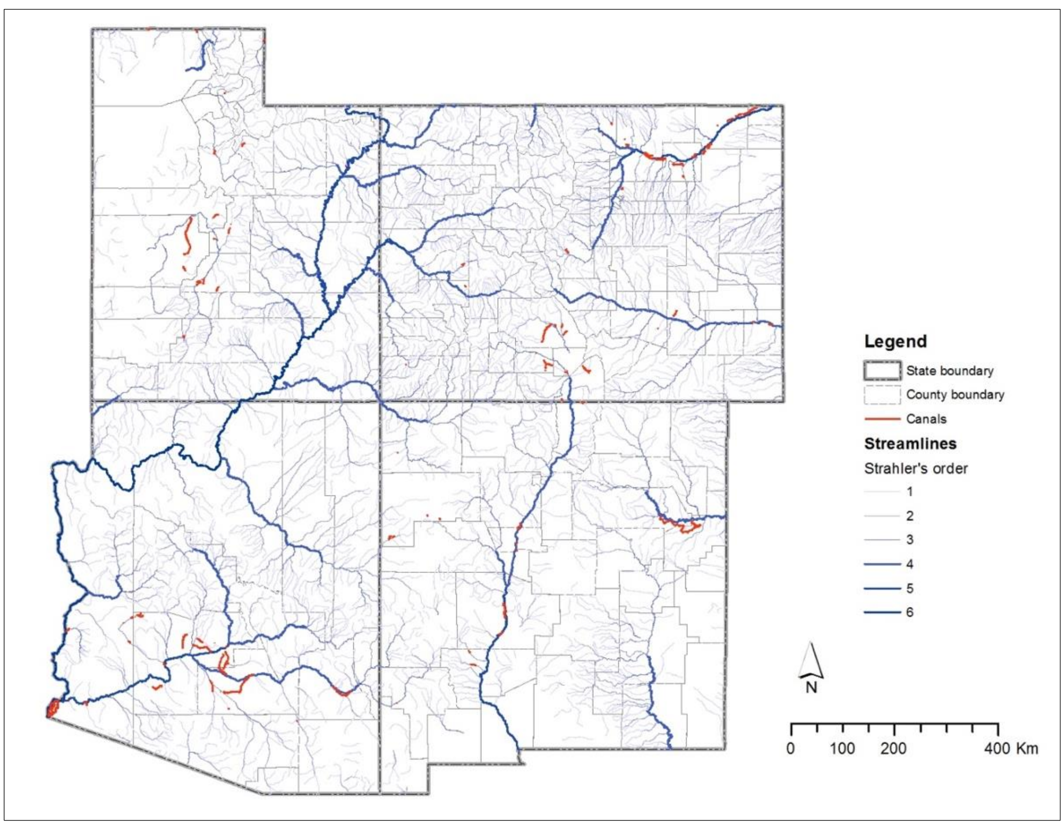


Figure 4.1 Stream flow connectivity in the four states in the US Southwest

Note: The stream lines are categorized by Strahler's stream order, and it increases numbers toward downstream.

Figure 4.2 displays the directionality of each stream edge. STARS checks the network topology for each node and converging stream nodes should be modified before the analysis. Converging stream node error occurs at the point of the downstream node when more than two edges converge but do not flow into another downstream edge.

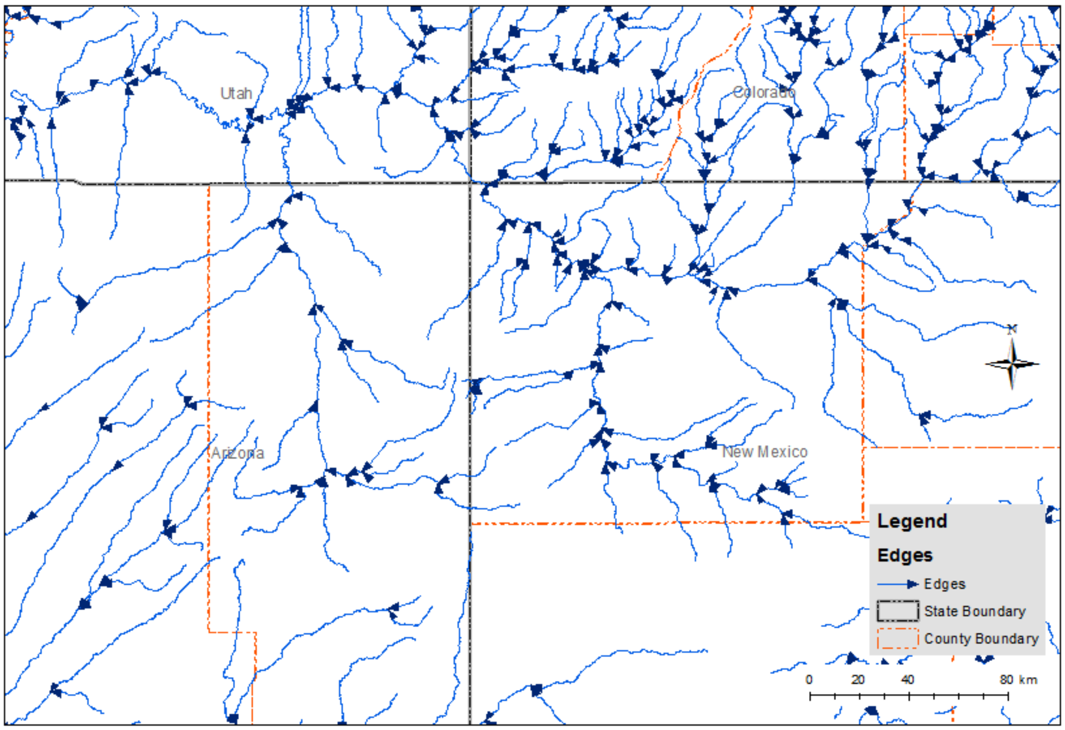


Figure 4.2 Flow network and directionality

Note: Regarding the stream flow direction, converging streams are manually removed before GIS analysis.

The first step to weight for the tail-up model consists in generating the PI**,** which is defined as the influence of an upstream location on a downstream location. To begin, each stream segment is represented as a directed line with nodes in ArcGIS. Those stream segments are identified as $j = 1, 2, 3, \dots . n$; therefore, each location of segment is denoted as x^j. The PI for each segment is the proportion of its cumulative watershed area for the total incoming area (Peterson et al., 2007). The watershed area of edge *i* is calculated by the Reach

Contribution Areas (RCAs) function that builds a one-to-one relationship between edges and RCAs. The PI should range between 0 and 1 and always sum to 1 at the stream confluences. The PI is calculated by equation (4.12), where W_i is the watershed area of edge i, and W_j is the watershed area of edge j.

$$\omega_i = \frac{W_i}{W_i + W_j} \tag{4.12}$$

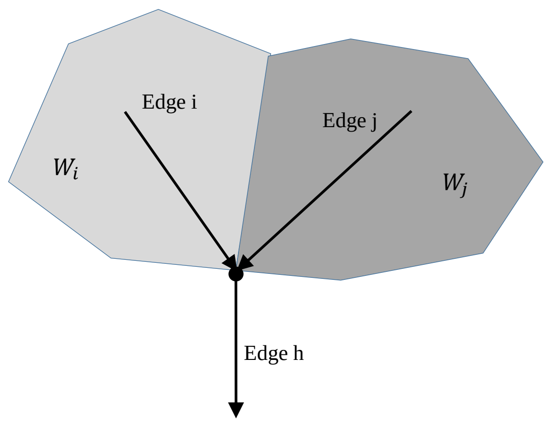
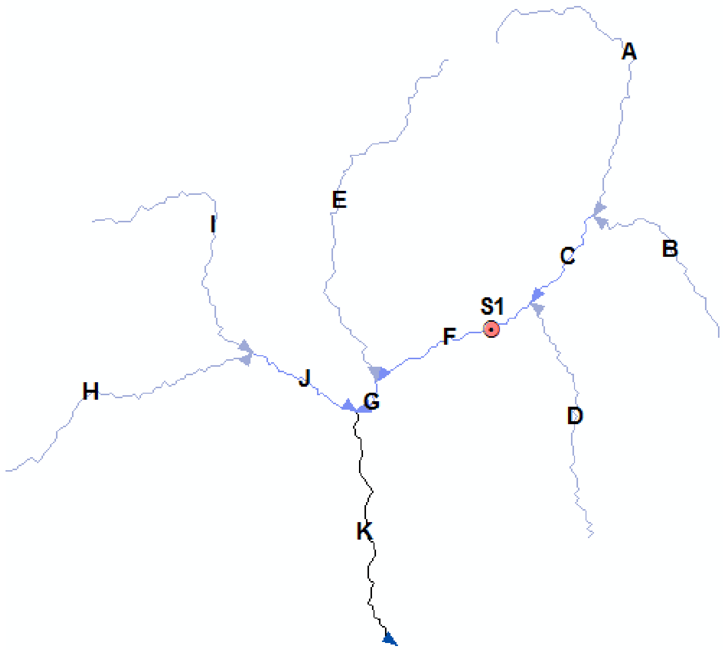


