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THE ECONOMIC IMPACTS OF THE CHANGE IN SECTORAL WATER USE IN MARICOPA COUNTY, ARIZONA: MODIFIED INPUT-OUTPUT APPROACH

Abstract:

This paper investigates the impact of change in sectoral water supply on employment in Maricopa County, Arizona using input-output model. The main contribution of this study is two-fold. First, we generate a database on water use by water source: surface water and groundwater. Second, we develop a modified input-output model that captures the economic impact of substitution in water use from surface to ground water due to variation in the cost of water supply.
The study exercises two water supply change scenarios. Scenario I assumes that the total water supply/use decreases by 1% but the reduction comes only from surface water use, holding groundwater use constant. Scenario II assumes that surface water supply/use in all sectors decreases by 1%, and the reduction in surface water use is replaced by the exact amount of more expensive groundwater. We found that the magnitude of economic impacts depends on consumer's responsiveness to water price change. When price elasticity of water demand is relatively low (<0.2), the economic impact of a 1 percent reduction in surface water supplies was smaller than under the first scenario. However, the more water users in all industries are responsive to a change in water price, the bigger are economic impacts are in terms of reductions in jobs, value added, and indirect business taxes.

Keywords:

economic impacts, input-output model, water supply

JEL Classification: C18, C67

1. Introduction

Of the two main options for responding to the local environmental consequences of climate change, adaptation and mitigation, adaptation is generally the preferred choice. Mitigation options are frequently compromised both by the public good nature of the benefits they offer, and by the fact that they require advance investment. The benefits of adaptation, on the other hand, generally accrue to those who adapt, while the costs of adaptation are not incurred until after the environmental consequences have happened. To evaluate the efficiency of particular adaptive responses to some environmental change, however, we need first to understand the costs of non-adaptation. Non-adaptive responses occur within a given technology, set of institutional conditions, or economic structure. They can be characterized as short-run responses—involving no variation in capital stocks, no technical change and no institutional reform. In this paper we describe a method for estimating the economic costs of non-adaptive responses to environmental change.

We take the example of climate-induced changes to water supplies in a semi-arid environment. Like energy, water is a 'basic' good—one that enters into the production of all other goods and services. Water is more important in some sectors than others—the agricultural, residential, energy and industrial sectors in particular. But all sectors use water either directly (to produce output) or indirectly in the supply chain of the sector. For instance, water is directly used in the U.S. electric power sector as a coolant for thermoelectric power generation or as an energy source for generating hydroelectricity (EPA, 2012). In the chemical, food and paper industries water is directly used in the production process to fabricate, process, wash, or transport products, but it is also used indirectly via the energy consumed in those industries (EPA, 2012). At a moment in time the use made of water will depend on the technology applied in each industry, and the final demand for all goods and services produced within the economy. We consider the short-run effect of changes in water supply in a water-scarce region: Arizona's Maricopa County and the Phoenix Metropolitan Area. Regional climate models suggest that the local consequences of climate change in the US southwest are likely to include a reduction in mean precipitation and an increase in its variability. We abstract from any effects of variability (assuming that groundwater storage and surface reservoirs have sufficient capacity to smooth variation in flows), and focus on the impact of a change in mean precipitation.

We wish to understand how a change in water supply impacts an economy of given structure, operating a given technology, and what that means for value added (and other indicators of human wellbeing). There have been previous studies of the effect of changes in water supply on, for example, output, employment, personal incomes and property prices (Howe et al., 1990; Howitt et al., 2009a; Howitt et al., 2009a; Michael, 2009; Lichty and Anderson, 1985; Yoo et al., 2013). As with these studies, we are interested in tracking the effects of water supply changes at the regional scale. Specifically, to capture the consequences of non-adaptive responses to a change in water supply we use a linear model, of the same general form as the Leontief input-output model (Leontief, 1941). The central characteristics of such models—their use of fixed coefficients and constant dimensions—make them appropriate to the analysis of short-run effects of exogenous supply shocks.

Input-output models, have been used to analyze a variety of sectors including energy (Proops, 1988; Liang et al., 2010), ecosystem services (Cordier et al., 2011), and wastewater treatment (Lin 2009). A number of studies have used input-output models to analyze the effects of changes in water demand. However, these mainly focus on water use allocation across different sectors, not on the economic impact of changes in water use (Llop, M 2013; Esthur, 2006; Duarte et al., 2002; Blackhurst et al., 2010). For example, using European data, Esthur (2006) combined an extended Leontief input-output model with the model proposed by Proops (1988) to investigate which sector consumed the greatest amount of water, both directly and indirectly. Similarly, Llop (2013) investigated how water would be reallocated in response to changes in final demand using changes in the water needs per unit of sectoral production. Within the USA, the first input-output study of water was done by Blackhurst et al (2010). Using the United States Geological Survey 2000 (USGS) water use estimates, they analyzed the allocation of water at a national-level. They disaggregated the seven aggregate categories of USGS water use estimates into the 426 U.S. sectors and estimated direct and indirect water use in each sector.

On the supply side, there have been no published studies. However, an unpublished study by Howitt et al. (2009a) explored economic impact of reductions in water supply in the Central Valley of California using a regional input-output model (REMI). They first estimated the Statewide Agricultural Production Model (SWAP) to calculate revenue loss from changes in agricultural production due to water shortages, and then converted revenue loss into job losses via the REMI model. They found that annual job loss due to water shortage was about 35,000. A review of this study by Michael (2009) found the employment impacts in Howitt et al. (2009a) to be overestimated, and re-estimated the employment impacts of water shortage in the same area using the IMPLAN model, reporting annual job losses of around 6,000. Neither study considered the price effects of changes in water supply.

