Linking an Equilibrium Displacement Mathematical Programming Model and an Input-Output Model to Estimate the Impacts of Drought: An application to southern Colorado

Allison Gunter[1]
Dr. Christopher Goemans
Dr. James Pritchett
Dr. Dawn Thilmany-McFadden

[1] Colorado State University, Department of Agricultural and Resource Economics, Clark B-307, (303)562-4949, allie.gunter@colostate.edu.

Introduction

In 2011, agricultural producers in southern Colorado suffered drought conditions. These conditions spurred the federal government to designate three counties in the Arkansas River Basin disaster areas on June 28th, 2011 and an additional nine counties in the basin disaster areas on July 13th, 2011 (Farm Service Agency , 2012). As the drought continued to worsen, an additional five counties in the Rio Grande River basin were declared disaster areas on August 1st, 2011 (Farm Service Agency, 2012).[2] Although the drought continued into 2012 and grew much larger in both size and severity, the focus of this particular study will be on the 2011 drought. Such widespread impacts and recent studies showing that agriculture is a major driver in many of these counties (Davies & Sullins, 2011), suggests there will be direct (agricultural production) and more community wide impacts from this climatic event. Quantifying the economic impact[3] of the drought will be important for policy makers and for future planning that may work to make this region more resilient to future periods of drought.[4]

Weather represents one of the greatest uncertainties faced by agricultural firms. Moreover, concerns about climate change suggest that such risks may increase moving forward. Drought events can have large impacts on the economies of rural communities, not only directly impacting producers, but also having an indirect effect on entities throughout the supply chain. The recent and still ongoing drought throughout southern Colorado provides an example of this.

The primary objective of this study is to provide policy makers with accurate information on the region-wide impacts of the current drought in southern Colorado using a combination of an Input-Output (I-O) model and an Equilibrium Displacement Mathematical Programming

---

[2] These 17 counties were chosen based on input provided by an advisory panel.
[3] Economic impact is defined as the net change revenue associated with the drought in the existing regional economy (Watson, Wilson, Thilmany, & Winter, 2007).
[4] Throughout this paper we will be using terminology to describe economics impacts as defined in Watson, et al. (2007). For readers interested in a full description of terms, please reference this paper.

model (EDMP). The secondary objective is to compare the results from the different modeling techniques, using each model separately and combining the two, to answer the question of whether the difference between the modeling approaches matters in terms of the magnitude and scope of impacts that are estimated, which may frame the policy choices differently for relevant stakeholders.

Modeling economic impacts generally implores the use of a model that provides the researcher with data on how industries in a community are linked together throughout the supply chain and a framework for analyzing the data. In this study, we consider three approaches to analyzing the economic impact of the 2011 drought in southern Colorado given currently available models. The goal is to capture the change in dollars spent within the region resulting from drought conditions. Our first approach is to utilize an I-O analysis; the second approach will utilize an EDMP model; and the final approach we link the EDMP model and the I-O model, using the EDMP model to determine impacts in the agricultural sector and the I-O model to extend those impacts across all sectors of the regional economy. This three-pronged approach provides us with a range of estimates of potential impacts, with each step becoming more sophisticated. However, each modeling technique has both advantages and disadvantages.

First developed by Leontief (1936), the I-O model provides a simple means by which to describe an economy by tracing a change in inputs purchased resulting from a shock in final demand[5]. An I-O model provides an estimate of the change in in economic activity, i.e. a change in total revenues[6], across all sectors of a local economy resulting from a change in final demand. I-O models are one of the main tools utilized to conduct regional impact analysis; evidence can

---

[5] Final demand is defined as the value of goods and services produced and sold to final users (MIG, 2012). This does not include the sale of intermediate goods used as an input to production in another industry.

[6] Economic activity is defined as the dollars spent within the region that are attributable to the drought (Watson, Wilson, Thilmany, & Winter, 2007). The focus is on revenue and does not consider changes in profits.

be seen in the *Journal of Regional Science* where an article utilizing I-O is found in almost every issue. I-O models have also been widely used to look at economic impacts related to water transfers in Colorado (Howe & Goemans, 2003; Thorvaldson & Pritchett, 2006) and to analyze drought impacts in other states (Diersen & Taylor, 2003; Guerrero, 2011).

I-O models are relatively easy to use, results can be obtained quickly and at a low cost (with the availability of data and software packages, such as IMPLAN), the model is very widely used so results are comparable to other studies, and all sectors of a regional economy are included. The main shortcomings of this approach for drought analysis are in the lack of flexibility in an I-O model and in its inability to fully model impacts.

The I-O model does not model impacts to industries in the supply chain that use the output from the primarily impacted industries (feedlots) and, in this case, is likely overstating impacts due to heard depopulation[7]. In the real world, producers facing drought are likely to make input substitutions so as to get the highest yield for a given circumstance; an I-O model does not allow for this type of change, likely overstating results (Miller & Blair, 1984). The last challenge occurs because the I-O model only considers changes in revenue, not changes in profit; impacts of the drought on the livestock sector illustrate why this is a problem. The cow-calf producers experience an increase in input costs but not a change in revenue and are thus not included in the I-O analysis even though their operations were impacted by drought conditions.

The next approach is to use the EDMP[8] model, first developed by researchers at the Economic Research Service in 1996 and later formalized in a report by Harrington and Dubman

---

[7] From the survey, we know that some producers sold off a portion of their herd due to high feed costs. This is likely to increase revenues in the current period, but likely decrease revenues in the future (Pritchett & Nelson, 2012).
[8] An alternative approach to analyzing regional economic impacts is with a computable general equilibrium model (CGE). In this case, we used the EDMP model instead of a CGE because the EDMP model was already built and provided us with the necessary information in short time frame. More generally, one of the main benefits of the EDMP model compared to a CGE model is its ability to more accurately model sectoral impacts due a greater degree of disaggregation of data in the model (Agra CEAS Consulting Ltd., 2004).

3

(2008) to provide a sector-wide comparative static analysis of the U.S. agricultural sector. This model combines and equilibrium displacement modeling approach, which can be traced back to Muth (1964), with the positive mathematical programming, explained by Howitt (1995). Following the Harrington and Dubman model (2008), researchers at Colorado State University developed a similar model that is focused on Colorado's agricultural sector and extended the model to include water as a factor of production. The theoretical model was developed by Pritchett, Fathelrahman, Davies, & Davies (Draft 2011).

