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Virtual water trade in times of drought – do property rights matter?

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Abstract.

The issue of water scarcity has been recognised as one of the greatest threats against global development. One of the proposed solutions to this issue is the indirect reallocation of freshwater through trade in agricultural products, also known as virtual water trade. This paper introduces water property rights as a determinant for trade in virtual water. Building on earlier work on trade in environmental resources and property rights, we estimate the volume of US interstate virtual water flows from Iowa, Kansas and Missouri during 2009-2014 in three major agricultural commodity groups. By estimating the effect of the Midwestern drought 2012 on the virtual water flows for the different states, we analyse the importance of water property rights as a determinant for virtual water flows. Our results are inconclusive, suggesting a need for further research in the area.

Keywords: virtual water trade, gravity model, property rights

JEL: F14, F11, O13, Q25, P48

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Important concepts

Virtual water content

The virtual water content of a product is the freshwater "embodied" in the product, not in real sense, but in virtual sense. It refers to the volume of water consumed or polluted for producing the product, measured over its full production chain. If a nation exports/imports such a product, it exports/imports water in virtual form. The "virtual-water content of a product" is the same as "the water footprint of a product", but the former refers to the water volume embodied in the product alone, while the latter term refers to that volume, but also to which sort of water is being used and to when and where that water is being used. The water footprint of a product is thus a multidimensional indicator, whereas virtual-water content refers to a volume alone.

Virtual water flow and virtual water trade

The virtual water flow between two geographically delineated areas (for example, two nations) is the volume of virtual water that is being transferred from the one area to another area as a result of product trade.

1. INTRODUCTION

Water scarcity is becoming a pressing issue in many regions of the world. As a result of population growth, rising living standards and increasing unreliability in water supply the world is projected to face a 40% global water deficit by 2030, under a business-as-usual scenario (UNWWAP 2015). Accordingly, water scarcity is increasingly recognised as one of the greatest threats against global development. In spite of the urgent need for action, policy makers have struggled to rise to the challenge (OECD 2010). One reason is that freshwater is unequally distributed throughout the world. Water scarcity is mainly a regional problem. On a global level there is plenty of freshwater, amounting to 13,302 m^3 per capita – well above the estimated subsistence freshwater needs of 1,700 m^3 per person and year (Falkenmark et al. 1989). Water scarcity can thus be framed as an allocation problem (Dudu and Chumi 2008).

The concept of virtual water, the total amount of freshwater needed for the production of a good or service, has been proposed as a tool to illustrate and ultimately guide such a process. With the use of this concept, agricultural trade flows can be seen as indirect flows of freshwater. The notion of virtual water has gained traction among policy makers, water researchers and economists alike. Policy makers and water researchers have used it as tool to highlight the connection between agriculture and water scarcity, and as a tool to overcome local water scarcity by importing virtual water through food imports. Economic research on virtual water trade has applied traditional economic trade models to examine the trade in virtual water, searching for its determinants. While the models have successfully explained trade of many other commodities, results with regard to virtual water trade have been inconclusive. Paradoxical observations of how arid countries export large amounts of virtual water while relatively well-endowed countries import virtual water, remains unexplained. It has been suggested that one reason for this is that international trade models do not sufficiently consider market distortions. A new perspective is thus warranted.

The effect of environmental property rights on trade in environmental resources has been studied widely. Chichilinsky (1994) proposed that imbalances in environmental property rights will lead to an illusory comparative advantage in the trade of a resource-intensive good in countries with weak property rights, leading to detrimental trade patterns from an environmental perspective. Brander and Taylor (1997) challenged Chichilinsky's proposal and showed that trade under heterogeneous property rights can actually help save environmental resources threatened by over extraction.

In the U.S, effects of water property rights have been studied extensively. The US is one of the largest agricultural producers in the world and within its borders there is an extensive trade network in virtual water, stemming from interstate agricultural trade. The US uses two different water rights doctrines, the prior appropriation doctrine in the western parts of the country and the riparian doctrine in the eastern parts of the country. The doctrines differ significantly in their abilities to exclude users, and to incentivise sustainable management of water resources. Accordingly, the appropriateness of the respective systems has been discussed, and large amounts of virtual water exports in the midst of drought have sparked an outrage about the country's water management policies.

The purpose of this study is to analyse whether virtual water flows are affected differently under different water rights doctrines in the midst of drought. By estimating the virtual water contained within crop flows from the major agricultural states Iowa, Kansas and Missouri during the 2012 Midwestern drought and developing a gravity model of trade, we estimate the different effects in the states.

The remainder of this paper is structured as follows: *Section 2* provides a background of virtual water trade, property rights and trade in environmental resources. *Section 3* presents an introduction to the literature on virtual water trade, on the effects of property rights on trade in environmental resources as well as on freshwater rights doctrines in the US. *Section 4* describes the proposed design of our research. *Section 5* explains our empirical method and data collection. *Section 6* contains our empirical results. *Section 7* consider alternative explanations and potential biases. *Section 8* contains a discussion on our findings and provides suggestions for future research. *Section* 9 presents our conclusion.

2. BACKGROUND

The purpose of this section is to provide an overview of how virtual water trade (VWT) and water property rights relate to water scarcity. Firstly, we describe the development of the virtual water concept as an important policy tool for the alleviation of water scarcity. Secondly, we present the findings of previous research on how trade affects natural resources extraction under heterogeneous property rights. Lastly, freshwater scarcity and water property rights in the US are described. We conclude the section by presenting the purpose of our thesis and how that purpose relates to the issues raised below.

2.1 Virtual water trade

One way of addressing the allocation problem of global freshwater resources is the concept of virtual water (OECD 2010). This concept was coined by British geographer John Anthony Allan (1998) as a way to describe how food imports in the Middle East have mitigated local water scarcity, by allowing domestic freshwater to be used for other purposes (see also Ward 2000). The concept has since gained traction among academics and policymakers alike (OECD 2010).

Virtual water trade builds on the notion that while water only rarely is traded directly, it is frequently traded indirectly in other forms, particularly in the form of agricultural products, as global agricultural production accounts for 70% of freshwater use each year (OECD 2010). Further, virtual water takes into account agricultural productivity differences in regard to freshwater. Water needs for crops vary with geography and technology and as such agricultural trade can play a key role in efficient reallocation of the earth's freshwater resources. By quantifying the amount of embedded water in international agricultural trade, such trade can be studied in a new light (OECD 2010).

The evaluation of the VWT concept's compatibility with standard economic trade theory has yielded mixed results (ibid.). The notion of freshwater endowments as a source of comparative advantage was one of the original motives for the invention of the virtual water concept (Allan 1998). This framework continues to dominate the literature on the area (Antonelli and Sartori 2015). Several studies have tested the Heckscher-Ohlin model's explanatory power for virtual water flows with regard to freshwater endowments, with varied conclusions (Debaere 2014; Ramirez-Vallejo and Rogers 2004). These results have led to a discussion on the applicability of standard international trade theory regarding the study of VWT (see Reimer 2012; Wichelns 2010). Some researchers have suggested that the use of other economic perspectives is warranted (Ansink 2010, see also OECD 2010), whereas others have advocated that research should include sub-national trade (Schendel et al. 2007). Given this background, this thesis aims to study virtual water trade patterns with a new approach, which we develop below.

2.2 Property rights and trade in environmental resources

In economic literature, private property rights have long been regarded as crucial for both personal welfare and economic development. "The term property rights refer to a broad set of policies, legal and political systems, and informal norms that define and protect private property" (Levine 2005 p.62). The importance of strongly defined and enforced property rights has also been recognised in regard to the sustainable use and management of environmental resources (UNWWAP 2015). In economic theory, the overuse of a good can often be linked to its characteristics in regard to two factors, rivalrousness and excludability. Rivalrousness concerns how the abstraction of benefits from a good's use limits subsequent benefit for other users. Excludability refers to whether it is possible to exclude others from using the good. In this framework, a good can take four different forms - private, club, common-pool and public (Lipsey & Chrystal 2007).

	Excludable	Non-excludable
Rivalrous	Private goods	Common-pool resources
Non-Rivalrous	Club goods	Public goods

Figure 1. Characteristics of economic goods based on their rivalrousness and excludability.

In its natural form, freshwater is most commonly either a public good or a common-pool good. Most water in the environment – waterfalls, rainbows, glaciers and the ocean – falls into the public good category. It can be enjoyed by everyone and its use by one individual does not preclude other consumption. Common-pool water can be water extracted from rivers or groundwater that are in limited supply (Feeny et all 1990). When freshwater takes the form of a common-pool good it may suffer from the tragedy of the commons (Hardin 1968). This refers to a situation where individual users acting according to their own self-interests behave contrary to the common good of all users by depleting or spoiling a shared resource. Assigning property rights that restrict and regulate the use of a good is a way to overcome this tragedy. It has been recognised that the process of allocating property rights to freshwater is more complicated than the same process for other economic goods,[1] mainly because of its unique characteristics (Dudu and Chumi 2008). For instance, the mobility of water limits the possibility of exclusion. As water moves through its hydrologic cycle, it flows, evaporates and drains. These characteristics make the establishment and enforcement of water property rights difficult and expensive (Young 2005). However, when water property rights are successfully implemented, they have been proven to increase the efficiency of extraction and management of freshwater resources (Ostrom et al. 1999, see also OECD 2010). In this study, we thus define a strong water property right as a right that both excludes other users and allocates resources among users in a well-defined way.

In international trade theory, environmental property rights were long ignored (Chichilinsky 1994). With the economic liberalization of many developing countries during the late 20th century, trade between developing economies and industrialised countries increased. This development led to a discussion on whether this trade could be linked to the depletion of environmental resources in the developing countries. In light of this background, Chichilinsky suggested that trade under imbalances in environmental property rights may lead to overexploitation of natural resources in countries characterised by weaker property rights. This hypothesis has later been challenged theoretically (Brander and Taylor 1997) and both empirically supported (Ferreira 2004) as well as questioned (Xu 2000). With regard to VWT, existing real world examples seem to mirror Chichilinsky's hypothesis. For example, some developing countries such as Burkina Faso have specialised in the production of water-intensive goods such as cotton, in spite of local water-scarcity (Allan 2013). At the same time, these countries rank low in property rights rankings (Schwab 2015). This empirical observation begs the question whether Chichilinsky's perspective can be applied to virtual water trade.