To understand the costs of a technologically and institutionally constrained response to an exogenous change in water supply—a non-adaptive response—we extend this literature in three ways. First, we generate a data base on water use by water source. The Phoenix greater metropolitan area secures water from three sources: surface water from the Colorado (limited by interstate agreements), surface water from the Salt and Verde watersheds, and groundwater. Using the method proposed by Blackhurst et al. (2010), we disaggregated 7 categories of USGS water use estimates into 232 sectors in Maricopa County. These water use estimates were then further disaggregated into surface and groundwater use in each sector.

Second, we develop a modified input-output model that captures the economic impact of substitution in water use from surface to ground water due to variation in the cost of water supply. The primary water providers in Maricopa County are Salt River Project (SRP) and other municipal water providers. SRP has been delivering water from both surface and

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ground sources to the 10 municipalities[1] in the Valley for over 100 years. Surface water is supplied from a series of SRP reservoirs[2]. Groundwater is supplied from a large number of wells that tap the Phoenix aquifer. Water from both sources is delivered through a canal system to farmers, industrial users, and homeowners. SRP stores water in the reservoirs and underground during wet periods in order to meet demand during dry periods (Phillips et al., 2009). It sets annual water allocations, consisting of partly surface water and partly groundwater. In general, once water allocation is set, the total amount of water is not reduced, but the mix of surface and groundwater can be changed. During the current drought, for example, the SRP has increased its groundwater pumping, as well as borrowing or buying water from Central Water Project (CAP) (surface water from the Colorado) to make up the reduced amount of surface water available from the Salt and Verde watersheds (Phillips et al., 2009). Since the cost of water from the three sources is different, substitution between them affects the cost of production. We develop a model that allows us to analyze the impact of substitution between water sources, while respecting that aggregate water use per unit of output may be unchanged. Ideally, we would like to model three different types of water use: surface water from the CAP, surface water from the Salt and Verde, and groundwater from the Phoenix aquifer. However, since water estimates from USGS data do not include CAP water, we focus on SRP surface and groundwater supplies only. By extending the regional input-output model we are able to evaluate the economic impact of switching water use between less expensive surface water to more expensive groundwater.

Third, in a traditional input-output model, economic transactions in each sector are equated to the value of output in that sector, expressed in dollar terms. This means that one cannot recover water prices or quantities from the model. As a result it is not possible to evaluate the economic impact of a change in price. In order to overcome this limitation, we break down the water industry into two separate water sectors—a surface water sector and a groundwater sector. The sectoral demand for water is then expressed in terms of both water prices and quantities. This makes it possible to explore the economic impact of a change in surface water supply by simulating the price elasticity of water demand in each sector.

Since the non-adaptive response to a change in surface water supplies allows for substitution between surface and groundwater, albeit at a cost, this enables us to estimate the cost of a climate-induced change in surface water supplies where there is no technical change, and no institutional reform. It is the 'business as usual' response in the sense of the IPCC. The advantage of being able to estimate the cost of the non-adaptive response is that it provides a measure of the damage avoided by adaptive responses.

The rest of this paper is organized as follows. Section 2 presents the modified input-output model used in the paper. Section 3 reports the data used for the particular area studied.

[1] 10 municipalities include most of major cities in Maricopa, such as, Gilbert, Tempe, Phoenix, Glendale, Tolleson, Avondale, Peoria, Chandler, Scottsdale, and Mesa.

[2] SRP operates four dams on the Salt River (Roosevelt, Horse Mesa, Mormon Flat, and Steward Mountain) and two dams on the Verde River (Horseshoe and Bartlett) (Philips et al., 2009).

Section 4 presents our results and discusses their general significance. A final section offers our conclusions.

2. Modeling the economic impacts of non-adaptive responses to exogenous changes in water supply

2.1. Water Allocation Method

The USGS reports total water use estimates (surface and groundwater) every 5 years by 7 broad categories: power generation, irrigation, self-supplied industrial, livestock, aquaculture, mining, and non-domestic water supply. We disaggregated the year-2005 USGS water use estimates into 232 water-using IMPLAN sectors using Blackhurst et al. (2010). “Public supply” refers to water distributed by public and private water suppliers for fees through water distribution networks. Public-supply water is delivered to users for domestic, commercial, and industrial purpose (USGS, 2005). Public supply (non-domestic) USGS water use estimates were allocated to I-O sectors by using the method proposed by Blackhurst et al. (2010) as follows:

$$Water\ Use_{PublicSupply} = \frac{Sector\ i's\ Demand\ from\ sector\ 3032}{Total\ Commodity\ Output\ of\ 3032} * USGS_{PublicSupply} \qquad [1]$$

Sector 3032 represents the water supply sector identified by the IMPLAN Model. The numerator is the purchase made by each sector from the water supply sector, and the denominator is total water output produced by water supply sector. $USGS_{PublicSupply}$ is the reported total water use estimates of surface water and groundwater.

“Irrigation water use” refers to water that is applied to irrigation of crops in the agricultural and horticultural sectors. “Livestock water use” is associated with livestock watering, feedlots, dairy operation, and on-farm needs. Water use in both categories was allocated to 10 agricultural/livestock I-O sectors in Maricopa County using USDA estimates of irrigation rates (USDA, 2002), and harvested land by crops (USDA, 2004) as follows:

$$Water\ Use_{agriculture/livestock_i} = Irrig\ Rate_i * Total\ Harvest_i * \frac{USGS_{irrigation/livestock}}{\sum_i Irrig\ Rate_i * Total\ Harvest_i} \qquad [2]$$

Agriculture/livestock$_i$ represents the amount of surface or groundwater use in agricultural/livestock sector *I*, *Irrig Rate*$_i$ represents the irrigation amount for harvested acre in sector *i*, *Total Harvest*$_i$ is the total production for agricultural/livestock sector *i*.