The EDMP model takes a change in supply and/or demand and endogenously solves for the equilibrium price and quantity, providing estimates of economic impacts for primarily impacted industries (crop producers) as well as economic impacts for entities along the supply chain, including input suppliers and output users. Results from the EDMP model provide information on both the change in revenue and change in profit in the agricultural sector resulting from an exogenous shift in supply and/or demand.

Although the use of EDMP models in the literature is limited, equilibrium displacement models (EDM) and positive mathematical programming models (PMP), the theoretical basis for the model, have been widely used by agricultural economists. Researchers have used the EDM approach to undertake "what if" analysis by using a comparative statics approach to measure the economic and welfare impacts resulting from an exogenous shifts in supply and/or demand. They are often used to analyze agricultural policy, with a common application being the analysis of marketing programs (Zhao et al., 2000; Agra CEAS Consulting Ltd., 2004; Balgatas & Kreutzer, 2007; Carpio & Isengildina-Massa, 2010). PMP models have been used to analyze policy decisions in the agricultural sector (Preckel, Harrington, & Dubman, 2002; He & Horbulyk, 2010; Kanellopoulos, Berentsen, Heckelei, van Ittersum, & Lansink, 2010). To our knowledge,

4

niether the EDMP, EDM or PMP models have been used to analyze the economic impacts of drought on rural economies.

The EDMP model allows for the substitution of inputs, inclusion of industries along the supply chain that are input suppliers and output users, and it models both changes in revenues and changes in profits. For these reasons, the EDMP model provides a more complex and realistic look at the producer response to drought conditions when compared with the I-O analysis. But, its main shortcoming is that impacts to the entire regional economy are not included; computational and data limitations require focus on one particular sector. And in a broader sense, to build an EDMP model involves a commitment of both time and money, which may or may not be available.

The final modeling approach is to link the two models together, using the output from the EDMP model to represent the change in output for each agricultural sector, and to input that amount directly into the I-O model (Figure 1). To our knowledge, this approach has not been previously utilized. Linking the two models together will provide information on the economic impacts of the drought for all entities in the regional economy, including impacts to both input suppliers and output users. Additionally, it will provide information on the changes in profits in the agricultural sector.

Figure 1: Linking EDMP and I-O
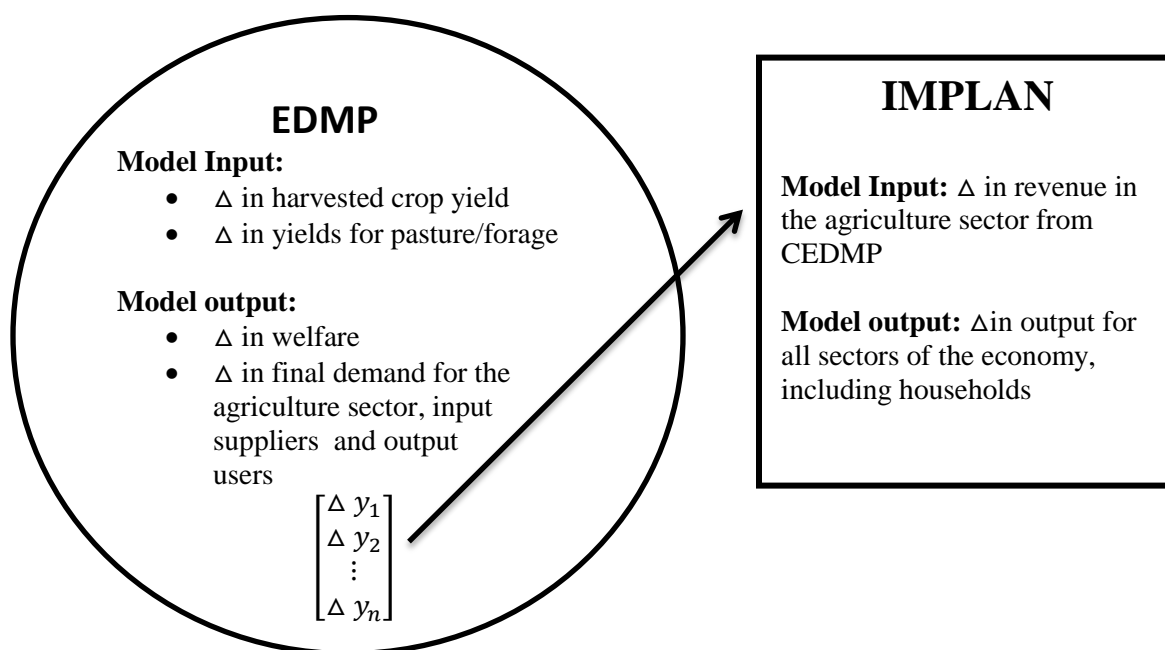
Researchers have utilized a linking or combing approach in the literature; utilizing an I-O model for some parts of the analysis and a variety of different model for others (Rey, 2000; Munksgaard, Wier, Lenzen, & Dey, 2005; Lenzen, Lundie, Bransgrove, Charet, & Sack, 2003). To our knowledge, there is one similar study in which an I-O model and equilibrium displacement model were linked to analyze economic impacts to the livestock sector (Pendell, Leatherman, Schroeder, & Alward, 2007).

Linking the EDMP model and the I-O model captures the benefits of the EDMP model (substitution of inputs, inclusion of input suppliers and output users, and models changes in revenues and profits), while overcoming its main shortcoming by being able to model impacts to all sectors of the regional economy. One of the challenges to this approach is in the non-conformity of the study areas. Some work in sector and regional disaggregation was necessary so that the study areas of the two models lined up correctly.

There is no clear hypothesis of which approach will yield the larger result but, theoretically, the linking approach should provide the more accurate result. Because the I-O model does not account for forward linkages, it might understate the true impacts; but because it does not allow the farmer to make any changes to production decisions, nor include elasticity of supply or demand, it might overstate true impacts.

The next section provides background information on the drought and how a rural community is impacted by drought. The following section describes our methodology, separated into three sections describing each modeling technique. The section after that describes the data used in the study. The following section provides results of the study, and the final section provides concluding remarks.