Figure 4.3 The segment Proportional Influence (PI) calculation

In the second step, the segment PIs are used to calculate the segment additive function value (AFV). We create the AFV for a given edge j that is defined to be equal to the value of PI of jth edge along the stream path downstream (Peterson and Ver Hoef, 2014). The most downstream segment is set as 1 in the network in the calculation of the AFV. It is considered that there exists a non-symmetric correlation between flow-connected downstream and upstream sites. The example calculation for a site located on the edge is illustrated in Figure 4.13.

$$AFV_j = \prod_{m=1}^{n} \omega_{D_{j,m}} \tag{4.13}$$



If site S_1 is located on edge F,

$$\omega_i = \frac{W_i}{W_i + W_j}$$

$$\omega_F = \frac{W_F}{W_F + W_E}$$

$$D_{[F]} = [\mathrm{F, G, K}] = [D_{F,1}, D_{F,2}, D_{F,3}]$$

$$AFV_{S_1} = AFV_F = \prod_{m=1}^{n} \omega_{D_{F,m}} = \omega_F \times \omega_G \times \omega_K$$

Figure 4.4 Calculating the AFV for a site on each edge

In the final step needed to generate a valid flow-connected weight matrix, the weighted stream flow matrix is built at the county level. Along the path downstream, the downstream counties are affected by upstream counties. If an edge j is lying across the county boarder, we assume that upstream segment group A inside county N_i affects county N_j directly as well as N_k indirectly (see Figure 4). The indirect impact diminishes in proportion to the distance between the upstream county and the downstream counties. To account for the impact of segment group A, the accumulated value of RCAs is captured in edge j. Note that the accumulated value is not the measure of stream flow quantity but the topological area that captures rainfalls. The covariance between two flow-connected counties, N_i and N_j, could be represented as in equation (4.14) where h is the hydrologic distance between two counties, and $\sum_{k=1}^{n} W_k$ represents the spatial weights based on RCAs accumulation.

$$C\ (N_i, N_j \mid \theta) = \begin{cases} 0 & \text{if } \mathrm{N_i} \text{ and } \mathrm{N_j} \text{ are flow} - \text{unconnected} \\ \sum_{k=1}^{n} W_k/(d|\theta) & \text{if } \mathrm{N_i} \text{ and } \mathrm{N_j} \text{ are flow} - \text{connected} \end{cases} \quad (4.14)$$

Because the value of RCAs accumulation on the downstream county becomes larger than on the upstream county, we input more weight toward the downstream counties by considering the topological concentration of stream flow. The distance between neighboring counties N_i *and* N_j is given the value of 1 to impose a higher connectivity weight. The final weight matrix for the 138 counties is calculated as follows:

$$\begin{bmatrix} c_{11} \times AFV_{11} & c_{12} \times AFV_{12} & c_{1n} \times AFV_{1n} \\ c_{21} \times AFV_{21} & c_{22} \times AFV_{22} & c_{2n} \times AFV_{2n} \\ \cdots & \cdots & \cdots \\ c_{n1} \times AFV_{n1} & c_{n2} \times AFV_{n2} & c_{nn} \times AFV_{nn} \end{bmatrix} \quad (4.15)$$

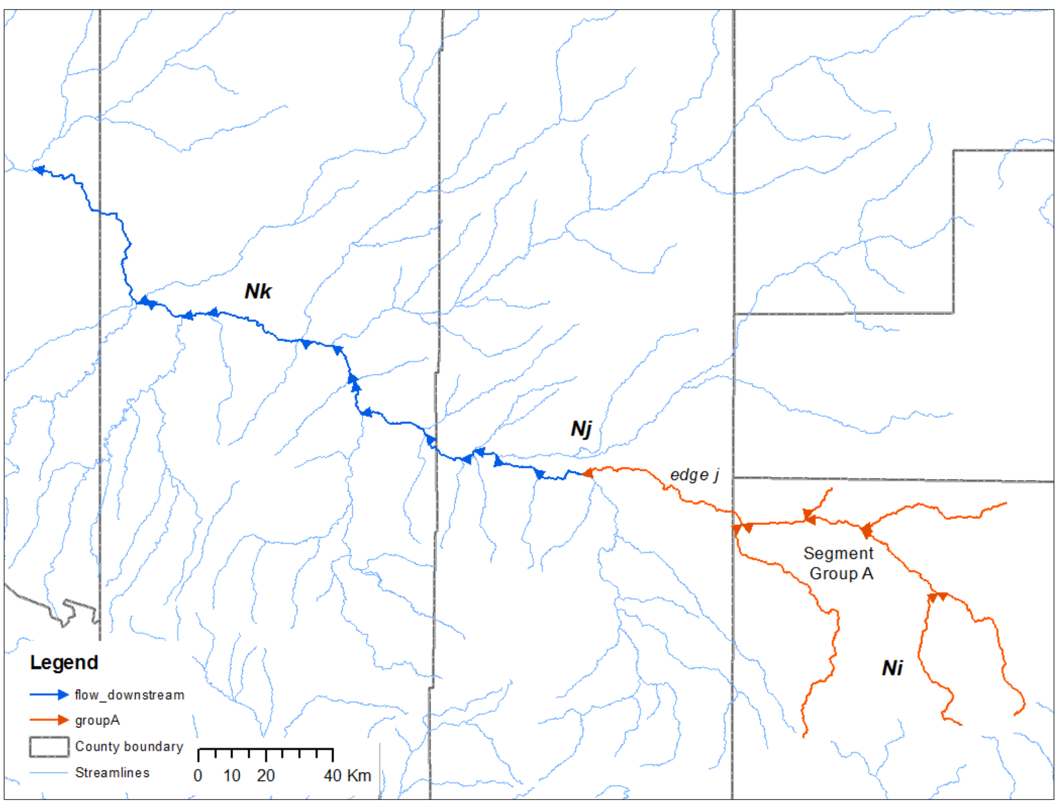


Figure 4.5 Flow-connectivity at a county level

4.4 Estimation results

Table 4.2 below starts with an OLS estimation of a pooled panel data model with time- and state-fixed effects[12] that can be written as follows:

$$\mathrm{y}_{ijt} = \alpha + X'_{ijt}\beta + Z'_{ij}\delta + \mu_j + \varepsilon_t + u_{ijt} \quad \text{with } u_{ijt} \sim N(0, \sigma_u^2) \qquad (4.16)$$

where $i = 1, 2, \ldots$n stands for the counties, $j = 1, 2, 3, 4$ denotes the states, and $t = 1, 2, \ldots$T is the time index. X is a matrix of space- and time-variant socio-economic and climate controls while Z is a matrix of space-variant soil conditions. μ_j and ε_t are state- and time-fixed effects respectively. They control for unobservable factors that might confound the marginal effect of climate (Schlenker et al., 2006; Deschênes and Greenstone, 2007). The year fixed effect captures the time trend, such as changes in commodity prices, weather shocks, technological innovations and policy shocks that are common to the entire sample. State-fixed effects, on the other hand, do the same but for each individual state. Finally, u_{ijt} denotes the error terms with the usual *i.i.d.* properties.

Diagnostic tests indicate the significant presence of remaining heteroscedasticity (BP test shows a p-value=0.000) and serial correlation (Breusch-Godfrey test has a p-value=0.000). On the other hand, there is no spatial error autocorrelation (Moran's I test) probably because the state-fixed effects already control for dependence across the counties of the same state and dependence across counties of different states is limited. As a result, the standard errors presented are robust to both heteroskedasticity and serial-correlation.

[12] In order to avoid perfect multicollinearity with the general intercept, Utah and the year 1997 have been arbitrarily chosen as the base State and year respectively. Other pooled panel data model specifications were estimated (without fixed effect at all and with one type only), but a likelihood ratio test confirmed they led to lower log likelihood values. We also tried a county fixed effect model since a significant Hausman test (p-value=0.000) indicates it outperforms the random effect model. However, model (15) still outperforms the fixed effect model. Complete results available from the authors upon request.