“Industrial water use” refers to water used for purposes such as fabricating, processing, washing, cooling, or transporting a product. It includes industries that use large amounts of water to produce commodities such as food, paper, chemicals, refined petroleum, or primary metals. Water for industrial use may be delivered from a public supplier or be self-supplied. USGS self-supplied water use refers to self-supplied industrial withdrawals only. Hence, USGS self-supplied water use estimates were allocated to thirty I-O industrial sectors in Maricopa. While it would be preferable to have US data on self-supplied water use per employee, relevant data were not available at the industry-level for the US. We therefore used Canadian statistics as a proxy for calculating surface and groundwater use in self-supplied industries. Our estimate was obtained as follows:

$$Water\ Use_{Self\text{-}Supplied\ Industry_i} = \frac{CAWater\ Use_i}{CAEmployees_i} * Maricopa\ Employees_i * \frac{USGS_{Industrial\ Self\ Supplied}}{\sum_i \frac{CAWater\ Use_i}{CAEmployees_i} * Maricopa\ Employees_i} \quad [3]$$

$WaterUse_{Self\text{-}Supplied\ Industry_i}$ is the amount of surface or groundwater use for self-supplied industry *i*, $CAWaterUse_i/CAEmployees_i$ is Canadian water use per employee in self-supplied industry *i*, $Maricopa\_Employees_i$ represents the number of employees in self-supplied industry in Maricopa County, and $USGS_{self\text{-}supplied}$ is the reported total water use for self-supplied industry category.

"Mining water use" is water used for the extraction of minerals that may be in the form of solids, such as coal, iron, sand, and gravel. This category includes quarrying, milling, re-injecting extracted water for secondary oil recovery, and other operations associated with mining activities. Since all mining withdrawals were considered self-supplied, USGS mining water use estimates were allocated to 4 mining I-O sectors in Maricopa County using a mix of process data (Gleick, 1994) , employee allocations (EIA, 2009), and the same allocation method as for industrial self-supplied water use.

Finally, USGS water use estimates for self-supplied withdrawals for power generation were directly mapped to I-O sectors such as power generation and supply and state & local government electric utilities. These two sectors were consolidated into one power supply sector by summing self-supply water, public water supply and other economic input and output.

2.2. The modified Input-Output Model

Input-output (I-O) models have long been used to trace the economy-wide impact of exogenous shocks to regional economies. Shocks that have been evaluated in this way include changes in final demand due to the profitability of gas extraction (Kinnaman, 2011) recreational spending (Bergstrom et al., 1990; Watson et al., 2008), national exports (Bairak and Hughes, 1996), construction projects (Babcock and Leatherman, 2011), or increases in government spending on energy (Paul, 2010). The standard representation of the I-O model is expressed as follows:

$$X = (I - A)^{-1} Y \quad [4]$$

where *X* and *Y* are n x 1 vectors, with each element of each vector representing, respectively, final output and final demand for each industry. *I* is an n x n identity matrix, and $(I - A)^{-1}$ is the *Leontief inverse* (or the matrix of input-output multipliers), *A* being an n x n matrix of technical coefficients, a_{ij} representing the economic flows from sector *i* to sector *j*. In a two sector economy, where:

$$A = \begin{bmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{bmatrix} \quad [5]$$

a_{11} is sector 1's purchases from the same sector per unit of output of that sector, while a_{12} is sector 1's sales to sector 2 per unit of output of sector 2. The other elements of *A* are defined accordingly. The *A* matrix is calculated from input-output tables (transaction matrices), showing the monetary flows of goods and services in a local economy for a given period, usually one year. In other words, the input-output table shows the value of goods and services produced by each sector (column), and value of goods and services demanded by each sector (row). Given that, the model can be used to calculate the economy-wide impact of a change in final demand for the output of a particular industry from:

$$\Delta X = (I - A)^{-1} \Delta Y \qquad [6]$$

This also makes it possible to map changes in industry output to other economic measures such as employment, or value added.

A limitation of the basic I-O model is that we cannot investigate the economic impact of changes in water supply because the elements of *A* matrix are expressed in dollar terms, and therefore do not have distinct quantity and price components. As a basic good, water is complicated for another reason. Since the water supply industry has few backward linkages, measuring the regional economic impact of the change in water use need to be done via forward linkages (via the rows of *A*). In order to address these issues, we first broke the water supply industry down into two different sectors—surface and groundwater. This was done by disaggregating purchases made by each water-using industry in the transaction matrix into separate purchases of surface and groundwater sector[3]. Using an adjusted transaction table, a new $\hat{A}$ matrix was calculated by adjusting the rows of groundwater and surface water sectors. Each element in the surface water (groundwater) rows in this matrix were expressed as the product of surface water (groundwater) use and surface water (groundwater) price, divided by the row sum of surface water (groundwater) sector in transaction table. Hence, the element of surface water and groundwater supply industry rows of adjusted $\hat{A}$ matrix is expressed as:

$$a_{surface\_i} = \frac{P_{surface} * Q_{surface\_i}}{Row\_Sum_{surface}} \qquad [7]$$

$$a_{groundwater\_i} = \frac{P_{groundwater} * Q_{groundwater\_i}}{Row\_Sum_{groundwater}} \qquad [8]$$

Where eq. [7] and [8] are represented by the direct requirement coefficient in the rows of surface water and groundwater sector for sector *i*. $P_{surface}$ and $P_{groundwater}$ are surface and groundwater price which are unknown, and constant across all sectors. $Q_{surface\_i}$ and $Q_{groundwater\_i}$ are surface and groundwater use estimates in each water-using sector, which were calculated from water allocation method introduced in previous section. Finally, $Row\_Sum_{surface}$ and $Row\_Sum_{groundwater}$ are row sum of surface and groundwater sector row in adjusted transaction matrix. Since $\hat{A}$ is now n+1 x n+1 matrix, thes vector of total

