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Socio-Economic Implications of Drought in the Agricultural Sector and the State Economy

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Academic Editor: Ralf Fendel
Received: 3 June 2016; Accepted: 17 August 2016; Published: 1 September 2016

Abstract: In 2011, the most severe drought in Texas history caused $7.62 billion in losses in the agricultural sector alone. This paper analyzes ripple effects of the 2011 drought in Texas agriculture on the entire state economy retrospectively in an effort to foster discussion on targeted mitigation measures in the long term. By using an Input-Output and social accounting matrix model, direct effects on livestock, cotton, sorghum, wheat, corn, hay, and timber production, as well as indirect effects on other related sectors, and finally induced effects from changing consumers behavior have been estimated. According to the results, the 2011 drought caused economic losses of $16.9 billion in the entire Texas economy and increased the unemployment by around 166,895 people. The agricultural sector alone lost around 106,000 jobs. The cotton farming experienced 91% of revenue losses (as compared to 2010), while the livestock production lost 32% in revenue. The decreased production yields and limited market supply directly influence market prices for those products, which might create additional spillover effects on export and import quantities. The presented analysis can be helpful for designing policies to launch mitigation programs for drought events in the future.

Keywords: socio-economic analysis; drought, agricultural production; input-output analysis; IMPLAN; Texas

JEL Classification: C67; Q25; Q5

1. Introduction

Considerable economic losses of $7.62 billion have been recorded in Texas' agricultural sector as a result of the 2011 drought [1–3]. In the same year, the agriculture, forestry, fishing, and hunting sectors combined generated only 0.8% of the total real GDP among all industries in the Texas economy [4]. This number might be misleading as to the role of agriculture in the state economy and potential repercussions of drought that impacted agriculture directly in the first place and created ripple effects on other economic sectors. In 2005–2009, Texas agriculture contributed on average $6.1 billion in GDP to the state economy, ranking Texas number two among the US state in the total GDP from the agricultural sector alone. Texas was outranked only by California, where agriculture contributed $17.9 billion on average to the state economy in the same time period [5].

On the other hand, in 2011 the agricultural sector (i.e., irrigation) used the highest percent of water (61%) among all water consumers in the state, including municipal use (27%), manufacturing (6%), steam electric power generation (3%), livestock (2%), and mining (1%) [6]. Texas ranks number one in the US in terms of the value generated by the livestock, poultry, and their products industries (11.9 million head of livestock). It ranks number three in the total value of agricultural products sold in the country, with cotton, hay, sheep, goats, mohair, and horses being the top agricultural sales products [7]. Thus, the high water demands from agriculture can be anticipated to be seriously compromised in times of drought.

As of late summer 2011, Texas had suffered the driest 10 months since record keeping began in 1895 [8]. Some rivers (e.g., Brazos River) dried up almost completely [9], while the exceptionally dry weather conditions coincided with extreme heat waves [10]. In October 2011, more than 90% of the entire state areas were in exceptional drought (Figure 1).