The results on the socio-economic variables meet the expectations of the Ricardian literature in general and of the cross-sectional results of Dall'erba and Dominguez (2016) in particular. Indeed, per capita income and density have a significant impact on farmland values at the 10% level (Plantinga et al., 2002). Denser areas have a higher propensity to buy farmland for higher-valued activities. Moreover, irrigation and fertilizer are also found to act positively on farmland values, which confirm our expectations too.

When it comes to the weather conditions, the results differ by season. Summer precipitation and temperature act negatively on farmland value. Garfin et al. (2013) have demonstrated that intense precipitation due to summer thunderstorms leads to floods, property damages and even casualties in the Southwest. Summer is also the period when heat waves take place (e.g., the 2013 heat waves that reached a record 49℃ in Arizona). On the other hand, winter precipitation and temperature display a positive impact on farmland values. The reason could be because "winter precipitation contributes to building a snowpack that provides a natural and reliable water reservoir for the region throughout the rest of the year" (Dall'erba and Dominguez (2016, p. 58). We also find that, for both seasons, there is a non-linear effect of precipitation as indicated by the significant coefficient associated to their squared value.

Finally, we find that erodibility reduces farmland values while permeability increases it. These results were expected as erosion and permeability act in opposite ways on productivity. Erosion is known to be a problem in the arid or semi-arid parts of the Southwest where the vegetative cover is too thin due to low annual precipitation and poor soil water storage capacity. While, in general, the soil in the Southwest is less permeable that in the rest of the country, the level of permeability differs across its areas (see table 1). Permeability promotes root development and water movement in the soil, hence its positive impact.

One assumption that has not been tested so far is the presence of heterogeneity in the sample. As indicated in Dall'erba and Dominguez (2016) and Garfin et al. (2013), the Southwest can be split between highland and lowland counties because of the difference in climate and ecosystems that goes with elevation. Furthermore, it is expected that the marginal effect of the weather variables varies with elevation. Zhang et al. (2013) show it is the case for extreme weather events. Such as model can be written as follows:

$$y_{ijt} = \alpha_L + \alpha_H + X'_{ijt}\beta_L + X'_{ijt}\beta_H + Z'_{ij}\delta_L + Z'_{ij}\delta_H + \mu_j + \varepsilon_t + u_{ijt} \text{ with } u_{ijt} \sim N(0, \sigma_u^2) \quad (4.17)$$

where the subscripts L and H stand for a dummy variable for the lowland and the highland counties respectively. The fixed effects and disturbance terms are the same as in equation (4.18).

The Chow test result, reported in the third column of table 4.2, confirms the significant presence of two sub-groups (p-value=0.000). Furthermore, a likelihood ratio test indicates this model outperforms the previous one in terms of (log) likelihood value. Due to the significant results of the BP and BG tests (but not Moran's I), the standard errors are again heteroscedasticity- and serial correlation consistent.

While most of the socio-economic variables display results that are consistent with the previous model, the marginal effect of income has become non-significant. One possible reason is offered in Dall'erba and Dominguez (2016, p.55) who claim: "in the Southwest the need for land to be converted to urban purposes is largely limited to the few existing urban centers". We note also that the role of precipitation is significant in the lowland counties only.

We hypothesize that it is because they are drier and their rainfall is delivered through extreme events more often than in the highland counties. On the other hand, agricultural productivity seems sensitive to both summer and winter temperature in the highland counties only. The lowland counties are affected by winter temperature only and, not surprisingly, when the latter goes down, so does their farmland value. The non-linear effect of precipitation is confirmed. Furthermore, we note that the influence of erodibility and permeability is significant in the lowland counties only. They display higher mean, maximum value and standard deviation in these variables than their highland counterparts. The pooled OLS failed to capture this heterogeneity as permeability has no significant influence on farmland value in this model.

Finally, our last model consists in testing if the weather conditions in the upstream counties affect farmland values in the downstream counties. In that purpose, we estimate the following model where the spatial lag of the weather conditions and of irrigation (noted W[13]) is based on the surface water irrigation flows depicted in section 4.3.2.

$$y_{ijt} = \alpha_L + \alpha_H + X'_{ijt}\beta_L + X'_{ijt}\beta_H + Z'_{ij}\delta_L + Z'_{ij}\delta_H + W'_{ijt}\theta_L + W'_{ijt}\theta_H + v_{ijt}$$

$$\text{with } v_{ijt} = \mu_j + \varepsilon_t + u_{ijt} \text{ and } u_{ijt} \sim N(0, \sigma_u^2) \qquad (4.18)$$

A significant Chow test and LR test indicate that structural instability, like in model (4.17), is still present but that model (4.18) outperforms model (4.17) in terms of (log) likelihood value respectively. The direct effects in each group display a fairly similar magnitude and precision and, more importantly, the exact same sign as in model (4.17).

[13] The surface water flow matrix is globally standardized (*ij* link divided by the sum over all links) so that we do not modify the internal neighborhood structure (Kelejian and Prucha, 2010).

However, one could claim that model (4.17) suffers from a missing variable bias as both theory (see section 4.2) and empirical evidence indicates that the weather in upstream locations influences the availability of water for irrigation, hence farmland value, in downstream locations. Our estimation results indicate that these spillovers are significant in the lowland counties only, which makes sense since they are the downstream counties too.

Interestingly, we find that winter precipitation, summer temperature and winter temperature in the counties upstream of the lowland counties display a significant impact on farmland value in lowland counties. As expected, we find that the marginal effect of these spillovers displays the same sign as the one of the direct effect. It also means that the overall marginal effect of any of these covariates is not $\partial y/\partial x = \beta_L$ anymore but $\partial y/\partial x = \beta_L + \delta_L$. For instance, while model (4.17) indicates that, across lowland counties, one additional mm of rainfall per day increases farmland value by \$ 1,363 per acre, model (4.18) indicates that the increase is actually \$ 1,383. In fact, 90% of the increase (\$ 1,248) comes from precipitation falling in the county itself while the remaining 10% (\$ 134.8) come from additional rainfall in the upstream counties that combine both lowland and highland counties. Similarly, we find that the effect of one additional °C in winter does not increase farmland value/acre by \$ 103 as predicted by model (4.17) but by \$ 84. 72% of it is due to an increase in local temperature while the rest comes from upstream counties. When it comes to summer temperature, the detrimental effect is only due to changes in upstream locations. In sum, our results show that ignoring such spillovers leads to erroneous conclusions about the extent and spatial origin of the marginal effects of the weather conditions.

Table 4.2 Estimation results of spatial models (dependent variable: farmland values per acre)

	OLS pooled model	A-spatial model		SLX model			
				High		Low	
		High	Low	Direct effect	Indirect effect	Direct effect	Indirect effect
Intercept	3,857.600 (0.000)	7,262.400 (0.000)	3,369.200 (0.049)	7,618.700 (0.000)		2,728.900 (0.110)	
Income	0.024 (0.076)	0.022 (0.181)	0.002 (0.874)	0.024 (0.144)		<0.001 (0.962)	
Density	8.174 (0.000)	9.572 (0.000)	7.221 (0.004)	9.159 (0.000)		11.004 (0.001)	
Fertilizer	16.867 (0.000)	10.848 (0.057)	15.869 (0.000)	9.188 (0.102)		16.217 (0.000)	
Irrigation	1,341.400 (0.000)	1,102.900 (0.000)	1,880.300 (0.000)	995.930 (0.006)	317.360 (0.529)	1,748.300 (0.001)	142.370 (0.387)
Prec. summer	-919.310 (0.032)	-126.450 (0.862)	-1,275.300 (0.015)	-167.540 (0.818)	-425.520 (0.188)	-1,155.1 (0.044)	5.310 (0.899)
Prec. winter	1,361.200 (0.007)	881.310 (0.165)	1,363.100 (0.051)	703.460 (0.289)	473.380 (0.270)	1,248.400 (0.076)	134.810 (0.099)
Temp. summer	-177.780 (0.000)	-256.73 (0.000)	-76.898 (0.191)	-257.090 (0.000)	4.652 (0.617)	-51.793 (0.383)	-8.213 (0.020)
Temp. winter	129.000 (0.000)	219.44 (0.000)	103.240 (0.000)	226.680 (0.000)	-14.728 (0.708)	61.688 (0.034)	22.532 (0.069)
Sq. prec. Summer	227.740 (0.032)	-151.080 (0.548)	352.420 (0.011)	-89.121 (0.723)		317.080 (0.027)	
Sq. prec. Winter	-601.310 (0.009)	-555.890 (0.059)	-400.420 (0.284)	-509.840 (0.091)		-461.770 (0.230)	
K-ratio (erodibility)	-5,212.100 (0.001)	-2,373.100 (0.309)	-9,527.200 (0.000)	-3,985.700 (0.093)		-9,393.600 (0.000)	
AWC-ratio (permeability)	3,723.700 (0.173)	733.760 (0.842)	9,699.000 (0.003)	1,204.000 (0.751)		10,210.000 (0.751)	
State dummies	Yes	Yes		Yes			
Year dummies	Yes	Yes		Yes			
N × T	500	252	248	252		248	
Adj. R^2	0.640	0.830		0.837			
Log Lik	-4,126.807	-4,107.910		-4,091.752			
Chow test	-	5.757 (0.000)		4.154 (0.000)			
Likelihood ratio test	-	37.193 (0.000)		32.316 (0.000)			
BP test	75.845 (0.000)	84.395 (0.000)		81.461 (0.000)			
Breusch-Godfrey test	101.300 (0.000)	89.023 (0.000)		74.229 (0.000)			
Moran's I test	0.021 (0.161)	0.0175 (0.205)		-0.009 (0.601)			

The reported p-values are based on heteroskedasticity (White) and serial correlation-robust standard errors. For the state- and year-fixed effects, the base State is Utah and the base year is 1997.

