IMPACTS OF REALLOCATION OF RESOURCE CONSTRAINTS ON THE NORTHEAST ECONOMY OF BRAZIL

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Impacts of Reallocation of Resource Constraints on the Northeast Economy of Brazil[1]

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Abstract: The present paper explores the role of water and energy resource constraints and allocation on the Northeast Brazil economy. The analysis centered on the creation of an intergrated model in which an econometric-input-output model was linked with a linear programming optimization model for resource allocation. Over the period 1999-2012, the impact on the six agricultural sectors was to reduce their output and employment by 15% annually. The reduction in employment in the rest of the economy was a little over 1% annually. However, since the agricultural sectors continue to employ a significant percentage of the labor force, the aggregate loss of employment amounted to 6% of the total regional employment on average, translating into 1 million jobs annually. When water allocation and energy resource allocations are considered simultaneously, the re-allocations are more limited, resulting in a loss of 0.78 million jobs annually. These results suggest the need for an active link between policy making and economic development when resource constraints are present. Some balance has to be provided between allocation and reallocation on the one hand perhaps driven by concerns with economic efficiency against anticipated losses of employment for part of the labor force with few other alternatives.

1. Introduction

There is a growing recognition in the economic development literature that one of the major impediments to growth and development in the next several decades will be access to water. In recognition of this emerging problem, the present research aims to provide a formal link between water consumption and economic growth and development. This is accomplished by linking an econometric input-output model of the Northeast Brazil economy to a water allocation model. The work can be considered as an important first step in placing water allocation the policy-

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making agenda; additional steps will require links to issues of climate change and water availability, potential water transfers between regions and sectors and consideration of the way alternative development strategies can be proposed that are in harmony with water availability.

The paper is organized as follows. In the next section, some background reviews of selected approaches to linking water and economic models will be provided. Section 3 focuses on the initial development of the water allocation model and then its subsequent modification and integration with the econometric-input-output model. Results of the analysis are also presented in this section. The addition of energy constraints are also considered here as well. Section 4 provides a summary evaluation and section 5 indicates some future directions for this research.

2. Resource Constraints and Integration with Economic Models

In this section of the paper, some prior attempt to handle resource constraints with input-output/econometric models will be reviewed. There is another set of models, computable general equilibrium models (CGE), that have been used to present the linkages between the economy and the environment. However, most of these models tend to be two-period models (base year and the result of some perturbation). Hence, the literature pertaining to CGE modeling will not be reviewed. Further, an input-output-econometric model for the region had previously been constructed, so the focus of intergration was limited to this class of models.

Carter and Ireri (1970) developed a two-region input-output model for California-Arizona to analyze water transfer patterns. The model was developed to help understand the nature of direct and indirect linkages between sectors in the demand for water and to provide an analytical framework to explore legal conflicts over water allocation rights from the Colorado river. They first developed a standard two-region model:

$$\begin{bmatrix} X^c \\ \hline X^a \end{bmatrix} = \left[\begin{array}{c|c} B_{cc} & B_{ca} \\ \hline B_{ac} & B_{aa} \end{array}\right] \begin{bmatrix} f^c \\ \hline f^a \end{bmatrix} \tag{1}$$

where the superscripts/superscripts *a*, *c* refer to Arizona and California respectively, X represents a vector of total production (*n* sectors), *B* is the partitioned Leontief inverse and *f* final demand. The principal diagonal matrix of *B* provides the multiplier effects within each state while the off-diagonal elements trace the trade flows. Water is introduced as follows:

$$R = WX \tag{2}$$

where R is the total water requirements by the endogenous sectors and W is a suitably partitioned vector with elements $\left(w_j^c \in W\right)$ representing the water use by sector j in California (with similar elements for Arizona sectors.

Combining (2.1) and (2.2):

$$R = \left[W^c \mid W^a \right] \left[\begin{array}{c|c} B_{cc} & B_{ca} \\ \hline B_{ac} & B_{aa} \end{array} \right] \left[\begin{array}{c} f^c \\ \hline f^a \end{array} \right] \tag{3}$$

or in more compact form:

$$R = WBf \tag{4}$$

Subsequently, they developed unweighted water multipliers:

$$\bar{M} = \bar{W}^{-1} V^{*/} = \left[\bar{M}^c \mid \bar{M}^a \right] \tag{5}$$

where $V^{*/}$ is the transpose of WB.