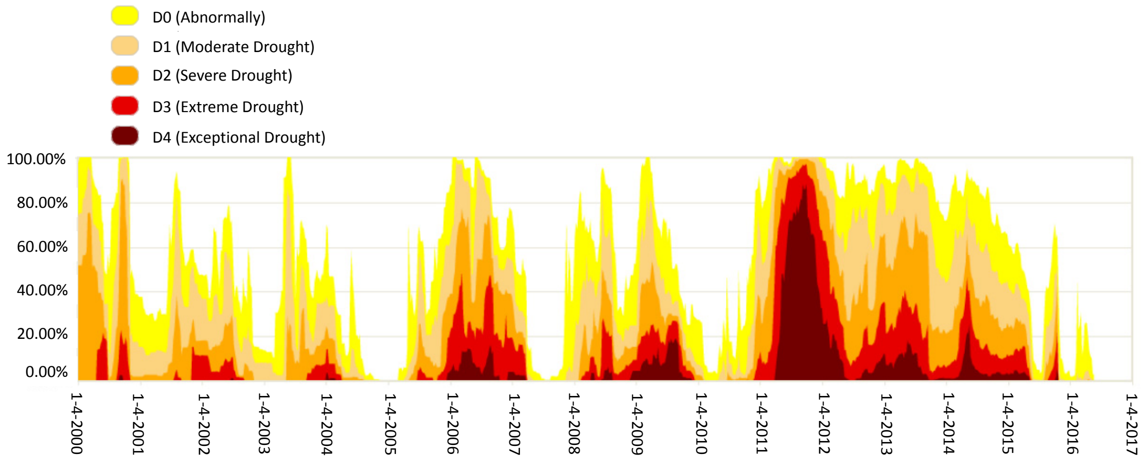

Figure 1. Percent of Texas area affected by drought in 2000–2016. Source: [11].

According to historical records, drought has proven to occur cyclically, thus creating a factor of uncertainty for agricultural production per se as well as the entire state economy. Recurring droughts and their implications on many areas have been investigated extensively in the literature. For instance, Venkataramana et al. [12] projected multi-year droughts in the late 21st century to occur across the state, with the worst droughts anticipated in El Paso. Effects of severe drought conditions on dissolved organic matter and ecosystems have been estimated by Miller and Shank [13], Acosta-Martinez et al. [14], Lebreton et al. [15], and Schwantes et al. [16]. Specifically, the 2011 drought has accounted for considerable losses in agricultural production of $7.62 billion in Texas (not including timber production) [1,2,17]. It affected mainly the livestock and cotton producers representing the highest agricultural production sales in the state (Table 1).

Table 1. Production losses in Texas agricultural sector resulting from the 2011 drought.

Sector	Production Losses (Billion $)
Livestock (beef, poultry, dairy)	3.230
Cotton	2.200
Hay	0.750
Corn	0.736
Timber	0.669
Sorghum	0.385
Wheat	0.314

Source: Author's presentation based on [1,2].

The 2011 drought was only a small indication of larger problems to occur in the following years and that are also anticipated in the future. According to Texas Water Development Board [6], Texas groundwater supplies are expected to decrease by 30% in 2010–2060 (from 8 million acre feet (af[1]) down to 5.7 million af).

[1] One acre-foot = 325,851 gallons = 1233.5 m^3

Regional drought analyses and their impacts are crucial for designing efficient and sustainable water management strategies, both on the demand and supply side. Therefore, this research aims at estimating socio-economic impacts of the 2011 drought on the entire Texas economy to emphasize potential drought-related issues in the future. However, regional evaluations are only a small part of the drought problem around the globe. Severe droughts and weather variability have been observed in many countries causing changes in ecosystems [18,19], availability of natural resources [20], economic losses [21], and changes to social welfare [22,23]. This continuous and repetitive pattern of mid- and long-term weather variability can be seen as an indicator of future long-term drought events and consequently induce new regional, national, and international institutions for mitigating drought.

2. Problem Setting and Research Objective

The main socio-economic problem in Texas related to weather stems from extreme and exceptional droughts overlapping with the decade of excessive water depletion due to rapidly growing population. The total population in Texas increased from 20.8 million in 2000 up to 26.4 million in 2013 (27% growth rate). At the same time, total annual statewide water use increased from 16.2 million af in 2000 up to 18.1million af in 2011, and further fell to 14.5 million af in 2013 (due to drought and conservation measures) [24]. The total municipal water use remained relatively steady throughout this time period, which directly indicates an increased water use in the agricultural sector due to its highest water demands among all economic sectors.

In 2011, Texas reported only 14.9 inches of rain statewide, which is far below the average 27 inches for normal precipitation conditions [11]. The 2011 drought had direct impacts on agricultural production outputs, while the impacts on the entire Texas economy have been mentioned in a very limited scope in a short briefing by Guerrero [3]. The author estimated the total impacts of the 2011 drought to amount to 12.5 billion in the entire Texas economy, without accounting for timber production. The study has not provided any further insights, macroeconomic sectoral implications or methodological specifications.