4.5 Conclusions

An increasing number of Ricardian studies have recently adopted a spatial econometric approach to highlight the role of interregional externalities in the impact of climate change on agriculture (Polsky, 2004; Seo, 2008; Lippert et al., 2009; Dall'erba and Dominguez, 2016). Yet, the large majority of these studies rely on a traditional definition of interregional linkages defined on geographical proximity. Our manuscript takes a novel approach in that dependence is based on upstream-downstream relationships of surface water flows. Moreover, it builds on the nascent panel data approach in the Ricardian framework (Deschênes and Greenstone, 2007; Fezzi and Bateman, 2012; Massetti and Mendelsohn, 2011) to uncover how weather conditions and irrigation in upstream locations affect water availability, hence agricultural productivity and ultimately farmland value in downstream locations. Our approach is applied to the counties of the four corner States because irrigation is critical for agriculture in general and for crop production in particular in that part of the country. Moreover, the combination of a growing urban population and of a projected increase in temperature and extreme heat events will offer new challenges to the local ecosystem (Garfin et al., 2013).

Our results indicate, first, that lowland and highland counties need to be treated separately as statistical tests and previous literature (Zhang et al., 2013; Dall'erba and Dominguez, 2016) indicate that the marginal effect of the weather variables varies with elevation. Second, while we find that local irrigation and weather conditions have the expected impact on local agriculture, we also highlight how the weather conditions in upstream counties significantly affects downstream agriculture. It allows us to provide a more accurate measurement of the marginal effect of the weather conditions and to disentangle its local amount from its interregional amount.

Future research efforts will focus on calculating the consequences of our new estimates on future farmland values. Indeed, even though our results are calibrated over historical data, it is straightforward to use them in combination with projected climate conditions to generate new predicted figures of farmland values. We anticipate that this exercise will suggest more accurate estimates of the impact of climate change and, subsequently, a set of adaptation strategies that encompass locations that share the same streamflow.

CHAPTER 5
CONCLUSION

In this dissertation, we have provided some improvements on the way to estimate the economic impact of climate change on agriculture and energy. All applications focused on the US Southwest as it is the driest and hottest part of the country, and its population is still growing. After a short introduction offered in Chapter 1, Chapters 2 and 3 focused on an input-output application. I/O is a powerful tool to understand how climate change-induced adaptation strategies have economic consequences and how the latter can be measured. In particular, we have estimated the impact on economic output, income, jobs related to installing a new utility solar farm. Results show that the benefits of such an infrastructure go beyond just a carbon emission reduction. In addition to demonstrating the economic compensation of these mitigation efforts, we also show how their impact varies based on the location of the facility. This result comes from different locations offering different levels of multipliers. Additionally, I/O is useful to capture the water content embodied in trade patterns, so that various water-saving scenarios and their impact on the local economy can be tested. The results generated by I/O could help state and local policy-makers justify investment for renewable energy facilities and manage future natural resources.

In Chapter 2, we examine the economic impact of a 550MW solar farm installation using the I/O framework. The Topaz solar farm, built in 2011 in California, serves as a benchmark to measure the economic impact of the same investment in Arizona. The results, generated by the IMPLAN model and the JEDI solar PV model, are also compared. Thus four models—TSF IMPLAN, California JEDI, Arizona IMPLAN and Arizona JEDI model—

are estimated. While their results differ, they offer a reasonable range. All four models estimate that the majority of job creation (80%) takes place during the construction period. One significant difference is that the direct labor income estimates from the JEDI Arizona model are almost twice larger than the IMPLAN Arizona model during the construction period. This could be due to JEDI providing more precise average income value per worker in the solar industry, while IMPLAN does not distinguish this sector from the general construction sector. Both the IMPLAN and JEDI models find out that there are slightly larger indirect and induced income effects in California than in Arizona: they are 1.08 times larger for income multiplier and 1.14 times larger for output multiplier. Although JEDI's multipliers are originally built on the multipliers from the IMPLAN data, their industry-specific adjustments make JEDI a very efficient tool to perform input-output on renewable energy.

In Chapter 3, the use of I/O is incorporated with virtual water multipliers which are calculated from water use in Arizona and the whole US. A virtual water flow analysis of the state of Arizona reveals that (1) the majority of water (73%) is used for crop production, (2) only 33% of state's water is consumed locally, and (3) Arizona is a net exporter of virtual water. These findings indicate that the current trade pattern imposes more water stress in Arizona. In order to enhance the water use efficiency, we propose three water-saving scenarios. Aiming at a 19.5% water-saving objective, each scenario ties in (1) the maximum of improvement of irrigation system, (2) a 27-fold increase of irrigated water price, and (3) a 19.5% reduction of crop export. We conclude that scenario 3 is the most feasible because it only reduces the total output of Arizona's economy by 0.3% and 59.6% of AZ's crop production can still be exported.

Chapter 4 offered a spatial econometric study highlighting the role of spatial dependency of upstream and downstream regions. The majority of previous spatial econometric studies that use the Ricardian framework rely on geographical proximity to define interregional linkages. Here, our approach accounted for directionality and connectivity in the surface water network. On the basis of a panel data model, the impact of long-term weather conditions in upstream counties on downstream counties are measured for the four corner States. The model results highlight several important points. First, the marginal effect of the weather variables changes with elevation; thus the Southwest can be split between highland and lowland counties (Zhang et al., 2013; Dall'erba and Dominguez, 2016). Second, we conclude that the weather in upstream counties has a significant influence on farmland values in downstream counties. This approach allows us to provide a more accurate measurement of the marginal effect of the weather conditions and to disentangle its local amount from its interregional amount.

Appendix A1. Industry Aggregation scheme of JEDI PV model

Aggregated JEDI industry name	IMPLAN Industry code
Agriculture	1-19
Mining	20-30
Construction	34-38
Construction – Nonresidential	39
Construction – Residential	40
Other Manufacturing	41-185, 187-206, 208-221, 225-231, 234-265, 267, 271, 274, 276-318
Fabricated Metals	186
Machinery	207, 222-224, 232-233
Electrical Equipment	266, 268-269, 273, 275
Battery Manufacturing	270
Energy Wiring Manufacturing	272
Semiconductor and related devices	243
Wholesale Trade	319
Retail Trade	320-331
Transportation, Communication, and Public Utilities	31-33, 332-335, 337
Finance	354-356
Insurance and Real Estate	357-361
Other Professional Services	367, 374-376, 381
Architectural and Engineering	369-370
Office Services	368
Other Services	336, 338-366, 371-373, 377-380, 382-426, 433-436
Government	427-432, 437-440

Edited from JEDI PV 2008 Industry Aggregation Scheme (PV model only), NREL.

Appendix A2. Input-output Data Aggregation Process

The "public supply" sector of USGS covers "users for domestic, commercial, and industrial purposes". The difference between the latter sector and the "domestic" and "industrial" sectors is unclear, hence we decide to aggregate them into a sector we call "Industry/services/domestic". The irrigation sector originally defined by USGS includes crops as well as golf course, parks, turf farms and other landscape-watering. IMPLAN provides a very detailed classification with regards to crops (IMPLAN sectors 1-10 in Appendix table A2), but golf courses and others are integrated in sectors 406-410. Thus we rename the "irrigation" sector as "crop" and merge the output and water requirement of the golf course sector in "Industry/services/domestic". We rely on the National Water Information System (NWIS, 2010) to access information on water used by golf courses across 33 states and proxy the consumption across the 19 remaining states by using the average of the former.