[3] For instance, the total value of surface water-related purchases demanded by crop farming sector is calculated by weighting the total value of water-related purchased demanded by crop farming sector by the ratio of surface water use in crop farming sector to the sum of surface and groundwater use in that sector. The total value of groundwater-related purchases demanded by crop farming sector is calculated accordingly.

output and final demand must be adjusted to include separate surface and groundwater sectors[4]. The adjusted vectors of total output and final demand are defined as $\hat{X}$ and $\hat{Y}$. A new I-O model with water price and quantity elements can be rewritten as follows:

$$\hat{X} = (1 - \hat{A})^{-1}\hat{Y} \qquad [9]$$

Using this relationship, unknown prices for surface and groundwater can be recovered since $\hat{X}$, $\hat{Y}$, and water quantity are known. We can then evaluate the economic impact of exogenous changes in water supply using eq. [9].

3. Data

To empirically estimate the model, we obtained data on water use, county-level economic transactions, sectoral final demand, final output, and employment. Seven categories of water use estimates—public supply, industrial, irrigation, livestock, aquaculture, mining, and power generation—are reported every five years in the United States Geological Survey (USGS) at county, state and national levels. Estimated use of surface water and groundwater are reported separately. The most recent water use estimates for Maricopa County are for 2005 (USGS, 2005). These are reported in terms of gallons per day, but were converted into gallons per year to match with economic data.

County-level economic data, including data on economic transactions, employment, output, value-added, indirect business tax, and final demand were recovered from the Arizona IMPLAN model, purchased from the Minnesota IMPLAN Group (www.implan.com). Since the Arizona IMPLAN model does not include 2005 economic data, we matched 2005 water use estimates with the 2004 IMPLAN Model, implicitly assuming no significant difference between 2004 and 2005 water use. In fact, comparison of 2000 and 2005 USGS water estimates show that water use for industrial and public supplied sectors did not change much (less than 1%) although agricultural and domestic water use both changed over that interval due to urbanization in the Phoenix Metropolitan Area.

Figures 1-3 shows the summary statistics of the top 25 sectors in terms of number of jobs, value-added, and total output calculated from 2004 IMPLAN Model. The number of jobs refers to average annual estimates of the sum of both wage and salary employees and self-employed persons in each sector in Maricopa County. Value-added is composed of employee compensation[5], proprietor income[6], other property type income[7], and indirect business tax[8]. Value added is calculated by taking a difference between total output and the cost of intermediate inputs. As shown in Figure 1, the top 20 industries—mostly

[4] The final demand for surface water sector (groundwater sector) was calculated by weighting the final demand for water supply sector by the ration of surface water (groundwater) use to the sum of surface and groundwater use. The total output for surface and groundwater sector were calculated accordingly.

[5] Employee compensation is the total payroll cost of the employee paid by the employer, which includes wage, salary, employer paid payroll taxes, and all benefits such as health insurance and retirement savings.

[6] Proprietor income is composed of payments received by self-employed individuals and unincorporated business owners.

[7] Other property income includes corporate profits, capital consumption allowance, dividends, royalties and interest income.

[8] Indirect business tax is represented by taxes on sale, property, and production, and excludes employer contributions for social insurance and income tax.

commercial and service sectors—account for more than 53.5% of the total employment in Maricopa County. Food and drink, real estate, wholesale trade, new residential 1-unit structures, and hospitals were the top industries in terms of both water consumption and the number of employees. Figures 2 and 3 indicate that industry rankings did not change much in terms of either total output or value added.

INSERT FIGURE 1, 2, and 3 AROUND HERE

4. Results

To explore the cost of non-adaptive responses to exogenous changes in water supply we considered two scenarios. The first assumed a reduction in surface water supply but excluded and substitution between sources of supply. This might be thought of as an extreme non-adaptive response. It implies that the industries relying on surface water would cut output proportionate to the reduction in surface water as an input. The second assumed that a reduction in surface water supply would be compensated by an increase in groundwater supply, but at a cost. Our two scenarios were:

> Scenario I: Total water supply/use decreases by 1%, but the reduction comes only from surface water use, holding groundwater use constant.
>
> Scenario II: Surface water supply/use in all industries decreases by 1%, and the reduction in surface water use is replaced by the exact amount of more expensive groundwater.

Since there is no price change allowed in the first scenario, there is no change in final demand in each sector. The second scenario does imply a change in final demand because it involves the switch to more expensive groundwater use. Calculating the change in sectoral final demand is complicated for two reasons. First, information on the price elasticity of water demand is not generally available, although some studies have estimated the price elasticitiy of water demand on a broad-scale (commercial, residential and industrial sector) (Hussain et al., 2002; Worthington, 2010). To address this we simulated the impacts of change in surface water supply over a range of price elasticities (-0.1, -0.75), assuming that the price elasticity of water demand did not vary across sectors. Second, final demand in each sector includes demand for both water-related, and non-water-related goods. Hence, water-related demand should be isolated from the total final demand in agricultural sector to calculate the change in final demand associated with water price change. To tackle this problem, sectoral gross absorption coefficients, obtained from 2004 IMPLAN Model, were used as a proxy for calculating the proportion of final demand associated with water use. Gross absorption coefficient (GAC) represents the value of goods and services purchased as inputs for producing the output of a particular sector. For instance, a GAC of 0.15 for the farming sector means that water accounts for 15% of total production costs in the farming sector. We assumed a similar relation between GAC and final demand, such that a GAC of 15% in farming means that water accounts for 15% of final demand for the products of agriculture. Hence, the adjusted vector of final demand in the second scenario was calculated as:

$$Y_i = Y_i - Y_i * GAC_i * e \qquad [10]$$

where $\tilde{Y}_i$ is final demand in sector *i*, GAC_i is the gross absorption coefficient in sector *i*, and ε is simulated price elasticity of water demand, which is assumed not to vary across sectors.