2.3 Water scarcity and water rights in the US

The US is the world's largest exporter of virtual water and is a major actor in international agricultural trade (Mekonnen and Hoekstra 2012). Recent droughts in the country have led to a debate on how freshwater resources are managed (The Economist 2014). For instance, the almond export industry in California,

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[1] The Fourth Principle of 1992 Dublin Statements defines water as an economic good.

accounting for 80% of the world's almond output, has received sharp criticism for exporting large amounts of virtual water in the midst of drought (Davidow and Malone 2015). Examples like this have shed light on the significance of the different water property rights doctrines used in the US (Wines 2014).

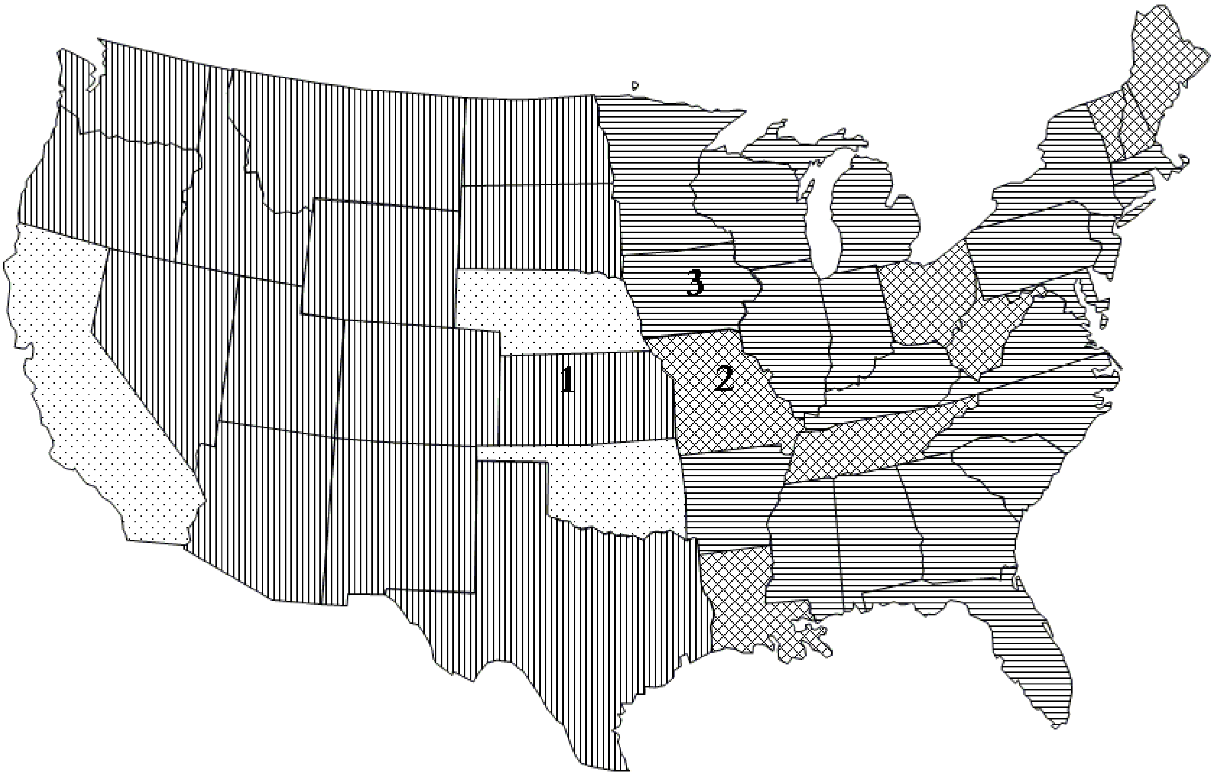

Figure 2. Water rights systems by state. The eastern states follow either the pure riparian doctrine (marked with squares) or the regulated riparian doctrine (marked with horizontal lines). Most of the western states follow the prior appropriation doctrine (marked with vertical lines). Some western states (marked with a dotted pattern) follow hybrid doctrines – mixtures between riparian and prior-appropriation doctrines (DOE 2014). Kansas is marked with 1, Missouri with 2 and Iowa with 3.

As can be seen in *Figure 1*, there exists a clear geographical divide with regard to water property rights doctrines in the US. The eastern states follow the riparian doctrine under which water property rights are tied to the ownership of riparian land, located adjacent to a body of water. Owners of riparian rights are granted reasonable use of freshwater adjacent to their property - water allowances are thus not clearly quantified under riparian rights. Further, the basis of the right and with it the formal exclusion, is defined by riparian land ownership (Mulroy 2017). This form of exclusion may however lead to an insecurity in water tenure for two reasons. New riparian claimants further upstream can for example dilute existing rights owners downstream and the water allowances for a riparian rights owner are subject to the changing use from other rights holders. Moreover, about half of the eastern states have adopted the regulated riparian doctrine, a doctrine under which permits can be issued that allow rights also to non-riparian land for limited time periods.

The western states, on the other hand, follow the prior appropriation doctrine. This doctrine allocates water property rights to the person who first discovers and claims a water resource. This is often referred to as "first in time, first in right" (Christian-Smith et al. 2012). In contrast to the riparian doctrine, water rights are therefore not linked to the ownership of land. The hierarchy of rights to the same water resource is determined by the time in which rights were claimed, older claims being more senior. In times of shortage, senior rights are prioritised in such a way that a senior right holder always receives her full allowance of water before the second most senior rights holder is allowed to extract her water allowance (Mulroy 2017). The characteristics of the different doctrines are described in *Table 1*.

Characteristics of US water rights		
Characteristic	Prior appropriation	Riparian
Limits of right	Specific place of diversion, quantity/rate of diversion, place and type of use	Unquantified, ‘reasonable us’, relative uses of other riparians
Basis of entitlement	Physical control, continued "beneficial" use	Ownership of land adjacent to water body
Duration of right	Permanent, except for abandonment or forfeiture due to continued non-use	Permanent, but subject to change with the changing uses of other riparians
Allocation rule	First in time, first in right	Similarly situated riparians share co-equal rights
Enforcement of allocations	State engineer or equivalent; court	Civil court in response to suits

Table 1. As shown in the table, the doctrines exhibit significant differences with regard to several important factors (Tarlock, 1989).

As *Table 1* shows, there are important differences between the two doctrines in the US. In particular, the definition of allowances and internal ranking are markedly different. In our view, the effects of these two characteristics are of special interest in times of water-scarcity and provide an interesting object of study with the VWT-concept. As the statutes regarding water provisions are explicitly quantified and rights holders are subject to internal ranking, we define the prior appropriation doctrine as a stronger water property right than the riparian doctrine. Given the existence of two water rights doctrines in the U.S, which differ with regard to strength, we argue that this is a country where domestic virtual water flows may be affected by differences in property rights. A more elaborate description of the historic background and differences between the doctrines is provided in *Section 3.2*.

2.4 Thesis purpose

The background and motive of our study can be summarised in the following way: Given that many areas of the world are becoming more water-scarce, the understanding of VWT under such conditions will become increasingly relevant. Ordinary trade models have not been able to explain the trade patterns of virtual water and a new perspective is thus warranted. Imbalances in property rights have been proposed as relevant determinants for trade in environmental resources. The relationship between water property rights and VWT has however not been recognised in the virtual water literature. We believe this is a gap that needs to be filled. As the impact of property rights on local water management has been confirmed, we believe that property rights could be a meaningful factor also for VWT.

The purpose of this study is therefore to analyse whether differences in water property rights in the US have an effect on domestic virtual water exports in times of freshwater scarcity. In our view, it is under such conditions well-designed water property rights are needed the most. We aim to contribute to the literature on virtual water trade in two ways: First, we introduce the perspective of imbalances in property rights as a factor that can explain virtual water trade. Second, in light of the increasing water-scarcity in the world, our study focuses on the effects of different water property rights on VWT under such conditions.

3. PREVIOUS RESEARCH

3.1 Virtual water trade and international trade theory

Research on virtual water trade has primarily focused on two areas. The first area has focused on establishing the size and direction virtual water trade. The second area has focused on testing the concept's compatibility with international trade theory. In the following section, previous research in these two areas is presented.

3.1.1 The size of virtual water trade

Several studies have assessed the volume and direction of virtual water trade, describing the existence of extensive VWT networks. As agriculture accounts for 70% of global water use, studies have mainly focused on agricultural trade. Hoekstra and Mekonnen (2012) find that the volume of freshwater indirectly traded through agricultural products amount to 20% of total global freshwater use for the period 1996-2005. In other words, 20% of global water consumption took place in countries other than the place of water extraction. The estimation of virtual water trade flows has illustrated how freshwater is reallocated through agricultural trade. Major virtual water exporters are the U.S, Brazil, Argentina, Australia and India (ibid.). It has been shown that trade in virtual water can be used to alleviate local water scarcity. For instance, Zimmer and Renault (2003) estimate that Egypt saved 5.8 billion m^3 of water through maize imports in 2000. These findings show how the virtual water concept can be used to illustrate the reallocation of water resources and how it may be used as a tool for mitigating local water scarcity.

The concept of virtual water has primarily been used for the analysis of international trade. Research on a sub-national level has however been done in the US, showing that interstate virtual water trade in the US is extensive. Dang, Lin and Konar (2015) estimate that agricultural virtual water flows within the US amounted to 317 billion m^3 in 2007, equivalent to 51% of the international virtual water trade.

3.1.2 Virtual water trade and the Heckscher–Ohlin model

Attempts to explain VWT from an economic perspective have mainly employed the Heckscher–Ohlin (H–O) model. This model relates international trade to comparative advantage from relative abundance of production factors such as land, labour and capital (Heckscher 1919; Ohlin 1933). When applied to VWT, the H-O model predicts that water-intensive products should flow from relatively water-abundant economies to relatively water-scarce economies. In a nutshell, more freshwater-abundant countries should thus export more virtual water than arid countries. Debaere (2014) finds that water is a source of comparative advantage in trade of water-intensive products, supporting the H-O model in the virtual water context. Yang et al. (2003) establish a positive relationship between water scarcity and virtual water imports only beneath a certain threshold of water endowments. Roson and Sartori (2010) study VWT between Mediterranean countries and find that lower water endowments lead to higher virtual water exports, directly contradicting the H-O predictions.