It is important to note that the sector "Industry/services/domestic" encompasses labor compensation by row and final demand by household by column. This choice is driven by the domestic usage of water embedded in the USGS classification. Moreover, while USGS separates water use by the "livestock" and "aquaculture" sectors, we aggregate them because IMPLAN's sector 14 "Animal production, except cattle and poultry and eggs" includes both livestock and fish farming (aquaculture).

Appendix A3. Aggregation scheme of USGS sectors

USGS sectors	Description	IMPLAN sectors
Crop	Irrigation water use includes water that is applied by an irrigation system to sustain plant growth in agriculture. Irrigation water use includes self-supplied withdrawals and deliveries from irrigation companies or districts, cooperatives, or governmental entities.	1-10
Livestock / Aquaculture	Livestock water use is water associated with livestock watering, feedlots, dairy operations, and other on-farm needs. The livestock category excludes on-farm domestic use, lawn and garden watering, and irrigation water use. Aquaculture water use is water associated with raising organisms that live in water—such as finfish and shellfish— for food, restoration, conservation, or sport. Aquaculture production occurs under controlled feeding, sanitation, and harvesting procedures primarily in ponds, flowthrough raceways, and, to a lesser extent, cages, net pens, and closed-recirculation tanks.	11-14
Mining	Mining water use is water used for the extraction of minerals that may be in the form of solids, such as coal, iron, sand, and gravel; liquids, such as crude petroleum; and gases, such as natural gas. The category includes other operations associated with mining activities.	20-30
Thermoelectric power	Water for thermoelectric power is used in generating electricity with steam-driven turbine generators. Since 2000, thermoelectric-power withdrawals have been compiled by cooling-system type. Thermoelectric power cooling water sources include fresh and saline water from both surface-water and groundwater sources.	31
Industry/ services /domestic	Industrial withdrawals provide water for such purposes as fabricating, processing, washing, diluting, cooling, or transporting a product; incorporating water into a product; or for sanitation needs within the manufacturing facility. Public supply refers to water withdrawn by public and private water suppliers that provide water to at least 25 people or have a minimum of 15 connections. Public-supply water is delivered to users for domestic, commercial, and industrial purposes. Part of the total is used for public services, such as public pools, parks, firefighting, water and wastewater treatment, and municipal buildings, and some is unaccounted for because of leaks, flushing, tower maintenance, and other system losses. *Domestic deliveries represent the largest single component of public-supply withdrawals* Domestic water use includes indoor and outdoor uses at residences, and includes uses such as drinking, food preparation, bathing, washing clothes and dishes, flushing toilets, watering lawns and gardens, and maintaining pools. Domestic water use includes potable and non-potable water provided to households by a public water supplier (domestic deliveries) and self-supplied water use.	15-19,32-440, labor compensation / final demand by household

Note: description of each sector comes from USGS itself.

REFERENCES

Alcon, F., de Miguel, M.D., Burton, M., 2011. Duration analysis of adoption of drip irrigation technology in southeastern Spain. *Technological Forecasting and Social Change* 78, 991-1001.

Allan, J., 1993. Fortunately there are substitutes for water otherwise our hydro-political futures would be impossible. *Priorities for water resources allocation and management* 13, 26.

Allan, J., 1994. Overall perspectives on countries and regions. Rogers, P. and Lydon, P. *Water in the Arab World: perspectives and prognoses,* Harvard University Press, Cambridge, Massachusetts, 65-100.

Allan, J.A., 1998. Virtual Water: A Strategic Resource Global Solutions to Regional Deficits. *Ground Water* 36, 545-546.

An, H., Eheart, J.W., 2006. Evaluation of programs for regulating withdrawal of surface water under the riparian legal system. Journal of Water Resources Planning and Management-Asce 132, 385-394.

Anselin L., 1988. *Spatial Econometrics: Methods and Models*. Kluwer Academic Publishers, Dordrecht.

Anselin, L. and Arribas-Bel, D., 2013. Spatial fixed effects and spatial dependence in a single cross-section. *Papers in Regional Science*, *92*(1), pp.3-17.

AZDOA, 2012. Arizona State and County Population Projections, 2012-2050: Methodology Report, in: Statistics, O.o.E.a.P. (Ed.). *Arizona Department of Administration*, Arizona, pp. 1-26.

Bae J. and Dall'erba S. 2015. Crop production, export of virtual water and water-saving strategies in Arizona, *paper presented at the 62nd Annual North American Meetings of the Regional Science Association International*, Portland, November.

Bae J. and Dall'erba S., 2016 The Economic Impact of a New Solar Power Plant in Arizona: Comparing the input-output Results generated by JEDI vs. IMPLAN, *Regional Science Policy and Practice*, 8, 1-2, 61-73

Baltagi, B.H., Song, S.H., Jung, B.C. and Koh, W., 2007. Testing for serial correlation, spatial autocorrelation and random effects using panel data. *Journal of Econometrics*, *140*(1), pp.5-51.

Bêche, L.A., Connors, P.G., Resh, V.H., Merenlender, A.M., 2009. Resilience of fishes and invertebrates to prolonged drought in two California streams. *Ecography* 32, 778-788.

Blanco, Maria Isabel and Glória Rodrigues 2009. Direct employment in the wind energy sector: An EU study. *Energy Policy* 37: 2847-2857.

Brozović, N., Sunding, D.L. and Zilberman, D., 2010. On the spatial nature of the groundwater pumping externality. *Resource and Energy Economics*, *32*(2), pp.154-164.

Brug, L. B. (2013). emPower Arizona, *Executive Energy Assessment and Pathways 2013*. Governor's office of energy policy.

Caldes, N., Varela, M., Santamaria, M., & Saez, R. (2009). Economic impact of solar thermal electricity deployment in Spain. *Energy Policy, 37*(5), 1628-1636.

Carley, S., Lawrence, S., Brown, A., Nourafshan, A., & Benami, E. (2011). Energy-based economic development. *Renewable and Sustainable Energy Reviews, 15*(1), 282-295.

Carley, S., Brown, A., & Lawrence, S. (2012). Economic Development and Energy: From Fad to a Sustainable Discipline? *Economic Development Quarterly, 26*(2), 111-123

CAP, 2009. 2009/2010 Water Rate Schedule, in: Project, T.C.A. (Ed.). Central Arizona Project, Arizona.

Cazcarro, I., Duarte, R., Sánchez Chóliz, J., 2013. Multiregional Input–Output Model for the Evaluation of Spanish Water Flows. *Environ. Sci. Technol*. *47*, 12275-12283.

Chatzopoulos T., Lippert C., 2016. Endogenous Farm-type Selection, Endogenous Irrigation, and Spatial Effects in Ricardian Models of Climate Change, *European Review of Agricultural Economics*, 43, 2, 217-235.

Chen Z., Haynes K. E., 2015. Spatial Impact of Transportation Infrastructure: A Spatial Econometric CGE Approach. In: Nijkamp P, Rose A and Kourtit K (ed.) *Regional Science Matters – Studies dedicated to Walter Isard*. Springer International Publishing, Switzerland, p 163-186.

Christensen, N.S., Wood, A.W., Voisin, N., Lettenmaier, D.P., Palmer, R.N., 2004. The effects of climate change on the hydrology and water resources of the Colorado River basin. *Climatic change*, 62, 337-363.

Colby, B.G., Crandall, K., Bush, D.B., 1993. Water right transactions: Market values and price dispersion. *Water Resources Research 29*, 1565-1572.

Dall'erba, S., & Domínguez, F. (2016). The Impact of Climate Change on Agriculture in the Southwestern United States: The Ricardian Approach Revisited. *Spatial Economic Analysis, 11*(1), 46-66. doi:10.1080/17421772.2015.1076574

Dang, Q., Lin, X., Konar, M., 2015. Agricultural virtual water flows within the United States. *Water Resources Research* 51, 973-986.

Dasberg, S., Or, D., 1999. Drip Irrigation, Berlin.

De Arce, Rafael, Ramón Mahía, Eva Medina and Gonzalo Escribano 2012. A simulation of the economic impact of renewable energy development in Morocco. *Energy Policy 46*: 335-345.

Del Sol, F., and Sauma, E. (2013). Economic impacts of installing solar power plants in northern Chile. *Renewable and Sustainable Energy Reviews, 19*(0), 489-498.

Deng, X.-P., Shan, L., Zhang, H., Turner, N.C., 2006. Improving agricultural water use efficiency in arid and semiarid areas of China. *Agricultural Water Management* 80, 23-40.