Summary statistics of water use estimates by sector (Top 20 in terms of water use) are reported in Table 1[9]. Most agricultural sectors ranked high in terms of 2005 water use, and groundwater use was, on average, is 4-5 times higher than surface water use. Agricultural water use accounted for 58% of the total water use, a figure that did not change much during the recession (Arizona Department of Water Resources, 2010). After agriculture, the largest water users in Maricopa County, AZ were the power generating and real estate sectors, along with some commercial sectors (which is consistent with national-level findings from Blackburst et al. (2010)). Table 1 also indicates that the largest share of groundwater was allocated to agricultural sectors, while largest share of surface water went to power generation and other commercial/service sectors.

INSERT TABLE 1 AROUND HERE

Using these data we recovered the unknown surface and groundwater prices by solving eq. [9] for $P_{surface}$ and $P_{groundwater}$. The estimated implicit price of water was $10.54/acre-foot for surface water and $14.88/acre-foot for groundwater, respectively. These prices are both a little lower than the official prices published by SRP (SRP, 2012), in which surface water and groundwater prices are $14.5/acre-foot and $20-$45/acre-foot, respectively. However, they are in the same order of magnitude. Using the estimated implicit prices into eq. [9], we first considered the first scenario where surface water use reduction occurred in all sectors, assuming no change in groundwater use. The associated reduction in jobs, value added, and indirect business tax associated with this scenario is reported in Table 2. This shows that a 1% water use reduction in all sectors with an extreme non-adaptive response would induce a loss of 2,571 jobs, $166.8 million in value added, and $13.9 million in indirect business tax revenue in Maricopa County. The table also shows the change in economic output for top 20 industries[10]. The water supply industry accounts for more than 50% of the reduction, followed by a number of commercial, sectors, such as construction and maintenance, wholesale trade and real estate, and by the energy sectors, particularly power generation. Interestingly, only 5 of the top 20 sectors in terms of water use-—wholesale trade, real estate, telecommunications, power generation and supply, food service and drinking places—were amongst the top 20 sectors most affected by a reduction in water supply.

Table 3 presents the results of the second scenario: a less extreme non-adaptive response that allows for substitution between water types. Under this scenario we found a 43.6% increase in water prices, due to the substitution of groundwater for surface water. This led each industry to respond not only through changes in water use, via our adjusted

[9] Only 20 sectors were presented here to space the space. The complete statistics for 232 sectors is available from authors upon request.

[10] Statistics for complete set of industries are available upon request from authors.

A matrix, but also to the decrease in the final water-related demand, via our adjusted vector of final demand.

We simulated industry responses over a range of price elasticities to calculate the economic impacts, and found that the cost of a non-adaptive response depends critically on this elasticity. In a standard input output model, where the price elasticities are implicitly assumed to be zero, all changes are due to the interaction between the final demand and industrial structure. We found that price elasticity of water demand is relatively low (≤0.2), the economic impact of a 1 per cent reduction in surface water supplies was smaller than under the first scenario. However, the more water users in all industries are responsive to a change in water price, the bigger are economic impacts are in terms of reductions in jobs, value added, and indirect business taxes. Of course short-run elasticities are typically low, and are always lower than long run elasticities precisely because technical change is a feasible response in the long term. The particular problem identified in our results is where the price elasticity of water demand is high but technology is fixed. We should also add a cautionary note that we would not in fact expect elasticities to be the same for all industries. For instance, power generation and supply sector that heavily withdraws water resource to generate electricity with stream-driven turbine generators, and to cool power generation system, might respond less to an increase in water price relative to other industries.

5. Conclusions

Regional input-output models are useful vehicles for examining the cost of non-adaptive responses to exogenous change precisely because they assume fixed coefficients and a constant structure to the economy. But in the case of basic goods that are generated from multiple sources the lack of any substitutability between sources can be problematic. In our first scenario we estimated the impact of a small (1 per cent) change in surface water supplies due to climate change. In fact, the change in mean precipitation is expected to be significantly more than this. Under an extreme non-adaptive response, every percentage point reduction in surface water supplies reduces value added in the county by $166.8 million in value added together with losses of both jobs and tax revenues.

To capture the effect of the limited substitutability between water sources allowed by the existing technology, we developed an extended regional economic model that incorporates each source of water as a separate sector, and that allows for substitution between water sources. This is in fact how the current system operates. This extends previous studies by (1) disaggregating 2005 UGSG water use estimates into sectoral surface and groundwater use on a county-level, and then (2) providing a more flexible input-output model that addresses both the change in water resource quantity, and the change in water resource price. This was achieved by disaggregating the technical coefficients of the water sectors into price and quantity components. We found that the economic impact of a change in surface water supplies in these circumstances depends on consumer’s responsiveness to water price change. While the results are sensitive to the assumptions made about price elasticities, they do make it possible to identify which sectors have the greatest impacts on economic variables, and therefore which might most benefit from a more adaptive response..