Background

Irrigated water and/or rainfall are critical inputs to most agricultural activities, thus drought conditions can lead to immediate reductions in output and lost revenues for agricultural producers. In the 17-county region recently declared a disaster zone, the agricultural industry as a whole employs 8% of workers and produces 7% of total output; and cattle ranching and farming is the sixth largest industry in the region (MIG, 2009). In the four counties that experienced exceptional drought (Alamosa, Baca, Conejos, Costilla), agriculture industry employs 17% of workers and produces 15% of total output in the region; cattle ranching and farming is the third largest industry, grain farming is the sixth largest, and vegetable and melon farming is the seventh largest (MIG, 2009). Given the critical role agriculture plays in many of the communities affected by the drought in southern Colorado, we would expect the drought to have a significant negative impact on communities, increasing the total impact in the region well beyond the impacts felt by the affected producers.

How does a drought impact a rural community? Figure 2 illustrates the linkages between those industries directly impacted and those industries indirectly impacted. It begins with the producer (often referred to as the direct effect[9]), where revenues for crop producers are lost due to lower yields and fewer harvested acres and where livestock producers see a decrease in profits due to an increase in input costs (center of Figure 2). The subsequent effects (indirect effects[10]) are for those businesses that share the supply chain with impacted producers, including both input suppliers, aka backward linkages (left side of Figure 2), and output users, aka forward linkages (right side of Figure 2). And finally, the resulting changes in household spending are represented by the induced impact[11] (left side of Figure 2). The total economic impact is comprised of the direct effect, indirect effects and induced effects.
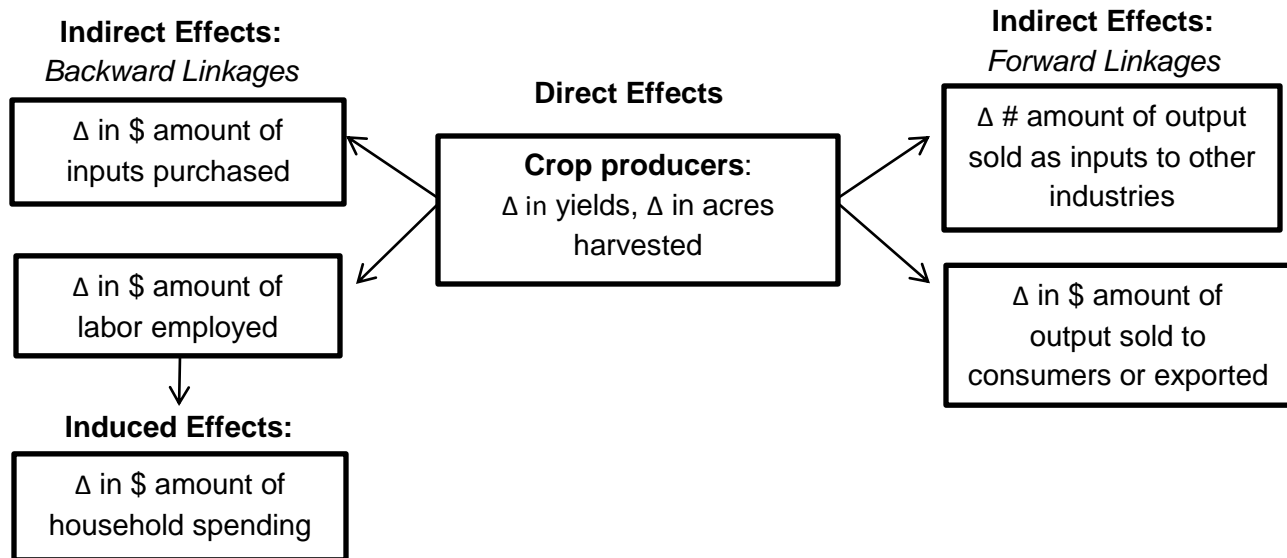
The extent of these forward and backward linkages depends on whether or not the drought was anticipated as well as the strength of the linkages within the local economy and the ability of producers to make changes to production decisions. If producers anticipated the drought and made changes to their production practices before planting, the indirect impacts for the backward linkages (and potentially forward linkages) are much larger than if they planted as they would in a typical year and made decisions due to drought conditions after the majority of inputs had been purchased.

---

[9] The direct effect describes the change in revenue for crop producers in the region due to a change in yield and change in harvested acres resulting from the drought.

[10] The indirect effect measures the impact of local industries buying and selling goods and services from other local industries. "[In an I-O analysis] the cycle of spending works its way backward through the supply chain until all money leaks from the local economy, either through imports or by payments to value added (MIG, 2012)." In the EDMP model, indirect effects include backward linkages (similar to I-O) but also include forward linkages; industries that use the output of producers.

[11] "[The induced effect is] the response by an economy to an initial change (direct effect) that occurs through re-spending of income received by a component of value added. This money is recirculated through the household spending patterns causing further local economic activity (MIG, 2012)."

Figure 2: How Drought Impacts a Rural Community

Indirect Effects:
Backward Linkages

Direct Effects

Indirect Effects:
Forward Linkages

Δ in $ amount of inputs purchased

Crop producers: Δ in yields, Δ in acres harvested

Δ # amount of output sold as inputs to other industries

Δ in $ amount of labor employed

Δ in $ amount of output sold to consumers or exported

Induced Effects:

Δ in $ amount of household spending

The I-O model captures the direct effect associated with a change in final demand, the indirect effect from backward linkages, and the induced effect from a change in household income for all sectors of the economy in a chosen region. The EDMP captures the direct effect associated with a change in conditions, and the indirect effects from both forward and backward linkages for the agricultural sector only and in a fixed region. The final approach, linking the two models, utilizes the EDMP model to analyze the direct and indirect impacts in the agricultural sector and then uses the I-O model to analyze how those impacts influence sectors outside of agriculture. Table 1 provides a description of each modeling techniques, and the aspects of the economic impacts to rural communities that are captured in each approach.