Deschênes O. and Greenstone M. 2007. The Economic Impacts of Climate Change: Evidence from Agricultural Output and Random Fluctuations in Weather, *The American Economic Review,* 97, 1, 354–385.

Dietzenbacher, E., Velázquez, E., 2007. Analysing Andalusian Virtual Water Trade in an Input–Output Framework. *Regional Studies 41*, 185-196.

Dominguez, F., Cañon, J., Valdes, J., 2010. IPCC-AR4 climate simulations for the Southwestern US: the importance of future ENSO projections. *Climatic Change 99,* 499-514.

DSIRE, 2014. Renewable Energy Standard. Arizona Incentives/Policies for Renewables & efficiency.

Dunning, H.C., 1977. Reflections on the Transfer of Water Rights. J. Contemp. L. 4, 109.

Easterling, W.E., 1996. Adapting North American agriculture to climate change in review. *Agricultural and Forest Meteorology 80,* 1-53.

EIA, 2013. Arizona State Profile and Energy Estimates, R14-2-1804. . U.S. Energy Information Administration.

EIA 2015 a. Electricity, Annual Data: Net Generation by State by Type of Producer by Energy Source (EIA-906, EIA-920, and EIA-923) 1990-2013. Retrieved March 2015, from Energy Information Administration http://www.eia.gov/electricity/data/state/

EIA 2015 b. Electric Power Monthly. In Electric Power Monthly: US Energy Information Administration. Retrieved April 2015, from: http://www.eia.gov.

Eliste P., Fredriksson P. G., 2004. Does Trade Liberalization Cause a Race-to-the-Bottom in Environmental Policies? A Spatial Econometric Analysis. In: Anselin L, Florax R and Rey SJ (ed) *Advances in Spatial Econometrics: Methodology, Tools and Applications*. Springer Berlin Heidelberg, Berlin, p 383-396.

Evans, A., & James, T. (2011). Impact of Solar Generation upon Arizona's Energy (Electricity) Security: L. William Seidman Research Institute W. P. Carey School of Business Arizona State University.

Ezcurra, R. and Pascual, P., 2008. Fiscal decentralization and regional disparities: evidence from several European Union countries. *Environment and Planning A*, *40*(5), pp.1185-1201.

Fezzi, C. and Bateman, I., 2012. *Non-linear effects and aggregation bias in Ricardian models of climate change* (No. 2012-02). CSERGE working paper.

Finster, R.D., 1971. Improving water resource allocation through demand-orinted water policy. *JAWRA Journal of the American Water Resources Association 7*, 17-25.

FirstSolar, 2014. Utility-Scale Generation, First Solar. First Solar.

Fishelson, G., 1994. The allocation and marginal value product of water in Israeli agriculture. *Studies in Environmental Science 58*, 427-427.

Foran, P.G., Beecher, J.A., Wilson, L.J., 1995. Survey of Eastern Water Law. Illinois Department of Natural Resources, Springfield, Illinois.

Frederick, K., Major, D., 1997. Climate change and water resources. *Climatic Change 37*, 7-23.

Frederick, K.D., 1991. Processes for identifying regional influences of and responses to increasing atmospheric CO2 and climate change: The mink project IV - water resources. US Department of Energy, Washington, D.C., p. 153.

Friedman, B 2012. PV Installation Labor Market Analysis and PV JEDI Tool Developments (Presentation). In PV Installation Labor Market Analysis and PV JEDI Tool Developments (Presentation): NREL (National Renewable Energy Laboratory).

Frisvold, G., Patton, W.P., Raynold, S., 2009. Arizona solar energy and economics outlook. Prepared for Arizona Solar Energy and Economics Summit.

Fu, R., Fernando, N., Yin, L., Ren, T., Yang, Z., Bowerman, A., Dickinson, R.E., 2012. Assessing Future Changes of Climate and Drought over South-Central United States 3 Projected by the CMIP5 Models. *Journal of Climate* submitted.

Garfin, G., Jardine, A., Merideth, R., Black, M. & LeRoy, S., 2013. Assessment of Climate Change in the Southwest. United States: A Report Prepared for the National Climate Assessment, A report by the Southwest Climate Alliance, Washington, DC, Island Press.

Ghimire, N., Griffin, R.C., 2014. The Water Transfer Effects of Alternative Irrigation Institutions. *American Journal of Agricultural Economics 96*, 970-990.

Gichuki, F.N., 2004. Managing the externalities of declining dry season river flow: A case study from the Ewaso Ngiro North River Basin, Kenya. *Water Resources Research 40*, W08S03.

Giesken, Mark Louis 2007. Economic Impact of Wind Farm Development in Oklahoma. Department of Geography, University of Oklahoma.

Grassini, P., Yang, H., Cassman, K.G., 2009. Limits to maize productivity in western corn-belt: A simulation analysis for fully irrigated and rainfed conditions. *Agricultural and Forest Meteorology 149,* 1254-1265.

Guan, D., Hubacek, K., 2007. Assessment of regional trade and virtual water flows in China. *Ecological Economics 61,* 159-170.

Hamilton, S.F., Berkman, M., 2011. Economic and fiscal impacts of the Topaz Solar Farm, in: The Battle group, I. (Ed.), prepared for First Solar. The Battle group, Inc.

Han, M.Y., Guo, S., Chen, H., Ji, X., Li, J.S., 2014. Local-scale systems input-output analysis of embodied water for the Beijing economy in 2007. Frontiers of Earth Science 8, 414-426.

Harou, J.J., Medellín-Azuara, J., Zhu, T., Tanaka, S.K., Lund, J.R., Stine, S., Olivares, M.A., Jenkins, M.W., 2010. Economic consequences of optimized water management for a prolonged, severe drought in California. *Water Resources Research 46*.

Heckscher, E.F., Ohlin, B.G., 1991. Heckscher-Ohlin trade theory. The MIT Press.

Hernandez, R.R., Easter, S.B., Murphy-Mariscal, M.L., Maestre, F.T., Tavassoli, M., Allen, E.B., Barrows, C.W., Belnap, J., Ochoa-Hueso, R., Ravi, S., Allen, M.F., 2014. Environmental impacts of utility-scale solar energy. *Renewable and Sustainable Energy Reviews 29*, 766-779.

Hillebrand, B., Buttermann, H.G., Behringer, J.M., Bleuel, M., 2006. The expansion of renewable energies and employment effects in Germany. Energy Policy 34, 3484-3494.

Hoekstra, A.Y., Chapagain, A.K., 2007. Water footprints of nations: Water use by people as a function of their consumption pattern, in: Craswell, E., Bonnell, M., Bossio, D., Demuth, S., Van De Giesen, N. (Eds.), *Integrated Assessment of Water Resources and Global Change*. Springer Netherlands, pp. 35-48.

Hoekstra, A.Y., Hung, P.Q., 2002. Virtual Water Trade: A quantification of virtual water flows between nations in relation to international crop trade Value of Water. IHE, Delft the Netherlands, IHE, Delft the Netherlands.

Howitt, R., Medellín-Azuara, J., MacEwan, D., Lund, J., Sumner, D., 2014. Economic analysis of the 2014 drought for California agriculture. Center for Watershed Sciences, University of California, Davis.

Hu, S., Song, Y., Zhou, H., Tian, C., 2001. Experimental study on water use efficiency of cotton in the Tarim River Basin. *Agricultural Research in the Arid Areas* 20, 66-70.

Hughes, J.A., 2013. Utilities right to seek most bang for their solar buck: Rules should be fair to all. AZ Central.

Huntington, H. G. (2009). Creating Jobs With 'Green' Power Sources. Paper presented at *the Energy Modeling Forum*, Stanford.

IMPLAN, 2010. IMPLAN System (data and software), in: IMPLAN MIG, I. (Ed.), 1725 Tower Drive West, Suite 140, Stillwater, MN 55082.

IPCC, 2013. Summary for Policymakers. In: Climate Change 2013: The Physical Science Basis., in: Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.) (Ed.), *Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge*, United Kingdom and New York, NY, USA.

IPCC, 2014a. 2014: Summary for Policymakers. In: Climate Change 2014: Mitigation of Climate Change., in: [Edenhofer, O., R. Pichs-Madruga, Y. Sokona, E. Farahani, S. Kadner, K. Seyboth, A. Adler, I. Baum, S. Brunner, P. Eickemeier, B. Kriemann, J. Savolainen, S. Schlömer, C. von Stechow, T. Zwickel and J.C. Minx (eds.)] (Ed.), *Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*, Cambridge, United Kingdom and New York, NY, USA.