However, these multipliers say little about the size (magnitude) of the water demands and thus one option would be to weight using final demand:

$$\bar{\bar{M}} = \left[\begin{array}{c|c} \Delta f^c & 0 \\ \hline 0 & \Delta f^a \end{array} \right] \left[\begin{array}{c} V^c \\ \hline V^a \end{array} \right] \tag{6}$$

where V^c, V^a are the partitions of the matrix $V = WB$ and the changes in final demand represent say a unit change in each sector.

One of the important findings of the research was the difference in direct water consumption and direct+indirect consumption. It turned out that comparable California sectors were much more efficient in their use of water than those in Arizona (more production per unit of water use).

Ghosh (1964, 1973) and Ghosh and Chakravati (1970) provided some of the first studies in which input-output models were cast in a linear programming framework. For example, in Ghosh and Chakravati (1970), an interregional allocation model was harnessed to an input-output system to explore optimal industrial expansion for different states within India. Other applications looked at the optimal allocation of fertilizer and cement factories.

The general results from these models reveals the importance of handling the indirect effects of decisions through some type of input-output structure. In the Indian applications, the intersectoral structure was complemented by an interregional flows matrix.

Water resources allocation models mainly deal with scarce resources (water and usually capital) which must be allocated among water users (i.e., hydroelectric energy production and irrigation, manufacturing sectors, households) to maximize a set of planning objectives. In addition, there may be control alternatives, for example reservoirs, which allow the resources to be used more effectively (scheduling problems). The objective function expresses the set of planning objectives in terms of decision variables in the model; for example, decision variables may represent the release of water from reservoirs, the diversion of water out of the stream for water uses, the realizable production from uses to which water is allocated, and the location and capacities of the structural components of the hydrologic system (i.e., rivers, canals, dam, pipes).

An extensive literature review of material focusing on the subject of optimization of water resources allocation reveals that no general algorithm exists. The choice of methods depends on the characteristics of the problem at hand, on the system being considered, on the availability of data, and on the objectives and constraints specified (for a review, see Hewings *et al*., 2005).

The underlying structure of the model developed for the Northeast of Brazil drew on the early attempts to integrate input-output models in a linear programming framework; however, as the next section will reveal, the input-output model was itself first embedded in an econometric model.

3. The NE Brazil Model

The modeling system employed draws a set of econometric-input-output models for the Brazilian economy that were built on the same foundation as those reported in Conway (1990, 1991) and Israilevich *et al*. (1997); an example of an application in Brazil can be found in Azzoni and Kadota (2001) The system combines in one model the time series features of econometric models with the interdependence implied in input-output systems; further, the system operates like a general equilibrium model, except that quantities adjust to clear markets in any year and the tatonnement process is accomplished through endogeous adjustment of the input-output coefficients.

Table 1: Major Water Consuming Sectors

Sector	Share of Water	Share of Employment 1998
Culturas industriais	45.5%	16.6%
Grãos	22.0%	6.6%
Fruticultura e olericultura	8.5%	2.7%
Bovinocultura	14.3%	5.1%
Avicultura e Suinocultura	5.5%	0.3%
Outros produtos agropecuários	2.8%	3.2%

We focused on industries that had high water consumption over the period 1970-98. The top water-consuming industries and their approximate water shares over the period 1970-98 are shown in table 1. There is an increase in the volume of water used by the above six (out of 35) industries; on average, they consume about 98.61 % of the total. Over the period 1970-1998, the importance of these sectors to the NE Brazil economy changed (in terms of employment generation) while their consumption of water did not. These major water-consuming sectors employed 62% of the total at the beginning of the period but this share decreased to 34% by 1998, but they still accounted for 6.4 million jobs.