There is a debate on why the empirical results do not fully comply with the H-O model's predictions. For example, Kumar and Singh (2005) discuss whether political factors such as export subsidies, import tariffs and quotas may affect VWT. The authors argue that such distortions may cause a structure of VWT that doesn't reflect the most efficient structure from with regard to freshwater resources. An example of this in practice is how concern over national food security may lead countries away from the most water-efficient food provisions (ibid.). Antonelli and Sartori (2015) point out that the true cost of freshwater use rarely is recognised. Since the environmental and social costs of extraction are usually not fully taken into account, water is consumed below its true cost. This may in turn lead to a distorted trade pattern from a freshwater perspective. There is thus a possibility that the modelling of VWT has been done on assumptions that do not hold in practice. The reason for this is that trade in environmental resources can be subject to several distortions, property rights differences being one, which the H-O model does not account for. Virtual water trade is likely to be subject to such distortions, and we thus seek to examine whether virtual water trade can be explained with the use of another perspective on international trade, a perspective which focuses on distortions stemming from one area – environmental property rights.

3.1.3 Trade and environmental resources

Chichilinsky (1994) proposes a model where imbalances in property rights can motivate trade between two otherwise identical countries. When one factor input is an environmental common property resource and one of the traded goods is intensive in this factor, heterogeneous property rights in the trading countries lead to overexploitation of the resource in the country with weaker property rights. This works through a mechanism by which the relatively weaker property rights country achieves an apparent comparative advantage in the good that uses the common property resource intensively. This comparative advantage is illusory since the full social and environmental costs of extraction of this resource are not internalised to the same extent as in the stronger property rights regime of the trade partner. A more elaborate description of this model is provided in our theoretical framework in *Section 4.2*.

Chichilinsky's theory has both been validated and challenged empirically. Ferreira (2004) finds that openness to trade can explain deforestation in Brazil when considering environmental property rights. A similar result was found by López (1997) with regard to biomass in Ghana. Xu (2000) finds that the introduction of stronger environmental standards had no effect on exports of environmentally sensitive goods for 34 of the worlds' major exporters during the period from 1965 to 1995, contradictory to Chichilinsky's hypothesis. Brander and Taylor (1997) also develop a model for trade and environmental resources and show that the opposite of Chichilinsky's predictions can take place under certain circumstances where the environmental resource is overused in autarky. The authors describe how trade then can lower resource use in the country with weak property rights and induce it to rebuild its resource stock. This process makes the country with weak property rights a net resource importer, and provides gains of trade to both countries.

The possible effects of property rights on VWT have only been briefly touched upon in the literature. Ansink (2010) points out that VWT is likely to be influenced by imbalances in water property rights and suggests that this can be an explanation to the inconclusive results with regard to H-O modelling of VWT. Finally, Ansink also points out that although it is often assumed that property rights are strong in developed countries and weak in developing countries, this is not necessarily the case in practice. This reasoning can also be identified in Chichilinsky when she notes that [water… is still treated as common property in parts of Texas and California] (Chichilinsky 1994, p. 853). The different outcomes in Chichilinsky (1994) and Brander and Taylor (1997) are of interest for our study. We will therefore use these two studies as our reference points. We develop this further in *Section 4.2*.

3.2 Research on water rights policy in the United States

Water property rights in the United States were, prior to the westward expansion in the 19th century, allocated under the so-called riparian doctrine. The basis for this doctrine is British common law, under which water property rights are intimately related to land ownership (Hodgson 2006). When the United States expanded westward, settlers were confronted with a more water scarce climate. From an economic point of view, western freshwater supplies were thus more rivalrous than those in the east. This challenging environment meant that actors in the west faced tough collective-action problems with regard to the use and management of the water (Ostrom 2011). While the riparian doctrine was originally used in many western states, it eventually became clear that the less well-defined statutes of the riparian doctrine were inadequate in this environment (ibid.). One such statute is the insecurity of water allotments under the riparian system, which rendered contracting difficult. This can be exemplified with a scenario in which an economic actor needs to invest in an irrigation system. She will probably not commit to this investment if there is a risk that other users may dilute her water allotments, which indeed is a risk under the riparian water system. The need for more secure water allowances was one reason for the development of the alternative prior appropriation doctrine, which remains in use today (Christian-Smith et al. 2012).

Why and how the western states developed the prior appropriation doctrine as an alternative to riparian rights have been studied by economists and economic historians alike. Coman (1911) discusses the development of the prior appropriation doctrine in the very first issue of *American Economic Review*. Ostrom (2011) reflects on Coman's paper and argues that Coman identifies several tough collective-action problems concerning water long before they were recognised in the economic literature. Ostrom suggests that the prior appropriation doctrine has its merits in a water-scarce environment, primarily in that it secures tenure. This in turn acts a foundation for building knowledge and trust among actors. The same processes of solving collective action problems with variants of water property rights have also been described in other places, such as Nepal (Ostrom et al. 1999).

Research has also been done on the economic and environmental outcomes of water property rights. Building on Ostrom (2011), Leonard and Libecap (2017) model irrigation as a contracting problem between heterogeneous actors. They empirically show that prior appropriation had a positive effect on economic development in the western states. One specific characteristic of the prior appropriation doctrine is that water rights can be forfeited if they are not put to beneficial use, i.e. if the water allotted is not extracted. As such, prior appropriation water rights holders are incentivised to always use their full allotment of water, regardless of variations in natural factors such as weather and climate and social factors such as market prices of crops (Christian-Smith et al. 2012). This has been a target of much criticism (Hodgson 2006). Burness and Quirk (1979) argue that this trait leads to inefficiencies, as rights holders divert more water than they can presently use profitably in order to maintain the right to use water in the future.

The importance of water rights doctrines for economic and environmental outcomes has been acknowledged in the US. They differ significantly in their design and as such their economic and environmental effects should too. In this paper, we are interested in whether virtual water flows are affected differently under different water property rights in times of drought, following the perspectives on trade in environmental resources described in *Section 3.1.3*. Since differences between water property rights have been shown to affect local use and management, we hypothesise that the same relationship should hold in respect to virtual water trade.

4. RESEARCH DESIGN

4.1 Research question

Water scarcity is becoming exacerbated in many parts of the world and is likely to worsen in the face of population growth and climate variation. While virtual water trade has proven to be a useful tool for the mitigation of local water scarcity, the virtual water concept still lacks a solid economic underpinning. The consideration of property rights has proven to be a relevant explanatory factor for trade in environmental resources in the examples of lumber (Ferreira 2004) and biomass (López 1997). As an economic good, freshwater bear much of the same characteristics as the aforementioned lumber and biomass. A possible explanation as to why previous research on the pattern of VWT is inconclusive may be the disregard of water property rights as an explanatory factor. We thus argue that the consideration of property rights in VWT analysis is warranted. To our knowledge, there is no previous research that theoretically explains and empirically confirms the link between virtual water trade patterns and water property rights.

In the United States, the world's largest exporter of virtual water, recent droughts have sparked a debate on the country's use and management of freshwater. It has been alleged that the country's differing water rights contribute to inefficient and environmentally detrimental freshwater use, particularly in times of drought (Wines 2014). To investigate whether heterogeneity in property rights lead to different patterns in VWT in times of water scarcity, we develop a sub-national gravity model of agricultural trade and water property rights. Thereafter, we test the statistical support of our predictions for the major agricultural states Iowa, Kansas and Missouri, using empirical data from 2009-2014, including the record drought year 2012. Thus, we settle for the following hypothesis:

Virtual water flows are affected differently under different water property rights during drought.

We believe this thesis adds to the research on virtual water trade in two ways. First, we introduce the perspective of property rights as a factor that can explain virtual water trade patterns. Second, in light of the increasing water-scarcity in the world, our study investigates the importance of differences in water property rights for virtual water flows during times of water-scarcity.

4.2 Theoretical framework

To test our hypothesis, we develop a model based on the gravity model of trade and incorporate variables for water property rights doctrines. The following sections expand on the theoretical foundations of the gravity model, and the respective environmental resource trade models of Chichilinsky and Brander and Taylor.

4.2.1 The gravity model of trade

The gravity model of trade was first proposed by Tinbergen (1962) and has been widely used in empirical research on international trade (Anderson and van Wincoop 2004). The gravity model, inspired by the original gravity model of Isaac Newton, predicts that trade flows between countries follow a gravitational pattern. Trade flows should therefore increase with the (economic) size of the trading partners and decrease with the distance between the partners. The gravity model of trade has been shown to have significant explanatory power for international trade in a wide range of settings (ibid.).

Although sometimes questioned for its lack of a clear-cut theoretic economic foundation (Anderson 2011) several authors have proven the model's compatibility with existing trade theory. Notable examples include Helpman (1987) and Bergstrand (1989) using the monopolistic competition model of new trade theory, and Deardroff (1998) and Feenstra (2004) using the Heckscher-Ohlin model.

The gravity model has been used extensively for research both on agricultural trade in general (Sun and Reed 2010; Hatab et al. 2010) and for specific VWT applications (Fracasso et al. 2016; Kagohashi et al. 2015). We therefore use it as the foundation for our model.

Following the classic Newtonian equation, the baseline gravity model takes the form:

$$F_{ij} = G \frac{M_i^{\beta_1} M_j^{\beta_2}}{D_{ij}^{\beta_3}} \eta_{ij}$$

Where subscript *i* denotes exporting country, subscript *j* denotes importing country, F_{ij} is the trade flow, *G* is a constant, M_i and M_j are the economic sizes of the importing and exporting countries respectively and D_{ij} is a variable for trade costs. It is usually constituted by geographical distance between the trading countries. The error term is represented by η_{ij}. Taking the logarithms of both sides of the equation and rearranging yields:

$$\ln(F_{ij}) = \beta_0 + \beta_1 \ln(M_i) + \beta_2 \ln(M_j) - \beta_3 \ln(D_{ij}) + \varepsilon_{ij}$$

The equation can now be estimated linearly. The form of the model is now log-linear and the constant G is part of the intercept. Coefficients on logarithmic independent variables are interpreted as elasticities, expected percentage changes in the dependent variable, given one percent-changes in the independent variables.

In empirical applications, other variables are included that are relevant for trade. These include variables for common borders and languages, colonial history, membership in trade agreements and tariff regimes as well as exchange rate regimes. Other variables of interest may be included for the study in question.