Table 1: Three modeling approaches

Approach	Linkages	Scope	Model input	Model output
I-O	Backward	All sectors of the economy in the 17-drought impacted counties	Δ in revenue attributed to drought due to decreased yields and fewer harvested acres	Δ in output for all sectors of the economy, including households
EDM	Forward/Backward	Agricultural sector in the Arkansas River Basin and San Luis River Basin[12]	Δ in harvested crop yield +Δ in harvested acres	Δ in output for the agriculture sector, input suppliers and output users
Linked	Forward/Backward	All sectors of the economy in Arkansas River Basin and San Luis River Basin	Δ in revenue in the agriculture sector from EDMP	Δ in output for all sectors of the economy, including households

Methodology

In this section we provide an overview of the steps taken to analyze the economic impacts of the drought in southern Colorado. We look at three modeling approaches and discuss how assumptions regarding whether the drought was unanticipated versus anticipated relates to each approach. The three modeling approaches are as follows: one, an input-output model (I-O); two, an equilibrium displacement mathematical programming model (EDMP); and three, an integrated approach that combines and I-O model and EDMP model.

Overview of the I-O Method

Equation (1) describes the calculation of the lost potential revenue for crop producers resulting from the drought, the direct effect. We utilize NASS data and assume the direct effect is calculated using current number of planted acres, historical adjusted averages for both yield and the percent of planted acres that are harvested and current prices. Using current prices assumes

---

[12] See the Data Section for a map of the impacted areas

price is exogenous; in essence, prices would have been the same whether Southern Colorado

experienced a drought or not[13].

Equation (1) $\Delta\,\text{revenue} = (\text{planted acres}_{2011} \times \text{adj. ave. \% harvested}_{1998-2010} \times \text{adj. ave. yield}_{1998-2010} \times \text{price}_{2011}) - \text{actual revenue}_{2011}$

$Planted\ acres_{2011}$: total number of acres planted in 2011.

$Adj.\ ave.\ \%\ harvested_{1998-2010}$: adjusted average percent of total acres planted which are harvested, calculated as the average rate of harvest over the period 1998 to 2010 excluding the two highest and lowest harvest rates over that period.[14]

$Adj.\ ave.\ yield_{1998-2010}$: adjusted average yield per harvested acre, calculated as the average yield over the period 1998 to 2010 excluding the two highest and lowest reported yields over that period.

$Price_{2011}$: price per unit of output in 2011.

The computation of economic impact from the change in revenue is calculated using will

a modified version of the direct requirements matrix (A). Equation (2) describes the equation

used to solve an input-output model. Where X is an output vector (what we want to predict), I is

an identity matrix, A is a matrix of direct requirements[15], and Y is a vector of the change in final

demand. In this case, we have calculated the change in output, not the change in final demand.

The modified version of the A matrix will allow us to utilize the I-O framework to determine

economic impacts with the information we have available.

Equation (2) $X = (I - A)^{-1}\,Y$

---

[13] High feed grain prices are in a large part due to an increase in world-wide demand for meat. High hay prices are a result of the drought in Texas and Oklahoma; both are States with very large agricultural production. Southern Colorado is a small enough market that it is unlikely to have a large influence on price.
[14] The total number of acres planted for hay is not reported. For this crop Potential revenue is calculated as the actual number of harvested acres times the adjusted average yield time the price in 2011.
[15] The direct requirements matrix shows the dollar amount of a commodity required directly by an industry to produce a dollar of the industry's output (MIG, 2012).

In this study, we know the change in output for the producers as a result of the drought. If we were to use the A matrix in IMPLAN to determine the economic impact, we would be overstating the impact because we would double count the portion of the output in the Y vector that is used as an input to another production process within the region. To avoid double counting, we zero out all elements of the rows of the A matrix corresponding to the affected crops, effectively making the multiplier on affected crops one. The augmented A matrix will then be used as in Equation 2 to determine the economic impact. The model uses data provided by IMPLAN.

Losses to the livestock sector were not included in the IMPLAN portion of the analysis. While input costs to the livestock sector increased for both cow-calf producers and for feedlots neither is appropriate to include. Cow-calf producers experienced an increase in input costs, leading to a potential decrease in profits. But an economic impact study only looks at revenues, which were not affected as a result of the drought. Feedlots are not accounted for because cows sold to a feedlot from Colorado producers are a forward linkage, and therefore, not captured in an I-O analysis.

One of the challenges in modeling the full impact to the region using an I-O model is that many livestock operations sold off their breeding stock, increasing revenues in the current period but leading to potentially smaller revenues in future years; 60% of survey respondents said they sold breeding stock as a response drought conditions. Due to incomplete data, we are not able to estimate the increased revenue from selling of the breeding stock, thus our estimates are likely to overstate the true impacts for the current period. Note that one unintended finding already becoming evident is that drought impacts are dynamic, and the true impacts may not be realized until subsequent production years.

Overview of the EDMP Method

The EDMP model maximizes the objective function Z, where x is a vector of endogenous price and quantity variable relating to agriculture sector demands and production processes, equation (3). The x vector can be decomposed into five groups: domestic sales of agricultural commodities (q), feed and crop activities (cl), inputs used in the production of agricultural goods (u), exports of agricultural goods (e), and imports of agricultural goods (m) as specified in equation (4).

Equation (3) $\text{Max: } Z = F'x - 1/2\, x'Hx \quad \text{with } x > 0$

Equation (4) $Z = \sum_j (F' - .5Hq)q - \sum_i \sum_b (F' + .5Hcl)cl - \sum_n u + \sum_t (F' - .5He)e - \sum_s (F' - .5Hm)m$

Where:

q_j = domestic sales of j agricultural commodities and livestock products;

cl_{ib} = feed and food crop activities indexed by i and identified by river basin b;

u_n = value of the n inputs used in activities;

e_t = exports of t agricultural commodities and livestock products;

m_s = imports of s agricultural commodities and livestock products;

F = vector of intercepts indexed under each set above, calculated in the calibration phase

H = the diagonal elements of the Hessian matrix that are derived from the first order behavioral equations. H is assumed to be negative semi − definite.

To model direct and indirect impacts of the drought using the EDMP model, we first need to calibrate the model to reflect current conditions outside of the study area. Namely, the high commodity prices due to drought in Texas and Oklahoma and world-wide demand for feedstuffs. This newly calibrated model reflects current conditions and makes the approach using the EDMP

model equivalent to our approach using the I-O model, where 2011 prices are utilized. Now to shock the model, we will change crop yields to include both the change in yield and the change in percentage of acres harvested as described by equation (5).