Reallocation of Water

In the initial experimentation, reallocation of water among major users was explored without a formal connection to the macroeconomic model. Based on the historical data, we estimate with almost a 100% confidence interval the parameters of the following model for each industry separately.

$$X_{i,t} = P_{i,92} A w_{i,t}^{\alpha} \tag{7}$$

The above model is linearized using the log(.) operator:

$$\log\left(X_{i,t}\right) = \log\left(P_{i,92} A\right) + \alpha \log\left(w_{i,t}\right) + \eta_{i,t} \tag{8}$$

So the model to estimate using OLS is now:

$$\log\left(X_{i,t}\right) = \beta_1 + \beta_2 \log\left(w_{i,t}\right) + \eta_{i,t} \tag{9}$$

The results of the regression show the existence of increasing returns to water inputs for many industries. In fact for some industries we have $\beta_1 = \alpha \approx 1$, with for some industries β_1 slightly greater than one. At the industry level this result should not be surprising, however at the firm level some authors showed that a concave relation should exist. The aggregation might lengthen the increasing portion of the industry's production function, that way it seems that the relation is almost linear. For details on returns to scale see figure 1. (Increasing returns poses convergence problems in the next step but it seems that the results obtained are good enough).

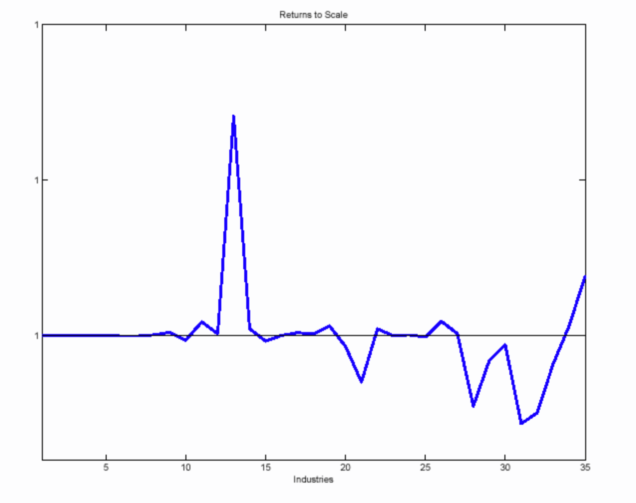

Figure 1 Returns to Scale

What we obtain is therefore a set of relations linking water use with the output value of each sector, $\hat{X}_{i,t} = f_i(w_{i,t}), \forall i,t$.

We then determine a new water quota for each period, to minimize for each industry the gap between the historic output value and the optimal output value obtained if water quotas were to be re-allocated.

$$\begin{aligned} &\min_{\hat{w}_{i,t} \geq 0} \left(\sum_i \lambda_{i,t} \left(X_{i,t} - f_i \left(\hat{w}_{i,t} \right) \right)^k \right)^{1/k} \\ &\text{s.t.} \qquad\qquad\qquad\qquad \forall t \qquad\qquad (10) \\ &\qquad \sum_i \hat{w}_{i,t} \leq \sum_i w_{i,t} \end{aligned}$$

For our purpose we chose $k = 2$ and the weight coefficient $\lambda_{i,t} = \dfrac{L_{i,t}}{\sum_i L_{i,t}}, \forall t$, that way greater importance in water rationing is given to industries with higher employment, in other words to minimize the impact of the reallocation on the employment in the industry.