Previous research on, or using, the gravity model has almost exclusively dealt with trade between nations. Our thesis differs from the main body of economic work on gravity trade in that we focus on trade patterns within a nation. As the foundation for gravity trade theory is mass and distance, properties that characterise states in the US as much as countries, we argue that the gravity model is equally valid to our analysis. However, the sub-national property of our data means that many of the usual control variables are irrelevant. Free trade agreements, common languages, colonial history, tariff regimes and exchange rate regimes are crucial in the analysis of international trade, but not so for subnational trade.

4.2.2 Trade in environmental resources and property rights

In this section, we discuss how the main findings of Chichilinsky (1994) and Brander and Taylor (1997) relate to our study. Chichilinsky and Brander and Taylor develop different frameworks for the modelling of trade in environmental resources under heterogeneous property rights regimes.

Chichilinsky develops a model of international trade between two countries, North and South, which are identical in all aspects but their environmental property rights. North has strict property rights for its natural resources and South has no property rights at all, making the natural resource an unregulated common property resource. In the former country, the strict property rights mean that the full social cost, the harvester's private cost and all externalities[2] from extraction, are borne by the harvester. By definition, the weak property rights of the South mean that it lacks the institutions needed to address externalities and regulate extraction accordingly. Thus, the resource harvester's cost of extraction in South is only the private cost of extraction - the opportunity cost of all inputs used for extraction. Therefore, more of the resource will be extracted in South at every given price of the resource.

Based on this, Chichilinsky then establishes two general propositions. First, she shows that the country without property rights will overuse the environmental resource as a production factor, and second, that the less well-defined property rights by themselves will create a motive for trade between two otherwise identical countries. This is because the weaker property rights regime fails to internalise the full social and environmental costs of depletion, incentivising extraction beyond the optimal level. This creates an illusory comparative advantage in the environmental resource intensive good for South, which leads to trade.

Brander and Taylor (1997) consider a similar situation but with a different model structure. They assume a case where a consumer country and a conservationist country trade in a renewable but depletable environmental resource. The former country has a weak property rights regime in that the resource is subject to open access. The latter, in contrast, regulates resource use to maximise domestic long-term utility. The only difference between the countries is in their resource management regimes. Contrary to in Chichilinsky's model, a conservationist country may in the long-run have a comparative advantage in the resource good and thus exports this good under free trade - in spite of its stronger property rights. This scenario arises in what the authors refer to as a case of severe overuse, in which the consumer country depletes the

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[2] "Externalities refers to situations when the effect of production or consumption of goods and services imposes costs or benefits on others which are not reflected in the prices charged for the goods and services being provided." (OECD 2003).

environmental resource to the limit that the cost of extraction in this country becomes higher than in the conservationist country. This is because extraction of the resource is characterised by decreasing returns to scale, raising the cost of extraction per unit with every unit extracted. When the stock is most endangered, it is therefore the conservative country that exports the environmental good. The key finding is that while a country with weak property rights may have a comparative advantage in the short-run, this may not be the case in the long-run if the resource is mismanaged. This contrasts Chichilinsky's hypothesised pattern of trade in cases where the extraction of the environmental resource is characterised by decreasing returns to scale.

As we elaborated in *Section 3.2,* previous research on water property rights in the US has shown that different water property rights doctrines have led to different economic and environmental outcomes. We argue that the heterogeneity in water property rights should lead to different outcomes in virtual water trade as well. The reason for this is that differences in water property rights should induce water rights holders to internalise the social cost of freshwater extraction to different degrees. Strong property rights clearly define ownership and thus also who will bear the full costs of extraction. This incentivises rights holders to extract at the optimal level, taking into account all the costs from extraction. In practice, the large social cost of a depleted water resource should therefore promote a more sustainable use of the water resource – if the water property right is strong. In a weak property rights system, the lack of clear ownership means that the full social cost of extraction is not borne by the users. As the ownership of the water is blurred, so is the allocation of the costs from depletion and users are thus incentivised to extract above the socially optimal level. This overexploitation translates into externalities for the economy as a whole, and might lead to a case of the tragedy of the commons. How this difference in the internalisation of social costs from resource extraction affects trade is, however, not as clear. As developed above, the effect can go both ways. Weaker property rights could lead to larger virtual water exports, as predicted by Chichilinsky. On the other hand, weaker property rights could reduce virtual water exports, as forecasted by Brander and Taylor in the severe overuse scenario. It is beyond the scope of this thesis to hypothesise on the likelihood of these outcomes. Rather, we wish to establish whether the differences in water rights doctrines translate to differences in the virtual water flows.

Chichilinsky and Brander and Taylor both assume a case in which the two trading countries are identical in all aspects except for their property rights doctrines. Our studied case differs from these models in three important aspects. Firstly, we study trade at a sub-national level. The effect of heterogeneity in property rights on trade should however not be confined to international trade. As shown in both models, it is profit-maximising behaviour under different environmental regulations that lead to overexploitation, and we argue this should be expected between trading parties on a sub-national level too.

Secondly, our analysis only concerns the property rights of the exporting state, not those of the importing state. The aforementioned models focus one a pair of trading partners and it is the imbalance between these trading partners' property rights that is the level of analysis. We argue however that as Iowa, Kansas and Missouri trade largely with the same importing states, the effects of the property rights in the importing states should be accounted for. We should therefore be able to assess the effects of the exporting states' property rights on their virtual water exports.

Lastly, it is not the case that the trading partners are identical apart from their property rights regimes. This assumption is unrealistic in the real world but underlines the risk of influence of other factors than water property rights. We address this issue in *Section 4.3*.

While we recognise that our case differs in important aspects from the scenarios depicted in the models of their respective papers, we withhold that their main ideas are applicable in our case too. As such, our theoretical framework draws freely from their ideas but cannot be seen as a strict representation of their models.

4.3 Identification strategy

To be able to infer causality in our analysis we follow a clear identification strategy, addressing several potential endogeneity issues. This strategy is outlined below.

One risk of endogeneity in our model stems from potential omitted variables that work as confounding factors. For example, the transfer to the regulated riparian and prior appropriation doctrines in Iowa and Kansas may have been a result of water scarcity, and this scarcity could be a determinant of virtual water exports too. This could lead us to falsely draw the conclusion that water rights doctrines causally affect virtual water exports while in reality they have no causal relationship, but are both determined by freshwater endowments. Other omitted variables could have the same effect. This is an important issue as differences in freshwater endowments did indeed play a role for the introduction of the prior appropriation doctrine, as was described in *Section 3.1.1*.

By including fixed effects in our model, we control for freshwater endowments that are largely stable from year to year, as well as for other time-invariant variables. To avoid bias from omitted variables that vary from year to year, and that are thus not captured in the fixed effects, we have aimed to conduct our study on as similar states as possible. We therefore identified the eleven US states located along the border between the eastern riparian states and the western prior appropriation states, as depicted in *Figure 1*. The underlying assumption of this selection method was that states in closer proximity should be more similar than states further away from each other, all else equal. To further limit the effects of omitted variables, we committed to identify the most homogenous states out of these eleven border states in terms of geography, demographics and economy. The chosen states Kansas, Missouri and Iowa tick most of the boxes in terms of similarity. A table on the respective states' similarity in terms of demographics, agricultural production and other relevant factors can be found in *Appendix 1*. Further, they follow different water rights doctrines, with regulated riparian in place in Iowa, prior appropriation in place in Kansas and pure riparian in place in Missouri.

As any effects of the differences in water rights doctrines during normal years are hard to test empirically, we commit to test whether differences in allocation mechanisms between the doctrines had an effect during the severe 2012 Midwestern drought[3], as well as the previous and subsequent years. This provides us with a period of water scarcity that is exogenous, allowing for the study of the doctrines' effects on virtual water exports during times of water scarcity.

Lastly, another potential issue in the design of our analysis is that of reverse causality. In our case, reverse causality would be present if it was the case that the amount of virtual water flows causally affect the choice of water property rights doctrine, instead of the other way around. We argue that it is unlikely that virtual water exports have a major direct causal effect on the choice of water rights doctrine, as these were decided upon long ago when agricultural trade was lower and as such virtual water trade was too. While our strategy most likely has not succeeded in completely omitting endogeneity issues, it should provide us with a relevant experiment. A detailed illustration of the effect and geographical extent of the drought can be found in *Appendix 2*.

5. METHOD

5.1 Application of the model

The framework developed in the previous section provides the theoretical explanation behind our model specification. We proceed by constructing a baseline gravity model of trade based on Fracasso et al. (2016). We introduce the effects of water property rights by adding dichotomous variables for the different water rights doctrines. To estimate the different effects of the doctrines during water scarcity, we interact the property rights variables with a dichotomous variable for the 2012 drought. To avoid the dummy trap the interaction variable for the prior appropriation doctrine is replaced by the drought variable, which then becomes the reference variable for the drought. We thus propose the following model:

$$\begin{aligned} vwf_{i,j,t} = {} & \beta_0 + \beta_1(GSP_i) + \beta_2(GSP_j) + \beta_3(distance) + \delta_1(drought) + \delta_2(pure\ riparian) \\ & + \delta_2(regulated\ riparian) + \beta_4(endowments_i) + \beta_5(endowments_j) \\ & + \beta_6(irrigation) + \beta_7(subsidies) + \alpha_{i,j} + \varepsilon_t \end{aligned}$$

Our dependent variable *vwf* is the agricultural virtual water trade flow from state *i* to state *j* in year *t*, GSP_i and GSP_j are the gross state products of the exporting state and importing state respectively and *distance* is

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[3] According to National Centers for Environmental Information of the National Oceanic and Atmospheric Administration, a scientific agency under the United States Department of Commerce, the drought surpassed all previous droughts except those in 1984 and in the 1930s dustbowl. The spatial pattern of drought this year closely overlaid the agricultural area of the US heartland, and the excessive temperatures and lack of rain during the critical growing season severely reduced corn and soybean crop yield. The Primary Corn and Soybean agricultural belt, collectively, experienced the warmest and seventh driest March-August in 2012, resulting in the fourth most severe Palmer Z Index for the season (behind 1936, 1934, and 1988) (NCDC 2017).

the distance between the capitals of the exporting and the importing states. *drought*, *pure riparian* and *regulated riparian* are dichotomous variables which adopt the value of 1 in 2012, and 0 otherwise. The two *endowments* variables are compounded variables constituted by *farmland*, *labour,* and *capital* for the exporting and the importing state, respectively. *irrigation* is a variable for the share of acres under irrigation in the exporting state. *subsidies* is a variable for agricultural subsidies in the exporting state. $\alpha_{i,j}$ represents the time-invariant unobserved variation, or fixed effects, on the state-pair level and ε_t is a time-varying error term. We explain the rationale for each variable in the next section.