This paper was inspired by Guerrero's outcomes and aims at assessing ripple effects of the 2011 agricultural drought on the entire Texas economy with the aim to quantify implications for the output, added value, and employment numbers at the state level with a comprehensive and detailed approach. The main focus of this paper is to evaluate:

(a) Direct effects on livestock, cotton, sorghum, wheat, corn, hay, and timber production,
(b) Indirect effects on other related sectors providing materials and production factors for the agricultural sector, and
(c) Induced effects denoting changes in household incomes due to changes in agricultural sector employment or employment in related sectors.

The total changes/impacts in an economy are a sum of direct, indirect, and induced effects.

The paper focuses on socio-economic drought that is the ultimate result of the meteorological, agricultural, and hydrological droughts. While addressing the macroeconomic perspective, the paper evaluates impacts of diminished agricultural production on the entire Texas economy, regardless of the drought type, extent of drought and the exact time when drought occurred during the analyzed year. Thus, this paper does not attempt to measure drought specifically in meteorological terms, but rather it aims at indirectly measuring impacts of meteorological, agricultural, hydrological drought expressed with direct changes in agricultural production. It further analyses implications for the agricultural sector itself as well as for the entire state economy.

3. Methodology and Data

Input-Output (IO) and Social Accounting Matrix model IMPLAN (IMpact analysis for PLANning) has been applied for this analysis to estimate impacts of drought (a market shock with economic implications) in one sector (agriculture) on other sectors of the Texas economy. The main goal of an input-output analysis is to determine the direction, scope, and extent of a change in the final demand on the final gross production output in a given sector and/or economy in the analyzed region. The sectoral multipliers methodology embedded in IMPLAN allows for estimating total economic impacts of changing expenditures within an economy, as a sum of direct, indirect, and induced effects. The model contains the most comprehensive coverage of all US sectors and thus allows for tracking welfare changes in different industries at the regional, state, and national level. It has been developed by Minnesota IMPLAN Group, Inc. [25] based on US Department of Commerce Input-Output tables originating from 1970s. It relies on a variety of data sets from US Bureau of Economic Analysis, US Bureau of Labor, and US Census Bureau. The US Census Bureau NAICS (North American Industry Classification System) classification (Table 2) is applied in the model as a standard by federal statistical agencies in classifying business establishments for the purpose of collecting, analyzing, and publishing statistical data related to the US business economy [26].

Table 2. NAICS classification for the analyzed sectors.

NAICS Classification	Sector Description	Notes
111140	Wheat farming	Establishments primarily engaged in growing wheat and/or producing wheat seeds
111150	Corn farming	Establishments primarily engaged in growing corn (except sweet corn) and/or producing corn seeds
111199	All other grain farming	Establishments primarily engaged in growing grains and/or producing grain(s) seeds (except wheat, corn, rice, and oilseed(s) and grain(s) combinations: barley farming, sorghum farming, oat farming, wild rice farming, rye farming)
111920	Cotton farming	Establishments primarily engaged in growing cotton (field and seed production, cottonseed farming)
111940	Hay farming	Establishments primarily engaged in growing hay, alfalfa, clover, and/or mixed hay
112111	Beef cattle ranching and farming	Establishments primarily engaged in raising cattle (including cattle for dairy herd replacements, calf e.g., feeder, stocker, veal production, cattle farming and ranching)
112120	Dairy cattle and milk production	Establishments primarily engaged in milking dairy cattle
112990	All other animal production	Establishments primarily engaged in: (1) raising animals (except cattle, hogs and pigs, poultry, sheep and goats, aquaculture, apiculture, horses and other equines; and fur-bearing animals including rabbits); or (2) raising a combination of animals, with no one animal or family of animals accounting for one-half of the establishment's agricultural production (i.e., value of animals for market)

Source: Author's presentation based on specifications by US Census Bureau [20].