IPCC, 2014b. CLIMATE CHANGE 2014: Impacts, Adaptation, and Vulnerability, in: [Field, C.B., V.R. Barros, D.J. Dokken, K.J. Mach, M.D. Mastrandrea, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken,P.R. Mastrandrea, and L.L. White (eds.)] (Ed.), Summaries, Frequently Asked Questions, and Cross-Chapter Boxes. A *Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.* World Meteorological Organization, Geneva, Switzerland, p. 190 pp.

Kang D., Dall'erba S., 2015. An Examination of the Role of Local and Distant Knowledge Spillovers on the U.S. Regional Knowledge Creation, *International Regional Science Review*, 39, 4, 355-385

Kapoor, M., Kelejian, H.H. and Prucha, I.R., 2007. Panel data models with spatially correlated error components. *Journal of econometrics*, *140*(1), pp.97-130.

Kay, A.L., Davies, H.N., Bell, V.A., Jones, R.G., 2009. Comparison of uncertainty sources for climate change impacts: flood frequency in England. *Climatic Change 92*, 41-63.

Kirshen, P., Knee, K., Ruth, M., 2008. Climate change and coastal flooding in Metro Boston: impacts and adaptation strategies. *Climatic Change 90*, 453-473.

Kammen, Daniel M., Kamal Kapadia, and Matthias Fripp (2004). “Putting Renewables to Work: How Many Jobs Can the Clean Energy Industry Generate?” RAEL Report, University of California, Berkeley.

Kumar K., 2011. Climate Sensitivity of Indian Agriculture: Do Spatial Effects Matter? *Cambridge Journal of Regions, Economy and Society*, 4, 2, 221-235.

Knutson, T.R., Sirutis, J.J., Vecchi, G.A., Garner, S., Zhao, M., Kim, H.-S., Bender, M., Tuleya, R.E., Held, I.M., Villarini, G., 2013. Dynamical Downscaling Projections of Twenty-First-Century Atlantic Hurricane Activity: CMIP3 and CMIP5 Model-Based Scenarios. *Journal of Climate 26*, 6591-6617.

Kundzewicz, Z.W., Hirabayashi, Y., Kanae, S., 2010. River Floods in the Changing Climate--Observations and Projections. *Water Resources Management 24*, 2633-2646.

Lacey, S., Trabish, H., Wesoff, E., 2013. Potraits of a manufacturing solar market : How key states are fairing. Greentechmedia.com.

Lehr, Ulrike, Joachim Nitsch, Marlene Kratzat, Christian Lutz and Dietmar Edler 2008. Renewable energy and employment in Germany. *Energy Policy 36*: 108-117.

Le Sage J., Pace K., 2009. *Introduction to Spatial Econometrics*, Taylor and Francis/CRC.

Lambert, R.J., Silva, P.P., 2012. The challenges of determining the employment effects of renewable energy. *Renewable and Sustainable Energy Reviews 16,* 4667-4674.

Leontief, W., 1953. Domestic production and foreign trade; the American capital position re-examined. *Proceedings of the American philosophical Society 97*, 332-349.

Leontief, W., 1956. Factor proportions and the structure of American trade: further theoretical and empirical analysis. *The Review of Economics and Statistics,* 386-407.

Leontief, W., 1970. Environmental repercussions and the economic structure: an input-output approach. *The review of economics and statistics*, 262-271.

Lippert C., Krimly T., Aurbacher J., 2009. A Ricardian Analysis of the Impact of Climate Change on Agriculture in Germany, *Climatic Change*, 97, 593–610.

LLC, I.G., 2013. About IMPLAN.

Lorca, Alejandro and Rafael De Arce 2012. Renewable energies and sustainable development in the Mediterranean: Morocco and the Mediterranean solar plant. Forum Euroméditerranéen des Instituts de Sciences Économiques.

Madeley, J., 2007. Flooding and climate change. *Appropriate Technology 34,* 69-70.

Markaki, M., A. Belegri-Roboli, P. Michaelides, S. Mirasgedis and D. P. Lalas 2013. The impact of clean energy investments on the Greek economy: An input–output analysis (2010–2020). *Energy Policy 57*: 263-275.

Marston, L., Konar, M., Cai, X., Troy, T.J., 2015. Virtual groundwater transfers from overexploited aquifers in the United States. *Proceedings of the National Academy of Sciences 112*, 8561-8566.

Massetti, E. and Mendelsohn, R., 2011. Estimating Ricardian models with panel data. *Climate Change Economics*, *2*(04), pp.301-319.

McCunn, A. and Huffman, W.E., 2000. Convergence in US productivity growth for agriculture: implications of interstate research spillovers for funding agricultural research. *American Journal of Agricultural Economics*, *82*(2), pp.370-388.

Mendelsohn, R., William D. Nordhaus, Shaw, D., 1994. The Impact of Global Warming on Agriculture: A Ricardian Analysis. *The American Economic Review 84*, 753-771.

Miao, R., M. Khanna and H. Huang, 2016. Responsiveness of Yield and Acreage to Climate and Prices, *American Journal of Agricultural Economics*, 98(1): 191-211, 2016.

Miller., R.E., Peter D. Blair, 2009. Input-output analysis: foundations and extensions, 2nd ed. Cambridge University Press, New York.

Moore, M.R., Gollehon, N.R., Carey, M.B., 1994. Multicrop Production Decisions in Western Irrigated Agriculture: The Role of Water Price. *American Journal of Agricultural Economics 76*, 859-874.

Moreno, B., & López, A. J. (2008). The effect of renewable energy on employment. The case of Asturias (Spain). *Renewable and Sustainable Energy Reviews*, 12(3), 732-751.

Mubako, S., Lahiri, S., Lant, C., 2013. Input–output analysis of virtual water transfers: Case study of California and Illinois. *Ecological Economics* 93, 230-238.

Mulligan, Gordon, Randall Jackson and Amanda Krugh 2013. Economic base multipliers: a comparison of ACDS and IMPLAN. *Regional Science Policy & Practice* 5: 289-303.

Munshi K., 2004. Social Learning in a Heterogeneous Population: Technology Diffusion in the Indian Green Revolution, *Journal of Development Economics*, 73, 1, 185–213.

Murphree, J., 2014. The Voice: $143 Billion Forecasted in Ag Trade; Cotton Remains Arizona Agriculture's Leading Export Crop Arizona Farm Bureau.

NREL 2008. JEDI PV industry aggregation scheme. In JEDI PV industry aggregation scheme.

NREL 2011. Dynamic Maps, GIS Data, & Analysis Tools: Lower 48 PV 10km Resolution 1998 to 2005. Retrieved 11/20/2014, from NREL http://www.nrel.gov/gis/data_solar.html

NREL, 2013. JEDI - Jobs and Economic Development Impact Models. National Renewable Energy Laboratory, from http://www.nrel.gov/analysis/jedi

NWIS, 2010. Water Use Data for Arizona, in: System, N.W.I. (Ed.). National Water Information System.

Olsen, J.R., 2006. Climate Change and Floodplain Management in the United States. *Climatic Change* 76, 407-426.

Peterson, E., Hoef, J.V., 2010. A mixed-model moving-average approach to geostatistical modeling in stream networks. *Ecology Law Quarterly* 91, 644-651.

Peterson, E., Ver Hoef, J., 2014. STARS: An ArcGIS Toolset Used to Calculate the Spatial Information Needed to Fit Spatial Statistical Models to Stream Network Data. 2014 56, 17.

Peterson, E.E., Theobald, D.M., VER HOEF, J.M., 2007. Geostatistical modelling on stream networks: developing valid covariance matrices based on hydrologic distance and stream flow. *Freshwater Biology* 52, 267-279.

Peterson;, T.C., Hoerling;, M.P., Stott;, P.A., Herring;, S.C., 2013. Explaining extreme events of 2012 from a climate perspective. *Bulletin of the American Meteorological Society* 94.

Pfeiffer, L., Lin, C.Y.C., 2012. Groundwater pumping and spatial externalities in agriculture. *Journal of Environmental Economics and Management* 64, 16-30.

Phare, M.-A.S., 2009. Denying the source: The crisis of First Nations water rights. Rocky Mountain Books Ltd.

Plantinga, A.J., Lubowski, R.N. and Stavins, R.N., 2002. The effects of potential land development on agricultural land prices. *Journal of Urban Economics*, *52*(3), pp.561-581.

Pollin, R., James Heintz, & Garrett-Peltier, H. (2009). The Economic Benefits of Investing in Clean Energy: Department of Economics and Political Economy Research Institute (PERI) & Center For American Progress.