5.2 Data

Since data on US interstate Virtual Water Flows (VWF) is not available, we estimate this on our own. In order to do this, we need three different datasets: (1) interstate trade flows for the studied states, (2) annual agricultural production data, (3) Virtual Water Content (VWC) on a commodity- and state-level. We obtain (1) from the Commodity Flow Survey (CFS).4 We compile (2) from the National Agricultural Statistics Service of the United States Agricultural Department for the years 2009-2014. Finally, we obtain (3) from Mekonnen and Hoekstra (2011). In this way, we were able to construct a dataset of annual Virtual Water Flows (VWF) from exporting state to importing state. A brief description of how data collection was performed is given below and a more elaborate one can be found in *Appendix 4*.

5.2.1 Data on interstate trade flows

Data on interstate trade flows US is obtained from the Commodity Flow Survey (CFS). The CFS flows are grouped in 43 commodity groups with the SCTG[5] coding system. Commodity groups consisting of food products are numbered 1 to 7, see *Table 2*. Since we need to combine CFS with VWC content estimates, careful consideration was given to the reliability on VWC estimates for each commodity. The VWC estimates include the full amount of embedded water in a product, including the VWC of all input products needed in its production. For this reason, some VWC estimates include virtual water extracted in a place other than the place of production. For example, the VWC for a kg of beef from Kansas may include VWC for livestock fodder produced in Brazil. Since we only want to calculate a virtual water flow whose sole origin is in the studied state, we exclude the intermediate food commodity groups 1, 5, 7 and 4. Instead, we focus our study on groups 2, 3 and 6. Groups 2 and 3 consist of crops. Since these are primary agricultural products, their full VWC can reasonably be ascribed to the exporting state. We also include the intermediate group 6, which consists of milled grains. The underlying assumption here is that the grains used to produce milled products are produced in the same state, an assumption we think is reasonable. For example, the full VWC of wheat flour exported from Kansas will be ascribed to Kansas, assuming that the wheat was grown there too. As a result of this, we need to include some other intermediate products from group 6 in our

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[4] CFS is a collaboration between the US Census Bureau and the US Bureau of Transportation Statistics.

[5] Standard Classification of Transported Goods.

analysis, such as bakery products. We do however argue that the benefit of including the large milled grain flows outweigh the cost of including relatively small flows in intermediate products.

We thus include SCTG groups 2, 3 and 6 in our analysis. SCTG 2 consists of different cereal grains, SCTG 3 consists of other agricultural products except for animal feed and SCTG 6 consists of milled grain products, preparations and bakery products. A full list of the commodities included in our SCTG groups and their individual codes is provided in *Appendix 6*. For the remainder of this paper, we refer to total amount the agricultural produce traded as crops.

	Food commodity groups provided in the CFS databases	
SCTG	Full Commodity Group Name	Short name
1	Live animals and live fish	Animals
2	Cereals grains	Cereals
3	Other agricultural products	Other
4	Animal feed and products of animal origin	Feed
5	Meat, fish, seafood, and their preparations	Meat
6	Milled grain products and preparations and bakery products	Milled
7	Other prepared foodstuffs and fats and oils	Prepared

Table 2. There are seven food commodity groups in the CFS. This study focuses on groups 2, 3 and 6.

As CFS data is only available for every fifth year, we are left to inter- and extrapolation methods to estimate yearly flows per SCTG group. Here, we followed the method used by Dang, Lin and Konar (2015). To improve the reliability of the data, we calculate export shares of production in 2007 and 2012. These export shares are then interpolated linearly between 2007 and 2012. For 2013 and 2014 the same export share of production as the one in 2012 is assumed. These export shares are then multiplied with annual production data from the National Agricultural Statistics Service. A detailed description of the process can be found in *Appendix 3*. While this method of data collection is certainly not optimal, the Commodity Flow Survey is the only real option for obtaining domestic trade data in the US.

5.2.2 Conversion of trade flows into virtual water flows

As the CFS data is provided at a commodity group level and the VWC estimates at a commodity level, we calculate a production-weighted average of the VWC for each commodity group in the CFS. We thus assume that the composition of the SCTG commodity group trade flows correspond to the composition of agricultural production for each exporting state. This means that if wheat production in tonnes contributes to 10% of the total commodity group production in tonnes, we assume that 10% of the commodity group trade flow consists of wheat. This assumption was also used by Dang, Lin and Konar (2015).

We obtain VWC data for crops and derived crop products for individual US States from Mekonnen and Hoekstra (2011). The data is averaged over the 1996–2005 time period and provide the green, blue, and grey VWC of crops.[6] We select both green and blue VWC and sum these values to arrive at the total crop VWC. Grey water is not included in the analysis. Since grey water is defined as the water "consumed" by pollution, it is not directly embedded in crops the same way green and blue water are. By combining data on trade flows with virtual water content estimates we obtain yearly aggregate virtual water flows between states for SCTG product groups 2, 3 and 6 within the United States. Each annual flow is given by:

$$vwf_{i,j} = \sum_{c} vwc_{i,j} * commodityflow_{i,j,c}$$

Where *vwf* is virtual water flow, *vwc* is virtual water content per ton of crop flow *commodityflow* is total flow of crops, *i* denotes exporting state, *j* denotes importing state and *t* denotes year. For a more detailed account of the construction of the dataset, see *Appendix 4*.

5.2.3 Data limitations

There are number of potential issues with our data methods which may lead to measurement error. Our estimates could be biased by intermediate trade in primary products. For example, it is possible that Iowa imports a primary product such as corn and then exports it. In this case, Iowa would act as an intermediary in the virtual water trade, and ascribing the corn VWC to Iowa would be incorrect. This is an endemic problem in trade data and is hard to get around without specific figures on intermediate trade, which in our case unfortunately is not available.

Furthermore, while the limited range of the agricultural products included in our analysis could bias our data, the effect of different water rights during drought is likely to be similar regardless of the subset of products studied. All agricultural products require water and the effect of a drought on different water rights doctrines is therefore not likely to be fundamentally different for different kinds of agricultural products. Moreover, primary agricultural products have been the choice of scope for earlier research (de Fraiture et al. 2004), allowing for a more direct comparison of our findings to previous literature.

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[6] *Blue water* content is defined as: "Volume of surface and groundwater consumed as a result of the production of a good or service. Consumption refers to the volume of freshwater used and then evaporated or incorporated into a product. It also includes water abstracted from surface or groundwater in a catchment and returned to another catchment or the sea. It is the amount of water abstracted from groundwater or surface water that does not return to the catchment from which it was withdrawn."

Green water content is defined as: "Volume of rainwater consumed during the production process. This is particularly relevant for agricultural and forestry products (products based on crops or wood), where it refers to the total rainwater evapotranspiration (from fields and plantations) plus the water incorporated into the harvested crop or wood."

Grey water content is defined as: "The grey water footprint of a product is an indicator of freshwater pollution that can be associated with the production of a product over its full supply chain. It is defined as the volume of freshwater that is required to assimilate the load of pollutants based on natural background concentrations and existing ambient water quality standards. It is calculated as the volume of water that is required to dilute pollutants to such an extent that the quality of the water remains above agreed water quality standards." (Mekonnen and Hoekstra 2011).

In constructing our dataset by inter- and extrapolating shares and flows, we are making strong assumptions. Straight linear developments of real world data are rarely realistic. Furthermore, the fact that the endpoint of our interpolation is 2012, the year the drought hit, means that data points for 2008-2011 are interpolated between a normal value in 2007 and an extreme value in 2012, as a result of the drought. As agricultural production and exports decrease in 2012, this means that data points for the normal years 2008 and 2011 are likely to be artificially low. This, however, means that the results for our main variables of interest - the drought dummies - will be conservative, as the estimated effects from them will be alleviated by the fact that data points before 2012 are artificially low. Results are therefore unlikely to be overestimated due to the inter- and extrapolation. Nonetheless, this is a limitation in the data that has to be taken into account in the interpretation of the results.

We also acknowledge that the interpolation of trade shares between 2007 and 2012 and the extrapolation of shares for 2013 and 2014 may lead to unreliable estimations of virtual water trade. In spite of these issues, we argue that the unreliability is mitigated somewhat by the fact that the trade shares are used in conjunction with yearly production data from NASS. Lastly, the fact that we can derive only 58 yearly trade flows compared to the theoretically possible 141 yearly flows is problematic for our study. This discrepancy stems from the fact that some of the trade flows in the CFS are not reported due to not meeting reporting standards.

5.2.4 Control variables

We utilise control variables inherent to the original gravity trade model as well as variables used in other studies of virtual water trade (for data sources, see *Appendix 4).* The "mass" component in the model traditionally consists of exporter and importer GDP. As we study interstate trade in the US we use Gross State Product (GSP). The economic size of a country has been shown to contribute in a country's ability to engage in trade, both as an exporter and an importer. In our view, the same relationship should hold in our sub-national setting. There are different approaches to account for the variables referred to as cost of trade, or multilateral resistance terms. On an international level, regional trade agreements, tariffs and other policies need to be taken into account. Many of these variables are not relevant to us due to our sub-national scope. We thus use distance multiplied by a yearly transport cost index as a proxy for transport costs, in line with previous applications of the gravity model (see, for example, Bergstrand 1985)

Further, we include endowment variables for arable land, agricultural capital and agricultural labour. To avoid multicollinearity with our drought– and doctrine variables, we do not include variables for freshwater endowments. As data on freshwater resources are largely stable over time, effects from water endowments are largely captured in the fixed effects. We use annual data on acres of farmland as a proxy for arable land. Different approaches have been used in the literature to model capital and labour. For instance, Fracasso et al. (2016) used the number of tractors as a variable to reflect capital. In our view, this measure lacks somewhat in scope, as capital use in agriculture is not limited to tractors. We utilise labour and capital variables based on yearly labour expenses[7] and yearly capital consumption in agriculture[8]. We believe labour expenses is a reasonable proxy for labour endowments. Further, we argue that a capital variable based on capital expenses will follow capital endowments better than the number of tractors. To measure labour- and capital intensity, both measures are included as ratios of arable land. We argue that an increase in these two variables should lead to a higher production of field crops and vice versa. For all endowment variables the intuition is that larger endowments, all else equal, for the exporting state should lead to higher virtual water exports, as more resources are available for crop production and thus for export. For the importing state, the opposite reasoning holds. Larger endowments should translate to an increased ability to produce crops and should thus decrease the need for agricultural imports.