For this analysis, livestock (beef, poultry, dairy) production has been aggregated to one 'animal production' sector, while corn, sorghum, and wheat were aggregated to 'grain farming'. The main reason for this aggregation was missing drought impact specifications for each group of livestock animals and specific grain production sub-sectors in Texas, while it was available for the entire livestock and grain production only. We realize that aggregation might cause some potential, but unintentional biases. However, they were unavoidable in this case due to missing input data points. Predictive multipliers used in this analysis for assessing relations between different economic sectors were based on the year 2010 (Figure 2). The IO model is a static model representing changes in one time period (here: one year) only. Thus, it does not represent changes over time or cumulative effects of drought in the mid and long term.

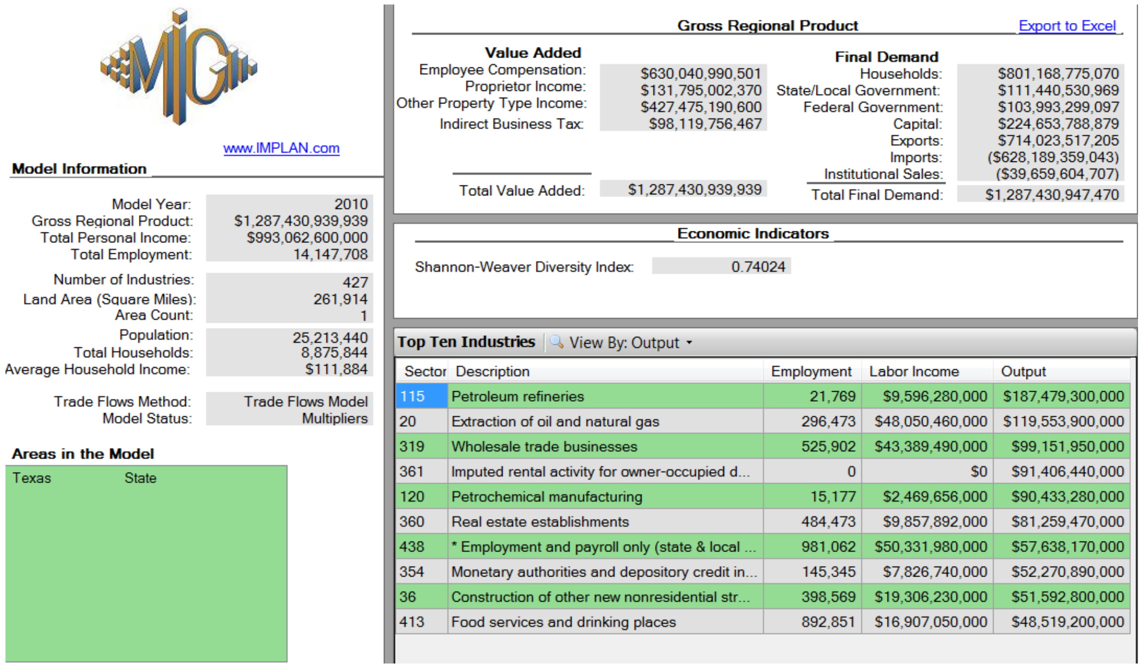

Figure 2. IMpact analysis for PLANning (IMPLAN) model interface for Texas. Source: [19].

The Input-Output methodology is commonly known in macroeconomic theory, and has been extensively applied to various problems and disciplines [27–32]. The main components of the methodology and data base are transactions tables, technical coefficients, and multipliers. A transactions table contains production flows between different industries, or sectors, in a given region's economy by representing the amount sold from sector *i* to sector *j* in a particular time frame. Technical coefficients are derived directly from the transactions table and represent the amount of inputs required from each industry for the production of one unit or one dollar's worth of output for a certain industry. They can be calculated as follows (Equation (1)):

$$a_{ij} = \frac{X_{ij}}{X_j} \tag{1}$$

with:

a_{ij}—technical coefficient

X_{ij}—demand for output from industry *i* by industry *j*

X_j—value of goods produced by industry *j*

Technical coefficients are used to determine the amount of output that is necessary from an industry to fulfill the direct demand from purchasing industries [33]. The table of coefficients represents the direct effects of a change in output in one industry on the other industries in an economy that supply its inputs [34].