Equation (5) Δ in yield and harvested acres = (harvested acres$_{2011}$ * yield$_{2011}$/planted acres$_{2011}$)/ (adj. ave. harvested acres$_{1998-2010}$ * adj. ave. yield$_{1998-2010}$/adj. ave. planted acres$_{1998-2010}$)

In the EDMP model, some crops are broken out into irrigated and non-irrigated. Because current NASS data does report irrigated and non-irrigated crops separately, we used survey responses to determine changes in non-irrigated yields and NASS data for changes in irrigated yields. When survey data was used, changes in harvested acres were not included. After the change in yield and harvested acres is calculated, the model will endogenously determine the market clearing price and quantity (supply of acres) resulting from these changes and produce and estimate of the change in revenue for the agricultural sector. This will affect backward linkages, remaining consistent with our approach when using the I-O model; but will also include forward linkages, more accurately describing true economic impacts. Equation (6) describes the calculation of the change in revenue from our EDMP output for each crop, *i*, resulting from the drought.

Equation (6) Δ Revenue$_i$ = (Supply of acres in the region$_i$ * Yield$_i$ * Price$_i$)$_{shocked}$ $-$ (Supply of acres in the region$_i$ * Yield$_i$ * Price$_i$)$_{calibrated}$

Overview of Linking the I-O Model and the EDMP Model Method

The final approach is linking the two models using the output from the EDMP model to represent the change in output for each agricultural sector, and to input that amount directly into the I-O model to determine the total change in economic activity throughout the region. We first

14

utilize the methodology described in the EDMP section to determine economic impacts from the drought in the agricultural sector. We then use these numbers within the I-O framework to expand impacts to all sectors of the economy using the methodology described in the I-O section. We compare the total economic impacts using only the I-O model with the results of linking the I-O and EDMP models together to provide insight into the two modeling approaches.

Unanticipated vs. Anticipated

Determining the impact of the drought involves comparing what realized sector revenues were during the drought against estimates of what revenues would have been without the drought. To estimate the latter, we utilize historical data to represent a "typical" year. The historical data spans from 1998-2010, covering relatively wet years (before 2002), drought years (2002-2003) with the remaining being moderate. The average of all years minus the two largest and two smallest values were utilized to determine the adjusted average of the period. Changes in revenue for crop producers due to drought arise from a change in yields and a change in harvested acres given their current planted acres, compared to a "typical" year. By modeling lost potential revenue in this manner, we are assuming producers did not anticipate the drought and planted as they would have in a normal year.

In a survey of producers in the region, about half of respondents made changes to their production decisions and half did not (Pritchett & Nelson, 2012). On the other end of the spectrum, assuming the drought was fully anticipated, we would need to compare current conditions with "typical" planted acreage. This presents a challenge as the number of acres planted is affected by a variety of factors including forecasted price, technological changes, and changes in water availability due to policy changes as well as drought conditions. Based on the many factors that influence the number of acres planted, it is not possible to estimate "typical"

acres planted and therefore we cannot analyze the effects of the drought assuming it were fully anticipated.

The challenge with this approach lies in using both the I-O model and the EDMP model to analyze the impact of backward linkages. If producers did not anticipate the drought, they purchased inputs as they would in a normal year and the resulting indirect effects for input suppliers in the current year would be zero. For the purpose of analyzing our hypothesis regarding the difference between using I-O alone and linking I-O and EDM, we will assume that the change in revenue due to the drought will have implications for backward linkages. Although this assumption means results should be interpreted with caution, consideration of backward linkages may be justified if one assumes these impacts are realized in the following year when producers will have a different net income to spend on inputs. In reality, the truth lies somewhere between the two estimates, where the direct impacts represent a lower bound and the total impact (direct + indirect + induced) represents an upper bound.

Data

The two models used in this analysis utilize different regional measurements, the EDMP model is built according to the water basin of interest and the I-O model is built according to county based on its reliance on secondary business and economic data. The water basins that will be utilized are the Arkansas and the Rio Grande. These basins include all of the counties designated as disaster areas and portions of five counties with a secondary designation as a contiguous county. To be conservative in estimating impacts, drought effects from only counties with a primary disaster declaration will be included in the analysis. These counties were the most effected by drought conditions.

The 17 counties that were determined to be a national disaster by the Federal Government due to drought conditions include Alamosa, Baca, Bent, Chaffee, Conejos, Costilla, Crowley, Custer, Freemont, Huerfano, Kiowa, Las Animas, Otero, Prowers, Pueblo, Rio Grande, and Saguache. Figure 3 shows the 17 counties with a primary disaster designation in circles, the 12 counties with a secondary designation as a contiguous county in squares, the Arkansas River basin outlined in a dotted line, and the Rio Grande River Basin outlined in a solid line.