Lastly, we choose to include controls for irrigation and federal subsidies. By including an irrigation variable, we control for the fact that irrigation infrastructure can increase drought resilience. Also, a control for government subsidies means that changes in agricultural production due to subsidies can be excluded in our model.

5.3 Descriptive statistics

Table 3 presents descriptive statistics for the variables used in the model. Endowment variables are presented as absolute figures and as ratios to acres, as they are used in our regression model.

We examine virtual water flows from the Midwestern states Iowa, Kansas and Missouri to other contiguous states, i.e. all states except Hawaii and Alaska.[9] As we are interested in interstate VWT, we do not consider intrastate flows in this analysis. That leaves each of the three exporting states with 47 potential trade flows per year, in total 141 potential flows per year. When specific CFS trade flows are not reported due to not meeting publishing standards for both 2007 and 2012, this flow is not included in the analysis. When flows are left unreported for either 2007 or 2012, they are also discarded since we cannot interpolate trade shares. Reported 0-flows are treated like any valid flow. The number of non-reported flows due to data not meeting publishing standards is unfortunately rather high. This is a limitation of our data, as we end up with less observations. Furthermore, these non-reported flows could potentially subject our data to selection bias. This needs to be taken into account when interpreting our results. All in all, we end up a panel data set with a yearly total of 58 interstate flows and thus 348 total state flows from 2009 until 2014.

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[7] Labour expenses include, financial and non-financial expenses for contract and hired labour.

[8] Capital Consumption: Declining balance of capital stock, ARMS-based capital expenditures, and NASS prices paid indexes.

[9] As Hawaii and Alaska differ significantly from the rest of the states geographically, we exclude them to allow for better comparision.

Variable	Obs	Mean	Std. Dev.	Min	Max
vwf	348	425.864	949.597	0	5 691.112
drought	348	0.144	0.351	0	1
pure riparian	348	0.052	0.222	0	1
regulated riparian	348	0.046	0.210	0	1
Gravity variables					
exporter GSP	348	192.926	60.458	122.431	283.280
importer GSP	348	455.356	501.353	37.214	2 459.000
distance	348	1 208.790	690.065	135.983	3 010.600
Endowments					
exporter farmland	348	34 700 000	7 725 857	28 300 000	46 200 000
importer farmland	348	23 800 000	28 000 000	70	132 000 000
exporter capital	348	1 426 479	933 063	581 508	3 997 605
importer capital	348	815 401	812 584	6 875	4 191 026
exporter labour	348	454 502	201 792	87 010	881 997
importer labour	348	976 083	1 786 608	13 435	9 646 897
exporter capital/farmland	348	0.044	0.032	0.013	0.131
importer capital/farmland	348	13.194	46.175	0.001	267.157
exporter labour/farmland	348	0.014	0.007	0.002	0.029
importer labour/farmland	348	20.381	71.320	0.003	385.435
Other control variables					
share of farmland irrigated	348	0.124	0.095	0.016	0.272
subsidies	348	548 124	255 886	6 318	1 024 838
subsidies/farmland	348	0.017	0.008	0.0001	0.033

Table 3. Descriptive statistics of the data used in the model. GSP figures in millions of USD, distance figures in km multiplied with the transport cost index, farmland figures in acres, capital and labour expenditures in thousand USD, subsidies in thousand USD.

5.4 Estimation method

Two major challenges arise when estimating the gravity model of trade in log-linear form with traditional ordinary least squares methods. Firstly, trade data is often characterised by heteroscedasticity, leading to inconsistent estimators when the model is log-linearised. Secondly, trade data is often characterised by a high presence of zero-values, for which the natural logarithm is not defined. Zero values can exist for several reasons. All potential trading partners might not trade, small values might be rounded to zero or missing observations might be wrongfully recorded as zero. Nonetheless, true zero values should be included in a gravity model. Observations of non-existent trade flows contain as much information, if not more, about the determinants for trade as an observation with a value. Hence, they are valuable for the estimation. Dropping zero-value observations is therefore not a desirable option; neither is adding a constant to the dependent variable to circumvent the issue. These solutions will lead to inconsistency in the estimators of parameters, the severity of which will depend on the particular sample and model.

As we use a trade dataset that contains zero-value trade flows, our model is likely to be fraught with both the challenges associated with the log-linear form of the gravity model of trade. We thus estimate our model with the Poisson pseudo-maximum-likelihood (PPML) estimator, as proposed by Santos Silva and Tenreyro (2006). The PPML estimator is robust to different patterns of heteroscedasticity and will as such estimate consistent estimators where OLS regressions would not. For a detailed explanation of the PPML estimator, we refer to Santos Silva and Tenreyros' original paper.

As state-pair trade flows are likely to bear similar characteristics over time, we estimate our model with standard errors clustered on the state-pair level to avoid bias from autocorrelation (Wooldridge 2013).

5.5 Tests

To test if multicollinearity is present in our model we calculate and examine the Variance Inflation Factor (VIF) values for the dependent variables in our model, following Williams (2015). To test our model for general functional form misspecification, we conduct Ramsey's regression specification error test (RESET) (Wooldridge 2013). We also conduct a Wald test on our explanatory variables' collective statistical significance for the independent variable

6. RESULTS

Table 4 presents the PPML regression results. Variables are added sequentially and each column presents each of the six model specifications.

	Dependent variable: vwf (annual virtual water flow)					
Explanatory variables	(1) Baseline model	(2) + Farmland	(3) + Labour	(4) + Capital	(5) + Irrigation	(6) + Subsidies
log_GSP_exp	-0.315	-0.124	-0.280*	-0.284*	-0.241*	-0.240*
	(0.195)	(0.150)	(0.151)	(0.149)	(0.139)	(0.134)
log_GSP_imp	0.996***	0.570***	0.761***	0.971***	0.969***	0.969***
	(0.310)	(0.197)	(0.209)	(0.217)	(0.216)	(0.216)
log_distance	-1.114***	-0.731**	-0.466	-0.701**	-0.698**	-0.698**
	(0.295)	(0.300)	(0.303)	(0.341)	(0.342)	(0.342)
drought	-0.161	-0.181	-0.360**	-0.351**	-0.389**	-0.386**
	(0.152)	(0.154)	(0.156)	(0.150)	(0.193)	(0.192)
pure_riparian	-0.515*	-0.307	-0.337*	-0.356**	-0.298	-0.300
	(0.267)	(0.197)	(0.200)	(0.160)	(0.227)	(0.228)
regulated_riparian	0.192	0.212	0.315*	0.278	0.301	0.298
	(0.162)	(0.161)	(0.191)	(0.179)	(0.211)	(0.209)
log_farmland_exp		22.63	32.35	30.37	32.52	32.66
		(26.85)	(29.10)	(31.51)	(31.59)	(31.28)
log_farmland_imp		0.727***	0.250	-0.00650	-0.00502	-0.00514
		(0.221)	(0.233)	(0.268)	(0.269)	(0.269)
log_labour_exp			1.125**	1.229***	1.213***	1.216***
			(0.468)	(0.415)	(0.421)	(0.421)
log_labour_imp			-0.756***	-0.787***	-0.788***	-0.788***
			(0.184)	(0.206)	(0.206)	(0.206)
log_capital_exp				0.389*	0.439*	0.438*
				(0.214)	(0.252)	(0.251)
log_capital_imp				-0.402*	-0.398*	-0.398*
				(0.211)	(0.211)	(0.211)
share_irrigated					3.280	3.123
					(5.012)	(5.004)
log_subsidies						-0.00301
						(0.0148)
Constant	9.356***	-394.1	-554.2	-515.4	-552.8	-555.1
	(2.331)	(462.2)	(500.2)	(542.3)	(543.6)	(538.2)
Observations	348	348	348	348	348	348
R-squared	0.140	0.347	0.381	0.402	0.403	0.403
Trade-pair fixed effects	YES	YES	YES	YES	YES	YES

Table 4. PPML regression results. Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1

As the model is of the log-linear structure, it is suitable to transform the regressor coefficients for intuitive and correct interpretation.[10] The transformed coefficients for our variables of interest, the dichotomous drought- and doctrine variables, are presented in *Table 5*. These coefficients are interpreted as semi-elasticities with regard to our dependent variable, the expected percentage change in *vwf* following the effect denoted by the dichotomous variable. Coefficients for the other variables can be interpreted as largely correct elasticities.

drought	-0.320
pure_riparian	-0.259
regulated_riparian	0.347

Table 5. Dichotomous variables as semi-elasticities

Table 4 and *Table 5* show that virtual water trade flows are not systematically affected differently by the drought under different water rights doctrines. When controlling for endowments, irrigation infrastructure and agricultural subsidies, the estimated effect of the drought on virtual water flows from all states is a volume reduction of 32%. This effect is robust at the 5% significance level from model specification three and onwards, emphasizing the magnitude of the studied drought. The differences in the effect of the drought due to differences in water rights doctrines are captured by the dichotomous variables *pure_riparian* and *regulated_riparian*. These differences are not systematically and statistically different from the effect in Kansas.

The estimated additional negative effect of the drought in Missouri, which uses the pure riparian doctrine, is ca 26 percentage points, indicating a substantially larger reduction of virtual water flows in Missouri than in Kansas. This additional effect is statistically significant at the 10% significance level for model specification 3 and at the 5% level for specification 4[11], but is insignificant when controlling for the ratio of acres under irrigation.

The estimated negative effect of the drought in Iowa, under the regulated riparian doctrine, is lower. The regulated riparian variable exhibits a positive coefficient of about 35 percentage points, largely offsetting the negative effect of the reference variable *drought* and thus indicating a relatively weaker negative effect of the drought on virtual water flows from Iowa. The effect is however insignificant in all but one model specification, and thus no real conclusions can be made about the effect of the drought under regulated riparian systems.