As the IO analysis focuses on determining impacts of a demand change on the gross production output, technical coefficients are established to provide the link between those two variables. To calculate the change in production output resulting from changing final demand, solving the Leontief inverse (1928) (or multiplier matrix) is necessary as follows (Equation (2)):

$$X = (I - A)^{-1} * Y \tag{2}$$

with:

X—$n \times 1$ vector of gross output (sales matrix)

Y—$n \times 1$ vector of final demand

A—$n \times n$ matrix of input coefficients a_{ij} with n sectors in the economy (coefficient matrix)

I—identity matrix

An important outcome of this study is employment changes as a result of drought. Employment effects have been calculated according to Equation (3):

$$N = \sum_{j=1}^{n} n_j X_j \tag{3}$$

with:

N—total employment

n_j—direct employment coefficient (calculated from estimates of employment and output).

Employment comprises both wage and salary employees and self-employed persons in Texas. Also, both full-time and part-time workers have been included in the data and calculations to estimate the annual average jobs [35].

In this paper, the IO model was used to generate four measures of economic activity: industry output, value added, labor income, and employment, and their changes subject to the analyzed 2011 drought.

4. Results and Discussion

The results show that the $7.62 billion of agricultural production losses caused irreversible ripple effects on the entire state economy in a direct or indirect way. Table 3 displays 'direct effects' (economic losses in the agricultural sector), 'indirect effects' (economic losses in related sectors supplying the agricultural sector), and 'induced effects' (economic losses resulting from changing human behavior due to increased unemployment). The total effect indicates the sum of the direct, indirect, and induced effects for the Texas economy.

Table 3. The 2011 drought effects on the Texas economy.

Impact Type	Employment (Number of Jobs)	Labor Income (million $)	Value Added (million $)	Output (million $)
Direct Effect	−106,437	−679.8	−2,076.3	−8,284.0
Indirect Effect	−42,305	−1,567.8	−3,197.8	−6,349.2
Induced Effect	−18,152	−784.8	−1,449.7	−2,354.1
Total Effect	−166,895	−3,032.5	−6,723.8	−16,987.3

The agricultural sector lost more than 106,000 jobs, while other sectors more than 42,000 jobs. The total impact on employment equaled more than 160,000 lost jobs in the entire state economy. Secondly, labor income decreased mainly due to indirect effects by more than $1.5 billion, while the total effect accounted for $3 billion. The Texas economy lost more than $6.7 billion in value added that is defined as the income or wealth portion of the industry output that includes employee compensation, proprietary income, other property income, and indirect business taxes [25]. Similarly, the industry output (value of total production of an economy) decreased mainly in the agricultural sector by more than $8 billion, and in agriculture related sectors by more than $6 billion. The total output loss amounted to nearly $17 billion, which is comparable with $12.5 billion estimated by Guerrero [3], while the difference can be accounted for hay production that was not included in Guerrero's study.

A sector specific analysis revealed sectors that were most affected by the 2011 drought (Table 4). Animal production and cotton farming were mostly affected with more than $1.8 billion and $1.2 billion losses in production output, respectively. Furthermore, grain farming, real estate establishments, and other crop farming have been affected also. The results can be clearly tied to the economic relevance of those sectors within the agricultural sector.

Table 4. Ten top affected sectors based on production output as the first ranking variable (in $).