Figure 3: Map of Counties Included in the Study Area

⬭ Primary disaster declarations
▭ Secondary designation as a contiguous county
— Arkansas River basin
— Rio Grande Basin
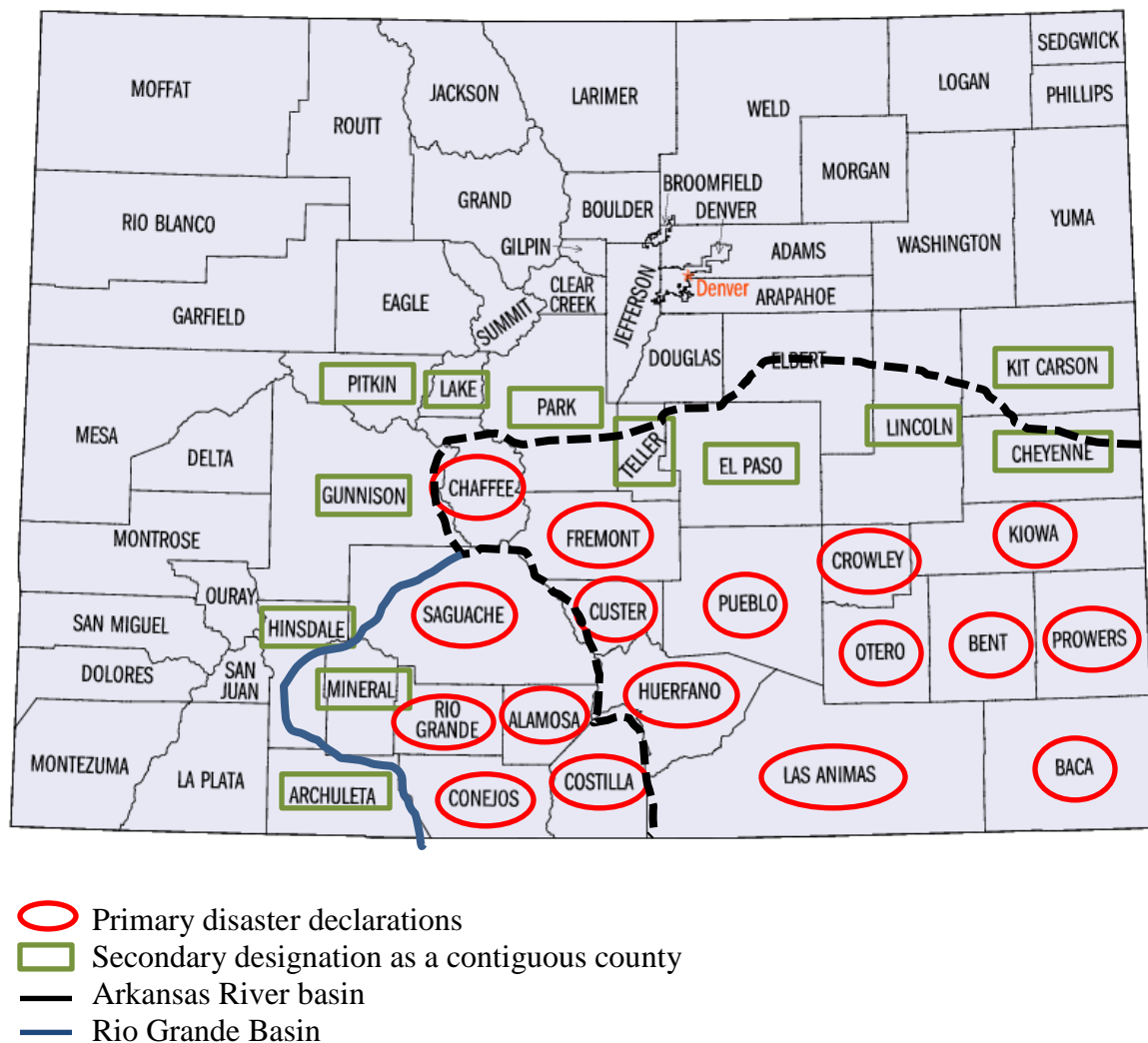
In addition to the data already integrated into the I-O and the EDMP models, additional data will be collected related to the changes that have occurred as a result of the drought. The key groups directly impacted by the drought are assumed to be the regional crop producers and livestock producers. Losses will be determined by acreage and yield data, livestock sales, and feed costs. Additional important data will be the amount of money awarded to producers under the crop and livestock federal aid programs. Secondary data, collected by the U.S. Department of Agriculture (National Agricultural Statistical Service, NASS; and Farm Service Agency, FSA) and from the Colorado Water Conservation Board will also be utilized to characterize macro-effects tracked for these sectors. Primary data from a survey of producers in the region will also be utilized to fill in the gaps where secondary data is not available (Pritchett & Nelson, Drought in Colorado, 2012).

Results

We present results on the total economic impacts using each of the three modeling approached detailed in the methodology section, with a description of the model input for each approach. A comparison of results across modeling approaches allows us to analyze differences among the models and to provide a range of potential impacts.

Estimating Total Economic Impact using the Input-Output Model

The first step to estimating total economic impacts when using the I-O model is to determine the direct impacts. In the I-O model, direct impacts are calculated outside of the model using Equation 1. Table 2 shows the direct impact to producers. Note that potato and wheat producers in the Rio Grande had better than average revenues resulting from the drought. This could be attributed to warmer and sunnier weather, with the drought having no negative impact because both crops in this region are irrigated, and potential "drawdowns" of soil moisture will

18

not impact yields until subsequent growing seasons (if moisture is not replenished through natural precipitation). In the Arkansas River basin, on the other hand, all crops saw a decrease in revenue as a result of the drought. The major contributor to this difference is the prevalence of dry land crop acres in each region, estimated at 4% in the Rio Grande and 37% in the Arkansas basins[16] (National Agricultural Statistical Service (NASS), 2008).

Table 2: Direct Impacts for I-O Analysis by Crop

	Rio Grande	**Arkansas**
Barley	($628,068)	$0
Corn	$0	($39,878,518)
Hay	($9,311,169)	($16,413,731)
Potatoes	$12,465,428	$0
Sorghum	$0	($12,232,433)
Sunflowers	$0	($2,641,452)
Wheat	$550,070	($14,552,800)
Total	**$3,076,261**	**($85,718,935)**

After direct impacts were estimated, the next step was to determine the appropriate multipliers to estimate indirect and induced effects for backward linkages in the regional economy. The change in revenue is multiplied by the regional multiplier get the indirect and induced effect, which can be added to the direct effect for the total economic impact. Results for the Rio Grande, the Arkansas and two combined river basins are listed in Table 3, Table 4, and Table 5 respectively. Total economic impacts are a positive $4.8 million for the Rio Grande, negative $104.7 million for the Arkansas, and combined of negative $100 million. This drastic

---

[16] Data collection of irrigated and non-irrigated acres in the region was last reported in 2008; the numbers listed above are an average from the time period 1998-2008 and are only an approximation of current conditions.

difference between the two regions demonstrates the large range of drought impacts where regional differences and crop type can have a large influence on results.

The estimated economic impact in Colorado is much smaller than the estimated $5.2 billion decrease in output from the 2011 drought in Texas (Guerrero, 2011) and the $1.4 billion decrease in output from the 2002 drought in South Dakota (Diersen & Taylor, 2003). There are multiple factors that influence this difference: one, the region we are considering is much smaller in total output than both Texas and South Dakota; two, the severity of the droughts were not equivalent; and three, estimation techniques differed. The main difference in estimation technique was that in both the Texas and South Dakota studies losses to the livestock sector were included (forward linkages and increased input costs), increasing the total impact of the drought.