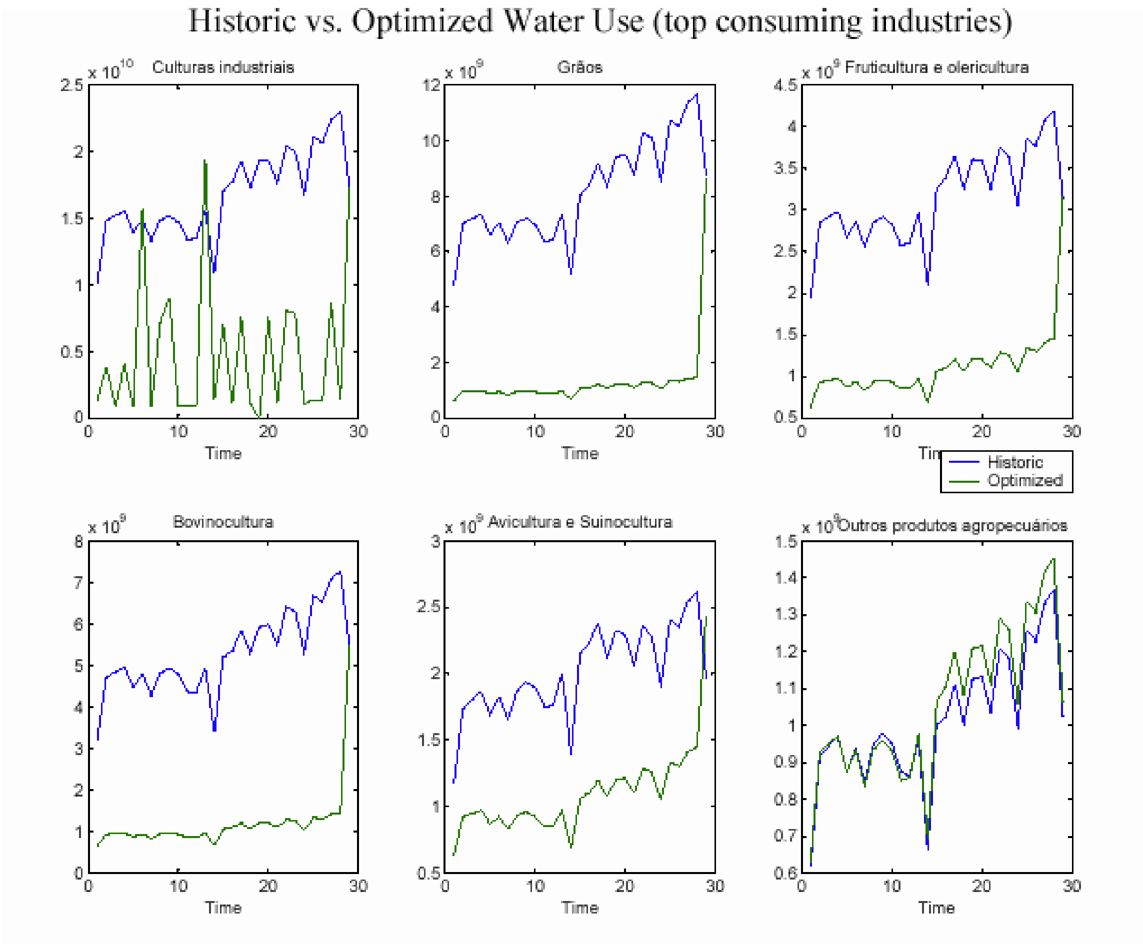

Figure 2 Historical versus Optimized Allocation of Water for Major Water-Consuming Sectors

A comparison of historic water use and optimized water use is given in figure 2, the results show that water has to be redistributed to other industries where more value added is produced. Recall that the objective was to essentially minimize the redistribution of water from sectors with high employment. Obviously, with a different objective function, it is possible that the reallocation system would be different. The water use for most of the sectors in industry and services are depicted in curves similar to figure 3 , with the exception of some seasonality in services the optimal result is always to provide those industries with more water, recall that they the data showed that they are using around 1.4% of all water input. For the 29 industries (the ones that use the least water), they have been employing an increasing proportion of the work force and also producing higher values of output.