Sector	Output	Employment	Labor Income	Value Added
Animal production	−1,879,060,031.0	−21,536.1	−121,140,146.3	−467,285,634.0
Cotton farming	−1,182,467,677.1	−9,575.1	−148,549,278.8	−301,873,250.1
Grain farming	−744,123,868.3	−23,735.4	−25,727,207.8	−183,031,797.1
Real estate establishments	−636,770,117.9	−3,124.3	−71,726,939.7	−525,831,927.7
All other crop farming	−404,231,345.9	−3,276.0	−38,022,754.4	−152,115,509.7
Monetary authorities	−371,945,465.9	−900.5	−54,709,361.1	−170,040,444.4
Greenhouse, nursery, floriculture	−358,650,052.4	−4,252.0	−99,070,457.4	−230,717,436.6
Petroleum refineries	−269,598,753.9	−28.6	−14,201,177.9	−63,928,043.4
Support activities for agriculture and forestry	−241,595,456.6	−6,588.7	−211,986,277.3	−207,506,141.4
Other animal food manufacturing	−217,507,893.2	−227.8	−13,278,861.9	−34,796,398.8

For the seven sectors specified for this analysis, animal production, cotton framing, and timber production were affected most in terms of the added value with nearly $450 million, more than $300 million, and $250 million losses, respectively. At the same time, cotton farming, animal production, and timber production were affected most in terms of labor income losses of around $160 billion, $140 million, and around $120 million, respectively. Grain farming and hay production were least affected both in terms of added value and labor income (Figure 3).

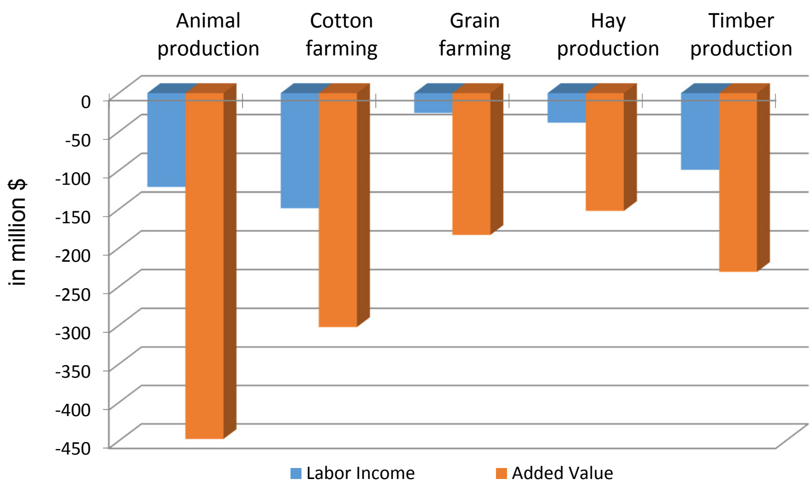

Figure 3. Losses in added value and labor income in the agricultural sector in Texas.

A slightly different tendency was found for the sectors based on employment and production output. Cotton farming and grain farming were affected most severely by a 52% and 42% decrease in employment, respectively, as compared to the employment levels in 2010 (right before the 2011 drought). Animal production and hay production were least affected with 16% and 21% losses in employment, respectively. The same tendency was found for production output losses with 45% and 36% in cotton farming and grain farming, respectively, while the least severe losses were found for the animal production and hay production with 15% and 18%, respectively (Figure 4). The results are based on the premise that commodity prices do not change in the analyzed time period (the model is static). The calculated IO transactions are represented with producers' prices denoting producers' revenue rather than purchasers' costs. Accordingly, a commodity price for the transaction from the producing sector to the consuming sector is determined by the producers' price [35].