Table 3: IMPLAN Results of Total Impact for the Rio Grande River Basin

	Change in revenue	Multiplier	Indirect & Induced	Total
Barley	($628,068)	0.20	($127,752)	($753,682)
Hay	($9,311,169)	0.26	($2,379,346)	($11,732,073)
Potatoes	$12,465,428	0.33	$4,075,776	$16,579,019
Wheat	$550,070	0.20	$111,887	$660,084
Total	**$3,076,261**		**$1,680,566**	**$4,753,349**

Table 4: IMPLAN Results of Total Impact for the Arkansas River Basin

	Change in revenue	Multiplier	Indirect & Induced	Total
Corn	(39,878,518)	0.21	(8,208,827)	(48,087,345)
Hay	(16,413,731)	0.29	(4,762,327)	(21,176,058)
Sorghum	(12,232,433)	0.21	(2,517,995)	(14,750,428)
Sunflowers	(2,641,452)	0.20	(536,676)	(3,178,128)
Wheat	(14,552,800)	0.21	(2,995,633)	(17,548,434)
Total	**(85,718,935)**		**(19,021,458)**	**(104,740,393)**

Table 5: IMPLAN Results for the Total Economic Impact for Combined River Basins

	Change in revenue	Multiplier	Indirect & Induced	Total
Barley	($628,068)	0.20	($127,752)	($753,682)
Corn	(39,878,518)	0.21	(8,208,827)	(48,087,345)
Hay	($25,724,900)	0.28	($7,141,673)	($32,908,131)
Potatoes	$12,465,428	0.33	$4,075,776	$16,579,019
Sorghum	(12,232,433)	0.21	(2,517,995)	(14,750,428)
Sunflowers	(2,641,452)	0.20	(536,676)	(3,178,128)
Wheat	($14,002,730)	0.21	($2,883,746)	($16,888,350)
Total	**($82,642,673)**		**($17,340,893)**	**($99,987,045)**

Estimating Total Economic Impact using the EDMP Model

The first step to determining the economic impact using the EDMP model is to determine the percent change in yield and harvested acres to input into the model. With this data, the EDMP model endogenously solves for the direct and indirect impacts within the agricultural sector. Results for total impacts are not separated by region, so the relevant comparison with the I-O results should be with the combined river basins.

The estimated percent changes in yield and in harvested acres are listed in Table 6. Note that percent of harvested acres is the same for both dry land and irrigated crops and is not listed for hay due to a lack of data. The combination of these two numbers to be input into the EDMP model is described in Equation 3. From these numbers, it is evident there is a significant difference in the changes in yield for dry land versus irrigated crops. Although this is to be expected, the fact that the two crops are broken out in the EDMP model but not in the I-O model will produce different results and backward linkages for each crop are likely to be different.

Table 6: Percent Change in Yield and Harvested Acres to Input into EDMP Model

	Rio Grande		Arkansas	
	% Δ in Yield	% Δ in Harvested Acres	% Δ in Yield	% Δ in Harvested Acres
Barley	-1%	-2%	-	
Dry Land Corn	-		-60%	-24%
Irrigated Corn	-		-7%	-24%
Irrigated Hay	-6%		-10%	
Potatoes	6%	0.33%	-	
Sorghum	-		-44%	-30%
Sunflowers	-		-31%	-9%
Dry Land Wheat	-	2%	-14%	-4%
Irrigated Wheat	3%	2%	-	-4%

After the percent change in yield and harvested acres are calculated and input into the EDMP model, the model produces an estimate of the direct and indirect impacts for the agricultural sector resulting from these changes. Total impacts for the agricultural sector for the Rio Grande and the Arkansas River Basins from the EDMP model are $67.6 million (Table 7).

Table 7: EDMP Results for the Total Economic Impact in the Agricultural Sector

	Arkansas and Rio Grande
Barley	$261,330
Corn	($46,000,000)
Hay	($3,942,083)
Potatoes	$2,293,781
Sorghum	($716,877)
Sunflowers	$996,399
Wheat	($22,000,000)
Total	**($69,107,450)**

Estimating Total Economic Impacts Linking the I-O model and the EDMP model

Results from the linking approach involve taking the output from the EDMP model for the change in total economic activity in the agricultural sector and applying the multipliers from the I-O analysis to get the total economic impact in the region resulting from the drought. When the two models are linked together, the total estimated economic impact of the drought is $83.3 million (Table 8). Results from the linking approach are about 16% lower than when using the I-O model alone. This difference in results can be attributed to the different assumptions of the two models. The main factor is the ability for producers to make input substitutions included in the EDMP model but not in the I-O model; which acts as a mitigating factor.

Interestingly, the forward linkages included in the EDMP model but not in the I-O model did not produce smaller results in the former, as would have been expected. This result is due to the very small impact of forward linkages. In Colorado, the feedlots import inputs of both feed and cows. Due to high beef prices and a reliance on imports, feedlots ran at capacity and did not feel the impacts of the drought on their revenue streams. Note that the numbers presented here

only reflect changes in revenue and do not reflect changes in costs. Increased costs were one of the main areas where livestock producers were impacted, but those impacts are not captured in an economic impact analysis.

Table 8: Results from linking I-O and EDMP of Total Impact for the Rio Grande River Basin and the Arkansas River Basin

	Change in revenue	Multiplier	Indirect & Induced	Total
Barley	$261,330	0.20	$52,266	$313,595
Corn	($46,000,000)	0.21	($9,468,909)	($55,468,909)
Hay	($3,942,083)	0.28	($1,143,767)	($5,085,850)
Potatoes	$2,293,781	0.33	$756,948	$3,050,729
Sorghum	($716,877)	0.21	($147,566)	($864,443)
Sunflowers	$996,399	0.20	$202,443	$1,198,842
Wheat	($22,000,000)	0.21	($4,528,609)	($26,528,609)
Total	**($69,107,450)**		**($14,277,194)**	**($83,384,644)**

Conclusion

The estimated impact of the drought for the economy of Southern Colorado ranges between $83 and $100 million. Linking the EDMP model and the I-O model provides the lower bound of estimated impacts because the EDMP model allows producers to augment input mixes. Allowing for these changes to occur within the model provides a smaller impact than described when the IMPLAN model is used alone, which does not enable any flexibility. Theoretically, the linking approach provides a better estimate of the impacts of the drought because of the EDMP's ability to more accurately model how producers respond to drought conditions. In reality, the

true impact of the drought most likely falls somewhere between the two estimates, so the value of this approach is framing that range.

The question to ask is whether the difference between the modeling approaches matters in terms of the magnitude and scope of impacts that are estimated; would results prompt relevant stakeholders to make substantially different choices in providing assistance to drought impacted communities? Although this is a question that must be answered on a case by case basis, the relatively similar estimate of impacts described by both modeling techniques provides some evidence of the benefits of using an I-O model; even though it is based on a more simplistic theoretical framework than the EDMP model. Results from this particular study suggest that the difference between the two modeling techniques is small, providing an argument that although an I-O model is sometimes seen as inferior to more complex regional models, it can provide accurate results at a low cost.