In conclusion, we do not find solid empirical support for the hypothesis that drought should affect virtual water flows differently under different water property rights doctrines.

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[10] When a dependent variable is logarithmic, a general rule of thumb is that a coefficient denotes the percentage change in the dependent variable following a change in the independent variable. This rule holds well for coefficients with a value between -0.1 and 0.1. Beyond this span, the approximation becomes increasingly distorted as the coefficient increases or decreases. As our variables of interest exhibit rather large coefficients, we calculate their correct semi-elasticity coefficients (Benoit 2011).

[11] The additional effect under the pure riparian doctrine is also statistically significant at the 10% level in model specification 1, with a substantially stronger effect. Without controlling for other variables, coefficients on the drought effects should be interpreted with care and we choose not to comment on it in this case. The same goes for importing state farmland in the second model specification.

The gravity variables importer GSP and distance are statistically significant at the 1% and 5% levels and display the expected positive and negative signs, respectively. Thus crop virtual water exports from the studied states tend to increase with the economic size of the importing state and decrease with the distance between the two states. Exporter GSP is statistically significant at the 10% level but exhibits a negative coefficient, contrary to gravity expectations. In our model, increased exporter GSP would thus decrease virtual water flows for crops. Apart from exporter GSP, there thus seems to be a gravity relationship in crop trade between the studied exporting states and the importing states.

Results for endowment variables are mixed. Endowment of labour is significant at the 1% level for both exporter- and importer state with expected signs, positive and negative respectively. Similarly, endowment of capital is significant at the 10% level for both exporter- and importer state with positive and negative signs, respectively. For exporter variables, these results are interpreted as the expected percentage increase (decrease) in virtual water exports following a 1% increase (decrease) in the particular endowment, ceteris paribus. For importer state the coefficients are negative and are thus interpreted as the expected percentage decrease (increase) in virtual water exports following a 1% increase (decrease) in the particular endowment. It thus seems as labour is the most important endowment determinant for virtual water flows. Farmland endowments are not significant for explaining virtual water flows. As other endowment variables are incorporated into the model as ratios to farmland, it seems as if productivity per acre is a stronger determinant of virtual water flows than farmland itself.

6.1 Tests

We perform a Wald test for the simultaneous significance of the explanatory variables on the dependent variable in the last model specification, and reject the null hypothesis that the explanatory variables do not equal to 0 simultaneously (see *Appendix 5* for the test specifics). The Variance Inflation Factor (VIF) values are high for some of the control variables, but low for our dichotomous variables of interest. The model is thus not severely biased by multicollinearity for our purpose. For exact VIF values, see *Appendix 10*.

Lastly, we test our model for functional form misspecification by conducting Ramsey's regression specification error test (RESET). Our model passes the test at the 10% level, but with little marginal for one of the test statistics. We conclude that we cannot rule out the risk of some form of misspecification in our model.

7. ALTERNATIVE EXPLANATIONS AND POTENTIAL BIASES

This section outlines potential biases in our study and discusses limits and alterations to the interpretation of our results in *Section 6*.

One potential bias in our study is the omitted-variable bias. By including fixed effects on the exporter-importer pair level, we control for unobservable time-invariant variables for each trading pair. We thus eliminate many potential sources for omitted-variable bias. Nonetheless, time-varying unobserved variables are not accounted for by this and as such our model risks to be biased by over- or underestimating parameters to account for the missing variables. Such time-varying variables are especially harmful to our analysis if they are inherently connected to the occurrence of drought. This would lead our model to over- or underestimate the effect of drought, the main focus in this study.

A second potential source of bias is the availability and quality of data. As CFS data is not available for every year, we were left with inter- and extrapolating data to obtain observations for all years. This is clearly a potential source of error, as inter- and extrapolation requires unrealistic assumptions about linear development of the data. Furthermore, the many data points missing from the CFS data due to not meeting publishing standards could pose a risk of selection bias, if this non-reported data is not distributed randomly. If for instance data on wheat exports from a particular state was systematically of bad quality and thus not reported, total virtual water flows from that state would be underestimated, given the high VWC of total wheat flows from the studied states. With regard to the VWC estimates provided by Hoekstra, averages over time necessarily mean deviations from true values and eliminates the possibility of taking into account improvements in water usage productivity on crop level.

With regard to our independent variables, we have in several instances had to use proxies. For capital and labour, expenditures are used as proxies for endowments. Thus differences in rents and wages are not taken into account, as we have to assume that a dollar spent on either one in one state is equivalent to a dollar spent in another, in terms of endowments.

8. DISCUSSION

In this thesis, we develop a gravity model of virtual water trade and incorporate water property rights into the model to test the effect of drought on US interstate virtual water trade under heterogeneous property rights. Based on the models of Chichilinsky and Brander and Taylor, we have argued that differences in the strengths of property rights should lead to differences in the internalisation of externalities. As agricultural production stands for the majority of freshwater consumption, this should then translate into differences in virtual water trade.

By constructing a dataset based on interstate trade data, estimates on virtual water contents of different commodities and the yearly production of each commodity, we estimate interstate virtual water exports in three important commodity groups from three major agricultural states in the U.S - Kansas, Missouri and Iowa - during 2009-2014.

We empirically test the effect of the 2012 Midwestern drought on virtual water flows under the different water rights doctrines- prior appropriation, pure riparian and regulated riparian. The results do not systematically support our hypothesis, which was that virtual water flows are affected differently under different water property rights during drought. This indicates that the extent of internalisation of the social costs of depletion is not dramatically different for the different states. Similar extents of internalisation would lead to similar responses to water scarcity in terms of export decisions of agricultural products, which can be seen as virtual water flows.

The results are inconclusive. For three of our model specifications, we find a stronger negative effect of the drought in Missouri than in Kansas. This indicates that virtual water flows could indeed be affected differently by water scarcity under different water rights doctrines. The stronger negative effect of the drought on flows under the pure riparian doctrine challenges Chichilinsky's hypothesis that environmental resources are extracted and exported to a larger extent under weaker property rights. Likewise, it supports Brander and Taylors' long-run hypothesis under the severe overuse scenario- that strong property rights will yield comparative advantage and turn the state to an exporter.

The estimated negative effect of the drought on virtual water flows from Iowa is weaker than in Kansas. This effect is only statistically significant for one model specification and thus no real conclusions can be made about the regulated riparian rights.

The inconclusive results can indicate two things. Firstly, there might be no causal relationship between the strength of water property rights and virtual water exports. If this is the case, the significant results that we do get are most probably a result or modelling issues. Indeed, the conducted RESET test indicates that our model may suffer from functional form misspecification, even though the model passed the test. Secondly, our sample size may be too small, preventing us from drawing any solid conclusions. If this is the case, the results that are statistically significant may be indicative of a strong effect of water property rights on virtual water flows under water scarcity, as the effect is statistically significant even though the sample is too small.

Furthermore, our modelling of water rights is quite simplistic. Within doctrines and states there exist variation of both statutes and enforcement. It is outside the scope of this paper to fully take into account such detailed variation, but we acknowledge that it is important for fully understanding the role that property rights may play for virtual water trade. One example of such detail is the statute of beneficial use under the prior appropriation doctrine, which dictates that water rights holders need to use their water allowances to get allowances in the future. This statute incentivises consumption of freshwater and could be a reason to why the reduction of virtual water exports from Kansas was not larger during the drought, as would have been expected with the Chichilinsky hypothesis.

9. CONCLUSION

The contribution of this thesis to the literature is twofold: First, we have introduced the perspective of water property rights as a factor that can explain virtual water trade patterns. Secondly, and more specifically, we have investigated the importance of water property rights for determining virtual water flows in times of water scarcity.

As our results are inconclusive, we argue that more research on water property rights and virtual water trade is needed to enhance the understanding for future water resource policy. In particular, we suggest improving on our study in the following ways: Firstly, we suggest conducting a similar study with more data of higher quality. Including more states, commodities and years can provide the sample size needed for further insight. Secondly, we suggest a more nuanced modelling of water property rights, taking into account specific statutes, seniority hierarchies and other dynamics of water property rights on state level.

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APPENDIX

Appendix 1 – Comparison of the studied states

State	Iowa	Kansas	Missouri
Water policy doctrines	Regulated riparian	Prior-appropriation	Pure riparian
Population (2016 estimate)	3 134 693	2 907 289	6 093 000
Rural population share	35%	24%	28%
Area km^2	145 746 km^2	213 100 km^2	180 533 km^2
Farm land acres (2016)	30 500 000	46 000 000	28 300 000
Principal crops acres (2016)	19 995 000	23 233 000	14 056 000
Principal crops share of farmland	66%	51%	50%
Irrigated principal crops acres (2016)	16%	18%	15%
Gross State Product in millions $ (2014)	174,103	147,765	293,378
Per capita GSP in $ (2014)	55 541	50 826	48 150

Table 6. The table shows that the studies states share a relatively high degree of similarity with regard to economic, agricultural and demographic factors. Principal crops include corn, sorghum, oats, barley, winter wheat, rye, durum wheat, other spring wheat, rice, soybeans, peanuts, sunflower, cotton, dry edible beans, potatoes, sugar beets, canola, and proso millet.

Appendix 2 – The effect of the 2012 drought

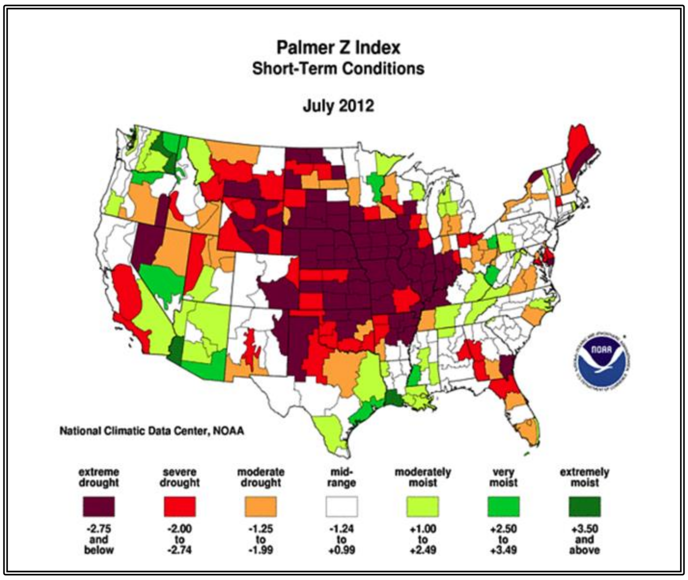

Figure 3. Drought conditions in July 2012, in the midst of the growing season. Iowa, Kansas and Missouri all faced extreme drought conditions. Illustration used with the authorization of the National Climatic Data Center.