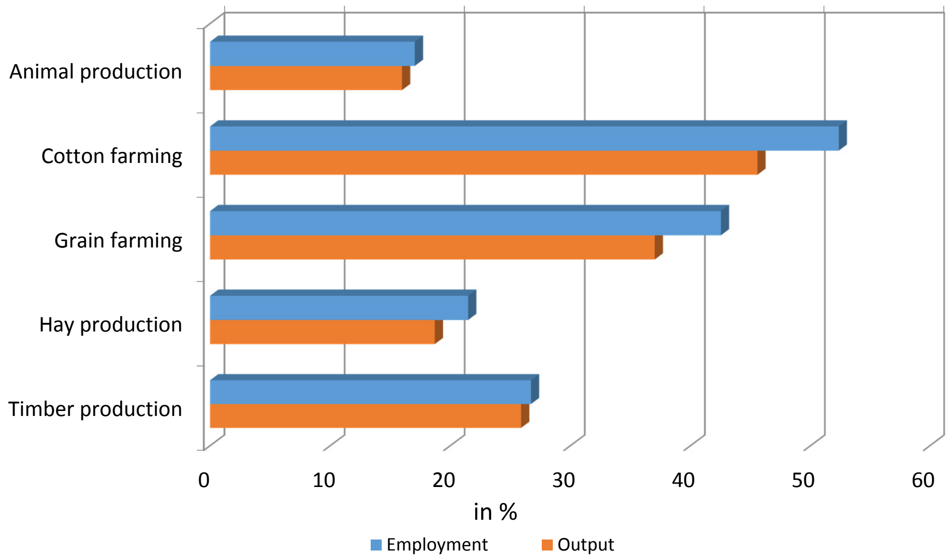

Figure 4. Employment decrease and output losses in the agricultural sector in Texas compared to 2010.

The results indicate statewide impacts on a multitude of sectors in Texas agriculture (but also outside of the agricultural sector) that were significantly affected by the 2011 drought.

5. Summary and Conclusions

The 2011 drought caused economic losses of $16.9 billion in the entire Texas economy. The unemployment increased by 166,895 people, while the agricultural sector alone lost more than 106,000 jobs. Cotton farming lost 46% of its production value (compared to the 2010 base year) while the animal sector lost $1.8 billion in production (16% compared to 2010).

The decreased production yields and the limited market supply directly influence market prices for those products, which creates additional spillover effects on export quantities and domestic consumption prices.

The IMPLAN model has proven as a valuable tool for a macroeconomic analysis at a state level; however it is a static model. Dynamic models (e.g., REMI—Regional Economic Model, RIMS—Regional Input-Output Modeling System) are recommended to account for dynamic market effects occurring as a result of drought (or any other change). Both models integrate the input-output analysis, computable general equilibrium, econometric approaches, and economic geography methodologies. Also, the Rectangular Choice of Technology model (RCOT) by Duchin and Levine [36] could serve as an extension of the traditional IO analysis. The model focuses primarily on cases where different regions have to choose between several different technologies in a situation of resource scarcity (e.g., drought as discussed in this paper). Thus, RCOT might provide valuable insights especially for designing programs and drought mitigation strategies in the future.

The results generated with this research create a basis for a follow-up analysis on the implications of less severe droughts in the state since 2011 that can be assessed as a cumulative effect for the Texas economy. The results indicate a larger problem in the long term and potential negative impacts for the state in cases of repetitive or long-term droughts, like the Millennium Drought in Australia (1997–2009) [37–39]. The results can be used by stakeholders and decision makers to design approaches for sustainable water management as the drought is a cyclical event. Mitigating drought effects by lessening severity of dry periods, preparing for future droughts, and adapting to drought conditions with a number of sustainable water management policies and measures [40,41] should be a priority for regional and state water planners and policy makers. The question is the more urgent and relevant as a decrease in production yields resulting from drought can lead to a limited market supply, thus directly impacting market prices for those products. The domestic market developments might also have repercussions for international trade and exported/imported quantities.

This analysis did not include compounded effects of wildfires as a result of drought that also directly impacted agricultural lands. This issue is a relevant question that could complement the impact analysis of economic losses of drought events.

Furthermore, follow-up analyses for drought in 2012 and 2013 are necessary to provide a comparison basis and develop possible approaches for a recovery of the agricultural sector. The presented analysis emphasizes the extent of drought effects on the state economy, thus pinpointing the urgency of concerted and sustainable water management measures for the agricultural production and other economic sectors.

Acknowledgments: This material is based on work supported by the National Science Foundation under Grant No. OIA-1301789. The author acknowledges the STARR (State of Texas Advanced Resource Recovery Program) project for providing the IMPLAN license. Thank you also to the anonymous reviewers for their valuable comments that helped to improve this paper.

Conflicts of Interest: The author declares no conflict of interest.

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