The methodology used in this paper is not without limitations, and leaves some topics for future research. First, our model does not allow price elasticities to vary across sectors. It is reasonable to think that price elasticities in the industrial and /commercial sectors will be higher than in the residential sectors because commercial/industrial sectors may have more options over water use than residential consumers (even within the existing technology), such as water recycling (Worthington, 2010; Olmstead and Stavins, 2007). It is also reasonable to think that elasticities will vary with the cost share of water inputs. Second, the impact of a change in climate on water supply is mediated by land use and land cover change in the watersheds. More than half of the total U.S water supply, and two-thirds of water supply in the southwest derive from forested land (Brown et al. 2008). We have not modeled changes in land use or land cover here, Complicating the model by including land use change component will enrich our model from forest management perspectivebut both will affect not only water supply but also the production of goods and services more generally. Finally, our interest in this paper is in the short-run response to an exogenous change in water supply. The study accordingly focuses on one-year snapshot of economic impacts to get the cost of non-adaptive responses. These costs would be expected to carry forward into future years if there were no adaptation and, if the costs were high enough, we would expect to see an adaptive response that was sensitive to the incidence of those costs. We would therefore expect to see a transformation of both the technologies deployed and the structure of the regional economy. While current input-output models are unable to address changes of this sort they do provide a way of systematically identifying where the failure to adapt is likely to incur costs, and therefore where an adaptive response is likely to be efficient. We leave such an extension of the model to future work.

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Table 1: Summary statistics of water use by type (top 22 sectors)

Sector	Total Water Use (million gallon/year)	Surface Water Use (million gallon/year)	Groundwater Use (million gallon/year)
1. All other Crop Farming	205,739	37,930	167,809
2. Cotton farming	96,770	17,879	78,891
3. Vegetable and melon farming	64,346	16,072	52,268
4. Real estate	60,753	43,393	17,358
5. Power generation and supply	49,871	32,739	17,132
6. Grain farming	20,087	3,686	16,399
7. Fruit farming	15,491	2,848	12,643
8. Tree nut farming	10,356	1,893	8,462
9. Management of companies and enterprises	8,646	6,175	2,470
10. Food Services and drinking places	8,379	5,985	2,394
11. All other miscellaneous professional and technical	8,245	5,889	2,356
12. Telecommunications	8,055	5,753	2,301
13. Wholesale trade	7,825	5,589	2,236
14. New residential 1-unit structures-all	7,294	5,210	2,084
15. Hotels and motels- including casino hotels	7,044	5,031	2,013
16. Hospitals	6,338	4,527	1,811
17. Travel arrangement and reservation services	5,945	4,246	1,699
18. Religious organizations	4,094	2,924	1,170
19. Greenhouse and nursery production	3,453	653	2,800
20. Recreation industry	3,376	2,411	965

(Source: Calculated by authors based on 2005 USGS water use estimates and 2004 IMPLAN Model)

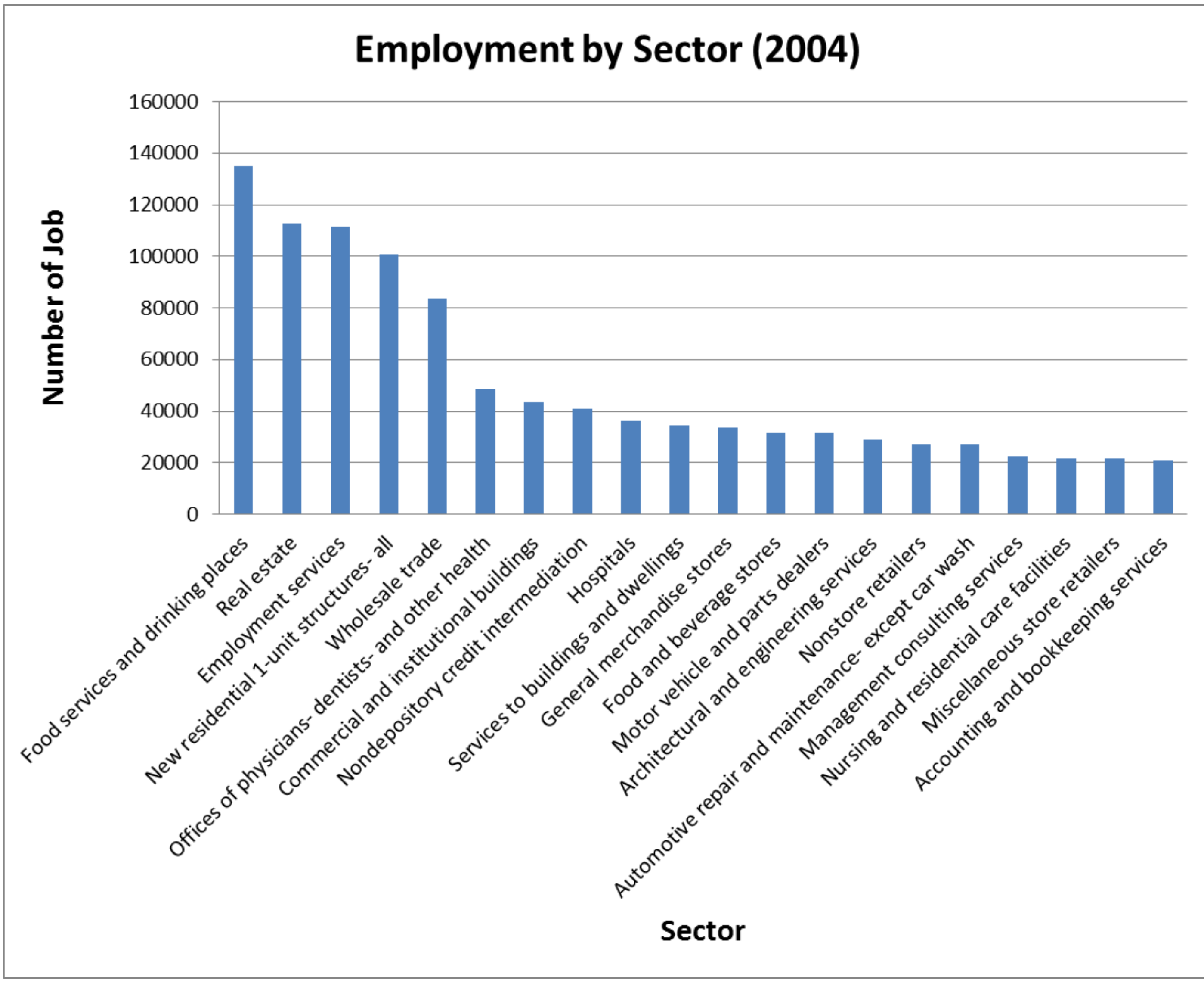
Table 2: Economic impact of baseline scenario (1% reduction in total surface water use)