Polsky C., 2004. Putting space and time in Ricardian climate change impact studies: agriculture in the U.S. great plains, 1969-1992, *Annals of the Association of American Geographers*, 94, 3, 549-564.

Provencher, B. and Burt, O., 1993. The externalities associated with the common property exploitation of groundwater. *Journal of Environmental Economics and Management*, *24*(2), pp.139-158.

Scheierling, S.M., Loomis, J.B., Young, R.A., 2006. Irrigation water demand: A meta-analysis of price elasticities. *Water Resources Research* 42, n/a-n/a.

Schimmelpfennig D., Lewandrowski J., Reilly J., Tsigas M. and Parry I. 1996. Agricultural Adaptation to Climate Change: Issues of Long Range Sustainability, *Agricultural Economic Report,* No. (AER740) 68 pp, June.

Schlenker, W., Hanemann, W. M. & Fisher, A. C. 2005. Will U.S. Agriculture really benefit from global warming? Accounting for irrigation in the hedonic approach. *American Economic Review* 95: 395-406

Schlenker W., Hanemann W.M. and Fisher A.C. 2006. The Impact of Global Warming on U.S. Agriculture: an Econometric Analysis of Optimal Growing Conditions, *Review of Economics and Statistics*, 88, 1, 113–125.

Schoengold, K., Sunding, D.L., Moreno, G., 2006. Price elasticity reconsidered: Panel estimation of an agricultural water demand function. *Water Resources Research* 42, n/a-n/a.

Schwer, R.K., Riddel, M., 2004. The Potential Economic Impact of Constructing and Operating Solar Power Generation Facilities in Nevada. NREL, Golden, Colorado.

SEIA 2014. Solar Market Insight Report 2014 Q1. In Solar Market Insight Report 2014 Q1.

Seo S.N. (2008) Assessing Relative Performance of Econometric Models in Measuring the Impact of Climate Change on Agriculture Using Spatial Autoregression, *The Review of Regional Studies,* 38, 2, 195–209.

Singh, V. and Fehrs J. (2001). The work that goes into renewable energy, Renewable Energy Policy Project, Report no. 13, November.

SEIA 2014. Solar Market Insight Report 2014 Q1. In Solar Market Insight Report 2014 Q1.

Storms, D., Dashiell, S.L., David, F., 2013. Siting solar energy development to minimize biological impacts. *Renewable Energy* 57, 289-298.

Swain, D.L., Tsiang, M., Haugen, M., Singh, D., Charland, A., Rajaratnam, B., Diffenbaugh, N.S., 2014. The extraordinary California drought of 2013/2014: Character, context, and the role of climate change. Bulletin of the American Meteorological Society 95, S3.

Tang, J., Folmer, H., van der Vlist, A.J., Xue, J., 2014. The impacts of management reform on irrigation water use efficiency in the Guanzhong plain, China. *Papers in Regional Science* 93, 455-475.

Tourkolias, C., Mirasgedis, S., 2011. Quantification and monetization of employment benefits associated with renewable energy technologies in Greece. *Renewable and Sustainable Energy Reviews* 15, 2876-2886.

USDA, 2008. Census of Agriculture, 2008 FRIS - General Data 91. Table 28. Estimated Quantity of Water Applied and Primary Method of Distribution by Selected Crops Harvested: 2008 and 2003.

USDA, 2012. 2012 Census Publications: Ranking of market Value of Ag Products Sold, in: USDA (Ed.).

US DOL (United States Department of Labor) (2014). Occupational Employment Statistics. May 2015, from http://www.bls.gov/oes/current/oes_az.htm#47-0000

USDOL, 2015. Occupational Employment Statistics. United States Department of Labor.

USGS, 2000. Ths USGS Water Science School - Irrigation: Typical sprinkler (spray) irrigation.

USGS, 2010. Estimated Use of Water in the United States County-Level Data for 2010.

USGS, 2016. The USGS Water Science School: Irrigation techniques. USGS.

van der Velde, M., Wriedt, G., Bouraoui, F., 2010. Estimating irrigation use and effects on maize yield during the 2003 heatwave in France. Agriculture, *Ecosystems & Environment* 135, 90-97.

Van Hofwegen, P., 2004. Virtual watertrade: conscious choices, Synthesis E-Conference. 4th World Water forum. World Water Council.

Velázquez, E., 2006. An input-output model of water consumption: Analysing intersectional water relationships in Andalusia. *Ecological Economics*, 226-240.

Ver Hoef, J.M., Peterson, E., Theobald, D., 2006. Spatial statistical models that use flow and stream distance. *Environmental and Ecological statistics* 13, 449-464.

Vörösmarty, C.J., Green, P., Salisbury, J., Lammers, R.B., 2000. Global water resources: vulnerability from climate change and population growth. *science* 289, 284-288.

Wang, H., Wang, Y., 2009. An input–output analysis of virtual water uses of the three economic sectors in Beijing. *Water International* 34, 451-467.

Wang, Z., Huang, K., Yang, S., Yu, Y., 2013. An input–output approach to evaluate the water footprint and virtual water trade of Beijing, China. *Journal of Cleaner Production* 42, 172-179.

Wei, M., Patadia, S., Kammen, D.M., 2010. Putting renewables and energy efficiency to work: How many jobs can the clean energy industry generate in the US? *Energy Policy* 38, 919-931.

Wichelns, D., 2001. The role of 'virtual water' in efforts to achieve food security and other national goals, with an example from Egypt. *Agricultural Water Management* 49, 131-151.

Williams, Susan K., Tom Acker, Marshall Goldberg and Megan Greve 2008. Estimating the economic benefits of wind energy projects using Monte Carlo simulation with economic input/output analysis. *Wind Energy* 11: 397-414.

Wollmuth, J.C., Eheart, J.W., 2000. Surface water withdrawal allocation and trading system for traditionally riparian areas. *Journal of the American Water Resources Associati*on 36, 293-303.

WRI 2014. CAIT 2.0, WRI's Climate Data Explorer. In CAIT 2.0, WRI's Climate Data Explorer, CAIT 2.0.

Wichelns, D., 2010. Agricultural Water Pricing: United States.

Wuebbles, D., Meehl, G., Hayhoe, K., Karl, T.R., Kunkel, K., Santer, B., Wehner, M., Colle, B., Fischer, E.M., Fu, R., Goodman, A., Janssen, E., Kharin, V., Lee, H., Li, W., Long, L.N., Olsen, S.C., Pan, Z., Seth, A., Sheffield, J., Sun, L., 2013. CMIP5 Climate Model Analyses: Climate Extremes in the United States. *Bulletin of the American Meteorological Society* 95, 571-583.

YAWC, 2015. A Case Study in Efficiency –Agriculture and Water Use in the Yuma, Arizona Area. Yuma County Agricultural Water Coalition, Yuma, Arizona.

Yegnes-Botzer, A., 2001. Virtual Water Export from Israel: Quantities, Driving Forces and Consequences. IHE.

Yu, Y., Hubacek, K., Feng, K., Guan, D., 2010. Assessing regional and global water footprints for the UK. *Ecological Economics* 69, 1140-1147.

Zhang, Z., Yang, H., Shi, M., 2011. Analyses of water footprint of Beijing in an interregional input–output framework. *Ecological Economics* 70, 2494-2502.

Zhao, X., Yang, H., Yang, Z.F., Chen, B., Qin, Y., 2010. Applying the input-output Method to Account for Water Footprint and Virtual Water Trade in the Haihe River Basin in China. *Environ. Sci. Technol*. 44, 9150-9156.

Zhang, Y., Susan, M. M., Nearing, M. A., Ponce Campos, G. E., Huete, A. R., Buda, A. R., Bosch, D. D., Gunter, S. A., Kitchen, S. G., Henry McNab, W., Morgan, J. A., McClaran, M. P., Montoya, D. S., Peters, D. P.C. & Starks, P. J. (2013) Extreme precipitation patterns and reductions of terrestrial ecosystem production across biomes, Journal of Geophysical Research: *Biogeosciences*, 118(1), 148–157.

Yu, Y., Hubacek, K., Feng, K., Guan, D., 2010. Assessing regional and global water footprints for the UK. *Ecological Economics* 69, 1140-1147.

Zhou, W., 2003. Review on the study of water resources utilization efficiency in irrigation district in arid and semiarid areas of China. *Journal of Arid Land Resources and Environment* 17, 91-95.

Zhang, Z., Cai, H.-j., 2001. Effects of regulated deficit irrigation on plastic-mulched cotton. Journal of Northwest Sci-Tech University of Agriculture and Forestry 29, 9-12.