References

National Agricultural Statistical Service (NASS). (2008). Retrieved February 2012, from U.S. Department of Agriculture: http://www.nass.usda.gov

Farm Service Agency. (2012). Retrieved June 2012, from U.S. Department of Agriculture: http://www.fsa.usda.gov/FSA/newsReleases?area=newsroom&subject=landing&topic= edn&newstype=ednewsrel&type=detail&item=ed_20110801_rel_0088.html

Farm Service Agency . (2012). Retrieved June 2012, from U.S. Department of Agriculture: http://www.fsa.usda.gov/FSA/newsReleases?area=newsroom&subject=landing&topic= edn&newstype=ednewsrel&type=detail&item=ed_20110713_rel_0074.html

Livestock Marketing Information Center (LMIC). (2012). Retrieved January 2012, from http://www.lmic.info

National Agricultural Statistics Service (NASS). (2012). Retrieved April 2012, from U.S. Department of Agriculture: http://www.nass.usda.gov

Agra CEAS Consulting Ltd. (2004). *Study on the socio-economic implications of the various systems to keep laying hens.* Final Report for the The European Commission.

Balgatas, J. V., & Kreutzer, K. N. (2007). Commodity Policies and Product Differentiation: the California Milk Marketing Order and Organic Dairy Sector. *Paper prepared for the 2007 American Agricultural Economics Association Annual Meeting.* Portland.

Carpio, C. E., & Isengildina-Massa, O. (2010). Measuring the Potential Economic Impact of a Regional Promotion Campaign: The Case of South Carolina. *Journal of Agricultural and Resource Economics, 35*(2), 245-260.

Davies, S., & Sullins, M. (2011). *The Contribution of Agriculture to Colorado's Economy.* Colorado State University, Department of Agriculture and Resource Economics.

Davies, S., Pritchett, J., Davies, A., & Fatherlrahman, E. (2010, September/October). Examining the Economics of Water Issues in Colorado: An Equilibrium Displacement Mathematical Programming Model. *Colorado Water: Newsletter of the Water Center of Colorado State University*, pp. 6-9.

Diersen, M., & Taylor, G. (2003). *Examining Economic Impact and Recovery in South Dakota from the 2002 Drought.* Economics Staff Papers, South Dakota State University, Department of Economics.

Guerrero, B. (2011). *The Impact of Agricultural Drought Losses on the Texas Economy.* Briefing Paper, Texas A&M System, AgriLife Extension.

Harrington, D. H., & Dubman, R. (2008). *Equilibrium Displacement Mathematical Programming Models: Methodology and a Model of the U.S. Agricultural Sector.* Technical Bulletin, U.S. Department of Agriculture, Economic Research Service.

He , L., & Horbulyk, T. M. (2010). Market-Based Policy Instruments, Irrigation Water Demand, and Crop Diversification in the Bow River Basin of Southern Alberta. *Canadian Journal of Agricultural Economics, 58*, 191–213.

Howe , C. W., Lazo, J. K., & Weber, K. R. (1990, December). The Economic Impacts of Agriculture-to-Urban Water Transfers on the Area of Origin: ACase Study of the Arkansas River Valley in Colorado. *American Journal of Agricultural Economics, 72*(5), 1200-1204.

Howe, C. W., & Goemans, C. (2003, October). Water Transfers and Their Impacts: Lessons from Three Colorado Water Markets. *Journal of the American Water Resource Association, 39*(5), 1055.

Howitt, R. E. (1995, May). Positive Mathematical Programming. *American Journal of Agricultural Economics, 77*(2), 329-342.

Kanellopoulos, A., Berentsen, P., Heckelei, T., van Ittersum, M., & Lansink, A. (2010). Assessing the Forecasting Performance of a Generic Bio-Economic FarmModel Calibrated With Two Different PMP Variants. *Journal of Agricultural Economics, 61*(1), 274–294.

Leontief, W. W. (1936, August). Quantitative Input and Output Relations in the Economic System of the United States. *The Review of Economics and Statistics, 18*(3), 105-125.

MIG. (2012). *IMPLAN Glossary*. Retrieved June 2012, from IMPLAN: www.implan.com

MIG, I. (2009). IMPLAN system (data and software). 502 2nd Street, Suite 301, Hudson, WI 54016.

Miller, R. E., & Blair, P. D. (1984). *Input Output Analysis: Foundations and Extensions.* Englewood Cliffs, NJ: Prentice Hall.

Muth, R. F. (1964, July). The Derived Demand Curve for a Productive Factor and the Industry Supply Curve. *Oxford Economic Papers, 16*(2), 221-234.

Pendell, D. L., Leatherman, J., Schroeder, T. C., & Alward, G. S. (2007, October). The Economic Impacts of A Foot-and-Mouth Disease Outbreak: A Regional Analysis. *Journal of Agricultural and Applied Economics, 39*, 19-33.

Preckel, P. V., Harrington, D., & Dubman, R. (2002, August). Primal/Dual Positive Math Programming: Illustrated through an evaluation of the impacts of market resistance to genetically modified grains. *American Journal of Agricultural Economics, 84*(3), 679-690.

Pritchett, J., & Nelson, R. (2012). *Drought in Colorado.* Draft.

Pritchett, J., Fathelrahman, E., Davies, S., & Davies, A. (Draft 2011). Welfare Impacts of Water Reallocation ad Declining Aquifers of Colorado's Rural Economy: An Equilibrium Displacement Approach.

Thorvaldson, J., & Pritchett, J. (2006). *Economic Impact Analysis of Reduced Irrigated Acerage in Four River Basins in Colorado.* Completion Report No. 207, Colorado State University, Colorado Water Institute.

Watson, P., Wilson, J., Thilmany, D., & Winter, S. (2007). Determining Economic Contributions and Impacts: What is the difference and why do we care? *Journal of Regional Policy and Analysis, 37*(2), 140-146.

Zhao, X., Mullen, J., Griffith, G., Griffiths, W., & Piggott, R. (2000). *An Equilibrium Displacement Model of the Australian Beef Industry.* Economic Research Report, NSW Agriculture.