Sector	Job	Value-Added ($)	Indirect Business Tax ($)
1. Water Supply Sector	-1,081.8	-94,011,425	-7,847,938
2.Other maintenance and repair construction	-122.9	-7,155,911	-521,704
3. Wholesale trade	-58.1	-5,942,946	-1,180,846
4. Legal services	-55.1	-4,530,929	-199,872
5. Employment services	-52.2	-1,461.413	-13,887
6. Real estate	-41.9	-4,313,281	-627,220
7. Telecommunications	-30.9	-3,614,431	-444,454
8. Management consulting services	-30.5	-1,760,627	-48,579
9. Architectural and engineering services	-28.3	-1,711,229	-37,748
10. Power generation and supply	-27.2	-3,978,301	-507,065
11. Electronic equipment repair and maintenance	-25.9	-1,967,531	-132,758
12. Food services and drinking places	-25.4	-706,230	-78,482
13. Postal service	-23.5	-1,278,679	-8,040
14. Truck transportation	-19.8	-1,231,468	-53,916
15. Services to buildings and dwellings	-18.9	-579,254	-35,289
16. Non-depository credit intermediation and related activities	-18.4	-1,570,683	-108,671
17. Environmental and other technical consulting services	-17.4	-1,095,350	-33,634
18. Nonstore retailers	-16.4	-758,323	-112,152
19. General merchandise stores	-15.9	-595,005	-120,805
20. Household goods repair and maintenance	-15.5	-1,522,711	-104,882
Total Sectors	-2,571	-166,829,157	-13,947,860

Table 3: Economic impact of substitution scenario (1% reduction in total surface water use is replaced by exact amount of groundwater)

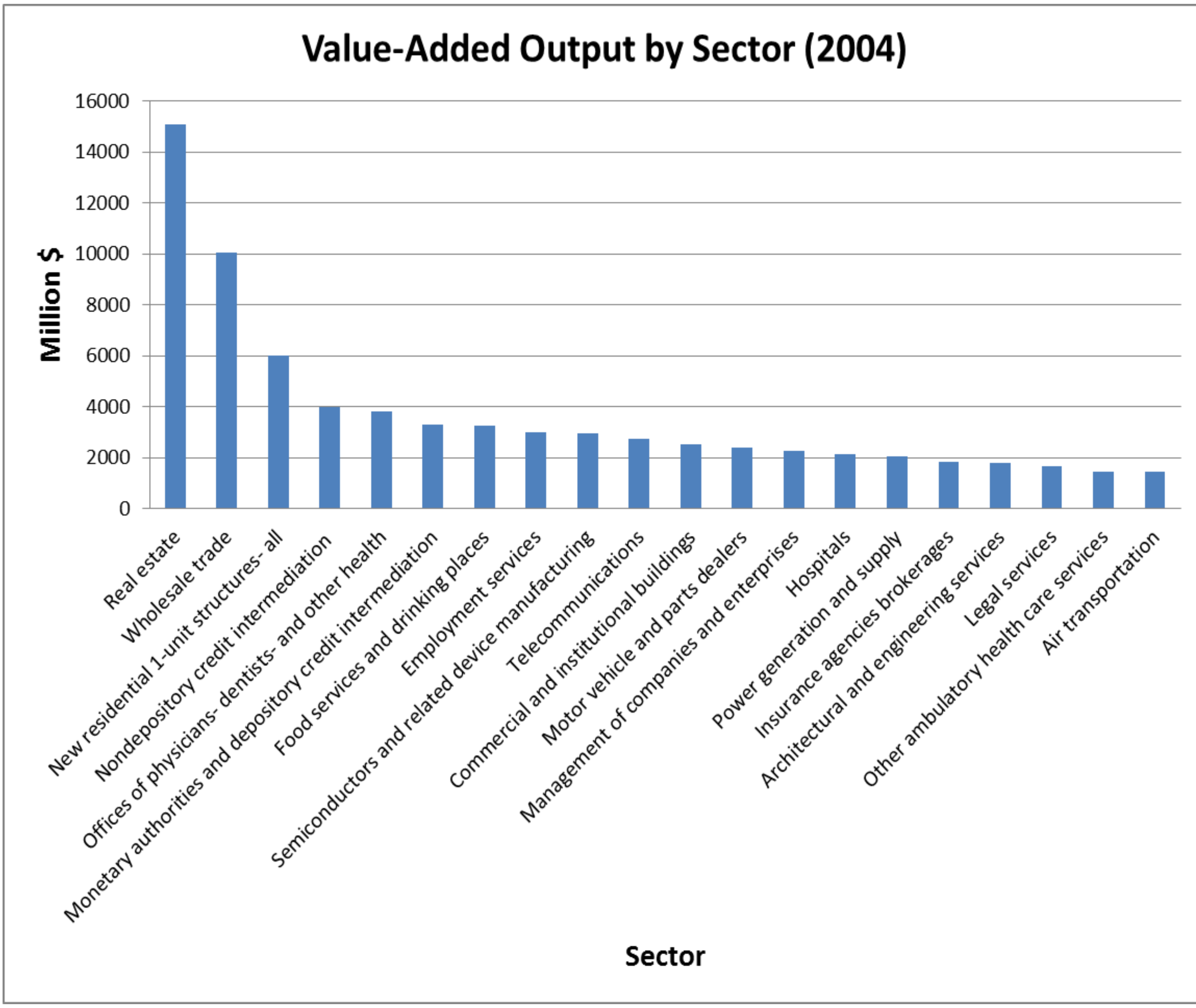
Simulated Price Elasticity of Water Demand	Total Job (per year)	Total Value Added (Million $)	Total IBT (Million $)
-0.10	-17	-0.4	-0.05
-0.15	-1,177	-75.7	-6.4
-0.20	-2,336	-151.1	-12.8
-0.25	-3,496	-226.4	-19.2
-0.30	-4,655	-301.8	-25.5
-0.35	-5,815	-377.1	-31.9
-0.40	-6,975	-452.4	-38.3
-0.45	-8,134	-527.8	-44.6
-0.50	-9,294	-603.1	-51.0
-0.55	-10,453	-678.5	-57.4
-0.60	-11,613	-753.8	-63.7
-0.65	-12,772	-829.1	-70.1
-0.70	-13,932	-904.5	-76.5
-0.75	-13,948	-979.8	-82.9