Appendix 3 – Description of data methods

In the section below, we elaborate on some of the methods used to refined data from the trade data from the Commodity Flow Survey (CFS). The CFS is a collaboration between the US Census Bureau and the US Bureau of Transportation Statistics and is published every year that ends with a "2" or a "7". The survey takes is normally published four year after the year of data collection. Each year a sample of 100 000 establishments is chosen based on industry type and geographic location. These establishments then report their shipments in dollar value, weight, commodity code and description, mode of transportation and final US destination for each quarter during the survey year. From the survey data, the total yearly figures are estimated by the CFS.

Since the CFS publishes data for every fifth year, we interpolate interstate trade figures for the years between 2007 and 2012. For those two years, we use the CFS data to obtain the size of each flow from state *i* to state *j* in tonnes per SCTG product group. First, the sum of trade flows, in tonnes, for commodity groups 2, 3 and 6 from exporting state i to all other states is calculated for the years 2007 and 2012. Then the export share in 2007 and 2012 of production per commodity is calculated using annual production data from National Agricultural Statistics Service (NASS). Next, these shares are interpolated linearly between the years 2007 and 2012 and multiplied with production data for years 2008-2011 to obtain total trade flows per exporting state and year in tonnes. For years after 2012, we use the same share of total exports of production as in 2012 and estimate total flows with annual production data for the years 2013 and 2014.

Given that the CFS data is provided at different commodity resolutions, one major challenge in our paper is how to combine CFS data with estimates of virtual water content. In order to remedy this mismatch, we calculate a production-weighted mean of the VWC for each commodity group from the CFS. The underlying assumption of this approach is that the composition of food trades corresponds to the composition of the agricultural production of each state. This means that if wheat production in tonnes contributes to 10% of the total commodity group production in tonnes, 10% of the commodity group trade flow is assumed to consist of wheat. Each state's production of, for example, wheat, corn, rye, barley, oats, grain sorghum and other cereal grains - the constituents of SCTG 2 - was therefore assembled from NASS. The volume measure of the data from NASS varied between different commodities (e.g., pounds, bushels, hundredweight, barrels, tons, etc.). These measures were converted into metric tons using a commodity specific converter provided by the Food and Agricultural Organization of the United Nations. The respective commodity's share of commodity group production in tonnes was then calculated and these shares were then used to disaggregate trade data from CFS. This disaggregation makes it possible to estimate the virtual water content of the trade flow. Similar methods have been used in previous studies (Dang 2014) (Fulton, Cooley and Gleick 2012, 2014) (Fulton 2015) (Scanlan and Kehl 2014) (Guliani 2015). In line with previous studies, we argue that this method based on reasonable assumptions given the availability of data.

As for the CFS data, there are some potential issues that warrant a discussion. Firstly, our estimates of virtual water trade flow are based on the assumption that the origin state of a trade flow also is the state where the commodities were produced. This assumption is employed in all virtual water "accounting" studies (Konar 2011, 2012). Secondly, we acknowledge that the interpolation of trade shares between 2007 and 2012 and the extrapolation of shares for 2013 and 2014 may lead to unreliable estimations of virtual water trade. For example, it is not unlikely that the financial crisis in 2008-2009 may have affected trade. Moreover, the drought conditions in 2012 may also have affected the traded shares during that year. In spite of these issues, we argue that the unreliability is mitigated somewhat by the fact that the trade shares are used in conjunction with yearly production data from NASS. Lastly, the fact that the we can derive only 58 yearly trade flows compared to the theoretically possible 141 yearly flows is problematic for our study. This discrepancy stems from the fact that some of the trade flows have not been properly reported in the CFS data and marked with "S". Since we cannot know for a fact whether these unreported flows are zero-flows or flows with a volume, we argue that the complete omission of these flows is the only reasonable method to handle this issue.

Appendix 4 – Regression variables and sources

Data	Description	Years	Source
State GSP for importer and exporter,	Exporter and importer	2009-2014	United States Census Bureau
Distance	Distance in km between state capitals	N/A	Google Maps
Acres in farmland	Exporter and importer	2009-2014	National Agricultural Statistics Service
Acres in crops	Exporter and importer	N/A	Exporter and importer
Labour expenses	Exporter and importer	2009-2014	Economic Research Service of the of the USDA
Capital consumption	Exporter and importer	2009-2014	Economic Research Service of the of the USDA
Population	Exporter and importer	2009-2014	United States Census Bureau
Water rights	Exporter	N/A	US Department of Energy
Drought	Exporter	N/A	National Climatic Data Center
Subsidies to crop sector	Exporter	2009-2014	Economic Research Service USDA
Irrigation	Share of irrigated acres used in crop production	2009-2014	National Agricultural Statistics Service
Transport cost index	Index of transport costs	2009-2014	US Bureau of Labour Statistics

Table 7. The used variables and their respective sources.

Appendix 5 – Test results

Wald Chi-square test for explanatory variables' collective significance

(1) log_GSP_exp = 0
(2) log_GSP_im = 0
(3) log_distance = 0
(4) drought = 0
(5) pure_riparian = 0
(6) regulated_riparian = 0
(7) log_farm_ex = 0
(8) log_farm_im = 0
(9) log_labour_ex = 0
(10) log_labour_im = 0
(11) log_capital_exp = 0
(12) log_capital_imp= 0
(13) share_irrigated = 0
(14) log_subsidies = 0

chi2 (14) = 880.75
Prob > chi2 = 0.0000

Table 8. The results from the Wald test show the explanatory variables' collective significance.

Multicollinearity – Variance Inflation Factor values

Variable	VIF	1/VIF
log_farmland_imp	32.82	0.030471
log_labor_imp	18.50	0.054056
log_capital_imp	17.65	0.056662
log_farmland_exp	15.39	0.064969
share_irrigated	14.02	0.071335
log_GSP_exp	5.21	0.192090
log_labor_exp	4.19	0.238518
log_capital_exp	3.84	0.260562
log_GSP_imp	3.77	0.265092
drought	3.52	0.284118
log_distance	2.53	0.395923
pure_riparian	2.37	0.421106
regulated_riparian	2.30	0.434513
log_subsidies	1.45	0.689839
Mean VIF	9.11	

Table 9. The results from the Wald test show the explanatory variables' collective significance.

Functional form misspecification – Ramsey's regression specification error test (RESET)

(1)	vwf_hat^2 = 0	
	chi2 (1)	= 2.63
	Prob > chi2	= 0.1051
(1)	vwf_hat^3 = 0	
	chi2 (1)	= 0.03
	Prob > chi2	= 0.8638

Table 10. The results show that the model does not suffer from model misspecification. However, the model passes the test with little margin.

Appendix 6 – constituents of SCTG group 2, 3 and 6

SCTG group 2 constituents	
02100	Wheat
02200	Corn (except sweet corn, see 03219)
02901	Rye
02902	Barley
02903	Oats
02904	Grain sorghum
02909	Other cereal grains

Table 11. SCTG group 2 contains the main cereal grains.

SCTG group 3 constituents	
03100 Potatoes, including seed, fresh or chilled (except sweet potatoes, see 03219)	03342 Shelled nuts)
03211 Tomatoes, fresh or chilled	03400 Soy beans, including for sowing
03212 Onions, shallots, garlic, leeks, and onion sets, fresh or chilled	03501 Peanuts, unroasted, including for sowing
03213 Lettuce, fresh or chilled	03502 Linseed (flaxseed), including for sowing
03214 Leguminous vegetables such as peas and beans, fresh or chilled	03503 Colza (rape) or canola seeds, including for sowing
03219 Other fresh or chilled vegetables including olives	03504 Sunflower seeds, including for sowing
03221 Leguminous vegetables, dried	03505 Cotton seeds, including for sowing
03229 Other dried vegetables,	03506 Mustard seeds, including for sowing
03312 Grapefruit, fresh or chilled	03509 Other oil seeds and nuts
03319 Other citrus fruit, fresh or chilled	03601 Bulbs and roots and similar products, live trees and other plants, and mushroom spawn
03321 Bananas and plantains, fresh or chilled	03602 Other seeds for sowing
03322 Grapes, fresh or chilled	03910 Fresh-cut flowers
03323 Melons, fresh or chilled	03921 Tobacco, not stemmed or stripped
03324 Apples, fresh or chilled	03922 Stemmed and partially stemmed tobacco
03329 Other fresh or chilled fruit (excludes olives, see 03219)	03930 Raw cotton (not carded or combed)
03331 Dried grapes (includes raisins and "currants")	03991 Unprocessed coffee and unfermented tea
03339 Other dried fruit, (includes mixtures of dried fruit)	03992 Sugar beet and sugar cane (see 07501 sugar)
03341 Nuts in the shell (not including peanuts, see 03501)	03999 Other agricultural products

Table 12. SCTG group 3 contains a large variety of different primary crops.

SCTG group 6 constituents	
06100	Wheat flour, groats, and meal (except byproducts, see 04130)
06210	Malt
06291	Milled rice including husked, broken, flour, groats, and meal
06292	Corn flour, groats, and meal
06293	Starches and modified starches
06299	Inulin; wheat gluten; milled cereals and other vegetables; and grains otherwise worked, including rolled, flaked, hulled, pearled, sliced, or kibbled (except milling byproducts, see 04130)
06310	Pasta and couscous
06320	Breakfast cereal foods, swelled, roasted, or partially cooked
06391	Mixes and dough for the preparation of bakery products, including batters
06392	Rice preparations, instant rice, and partially cooked rice
06399	Other food preparations of cereals
06410	Baked snack foods including pretzels, cheese sticks, and tortilla chips
06420	Frozen baked products, including quiche, pizza, bagels, waffles, and pastries
06431	Perishable baked products (including fresh bread, pastries, pies, cakes, doughnuts, pizza, and quiche)
06432	Dry baked products (including cookies, crackers, and taco shells)

Table 13. SCTG group 6 mainly contains milled and refined forms of cereal grains.