Figure 1: Summary statistics of employment by sector in Maricopa County, AZ (top 20 sectors)



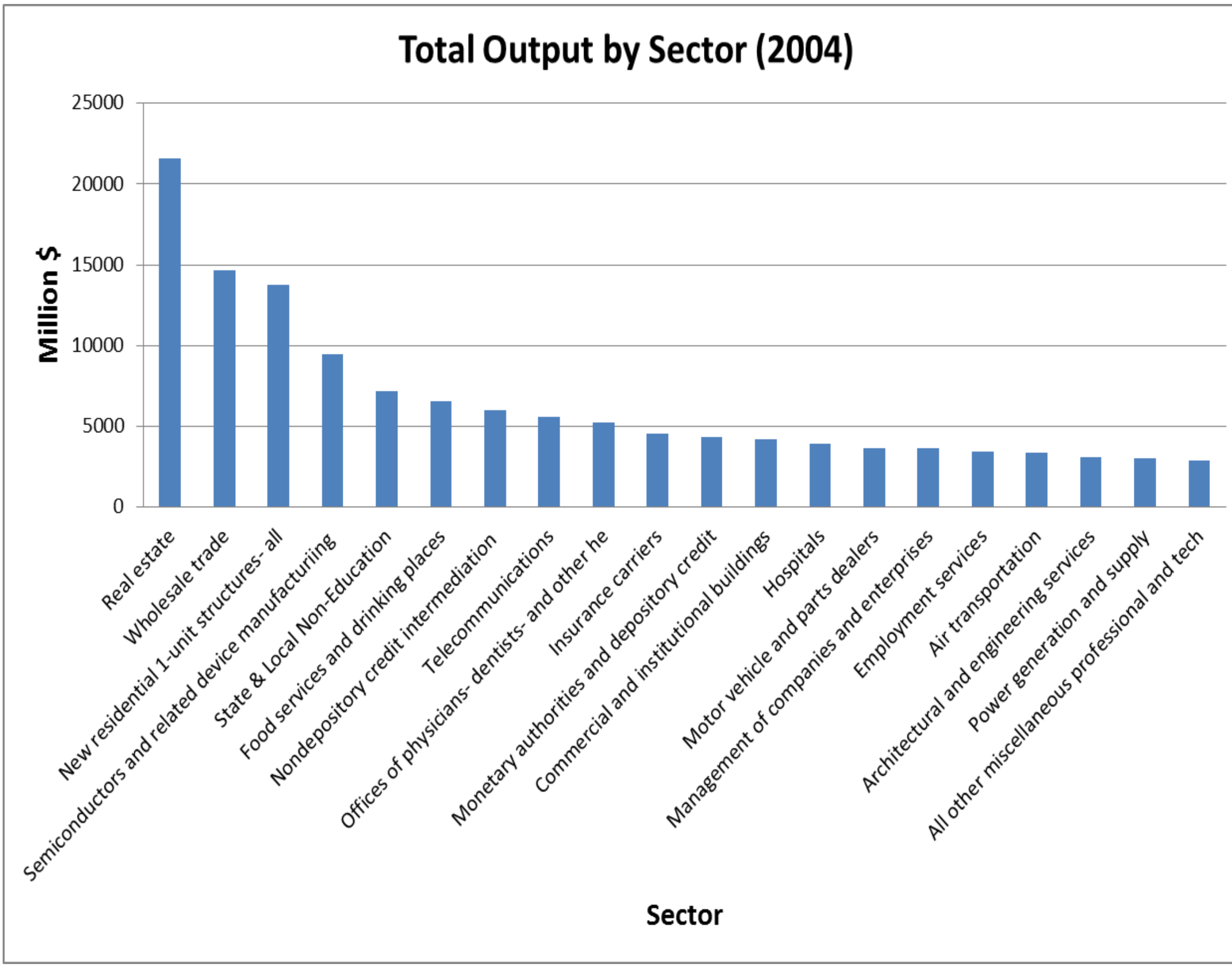
(Source: 2004 IMPLAN Model)

Figure 2: Summary statistics of value added output by sector in Maricopa County, AZ (top 20 sectors)



(Source: 2004 IMPLAN Model)

Figure 3: Summary statistics of total output by sector in Maricopa County, AZ (top 20 sectors)



(Source: 2004 IMPLAN Model)