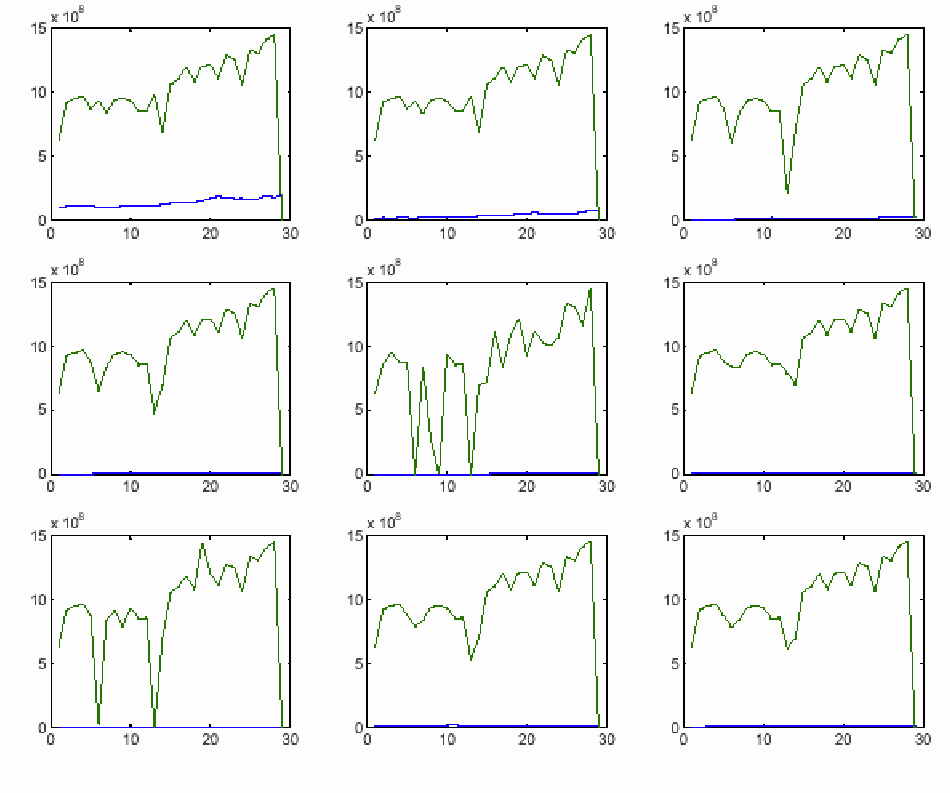

Figure 3 A Sample of Water Use in Non Major Water-Consuming Sectors

In the previous model, we considered only the redistribution of water across sectors in a single period; however, other *voluntary* mechanisms exist to transfer water rights between periods. Such mechanism function might be to adopt a *water banking system* (with similar properties to a financial bank save for the interest rates aspect) and they have been promoted by water users associations (WUA) at the district or regional levels for the agricultural sector, and they are referred to by "water banks" by some authors. Water banks function as follows: firms in all kinds of activities, when not possible or not preferable for them to buy/sell water quantities in a given period might prefer to find a water user who is willing to use/give water in the current period. Such mechanism should be promoted because under some legislation water rights transfers are not allowed, and water rights are attributed on a use-it-or-loose-it basis, providing incentives for firms to use all their water quota even inefficiently to avoid a revision of the quota level in future periods.

Using the same notation as before, the optimal transfer for a given industry is given by the following program for each industry (here we are dealing with industries: we assume that it is the aggregation of firms' behaviors, not necessarily a cooperative behavior. Basically, we focus on the resulting behavior of the industry and not the micro behaviors):

$$\max_{\{q_{i,t}\}_{t=1}^{T}} \sum_{t=1}^{T} \theta^{t-1} \left(f_i \left(w_{i,t} + q_{i,t} \right) \right) \quad \forall i \tag{11}$$

$$\text{s.t.} \quad 0 \le q_{i,t} + w_{i,t} \quad \forall i \tag{12}$$

In the above program, obviously no restriction on the sign of the lent/borrowed water, $q_{i,t}$ is imposed, since it has a positive sign for borrowing and a negative sign for lending. In the case where $q_{i,t} < 0$, then the volume of water lent cannot exceed the available amount quota for that period. Also, no concerns are to be considered about changes in the value of output from changes in price since we are using constant prices (base year 1992). In the above program the discount rate is $\theta = 1/(1+r)$, where r is the long-term interest rate to account for the future value of output; we assume that $r = 15\%$. In a voluntary mechanism, all firm have to solve the program (11)-(12); however, since water is physically limited, then an additional condition (similar to the market clearing condition) has to be imposed so that at each period only available water is traded between industries (every periods markets are cleared):

$$\sum_{i=1}^{n} q_{i,t} = 0 \quad \forall t \tag{13}$$

Using the second welfare theorem (in our context: A Pareto optimal allocation can be decentralized into a competitive equilibrium provided that $f_i(.)$ is quasi-concave[2]), then the problem (11)-(12) for each industry and (13) is transformed into the Pareto allocation problem:

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[2] Recall that for some industries we have increasing returns, this violates the quasi-concavity, but very slightly since their returns to scale are almost constant (homogeneity barely greater than 1).

$$\max_{\{q_{i,t}\}_{t=1}^{T}} \sum_{i=1}^{n} \sum_{t=1}^{T} \theta^{t-1} \left(f_i \left(w_{i,t} + q_{i,t} \right) \right) \quad \forall i \tag{14}$$

$$\text{s.t.} \ \sum_{i=1}^{n} q_{i,t} = 0 \quad \forall t \ \text{ and} \tag{15}$$

$$0 \le q_{i,t} + w_{i,t} \quad \forall i \tag{16}$$

Figures 4 through 5 show the results of the above program for the large water using sectors and a selection of other sectors.

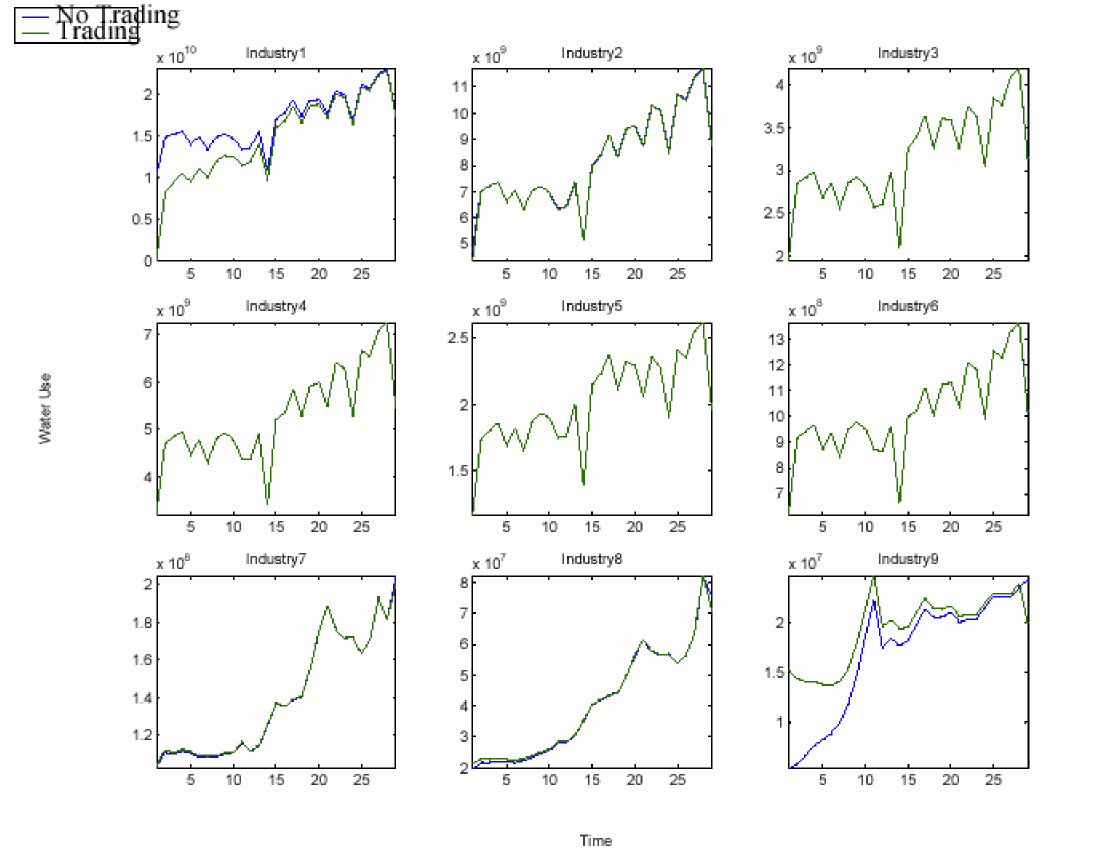

Figure 4 Water Allocation Under Trading and Non Trading Regimes: Sector 1-9

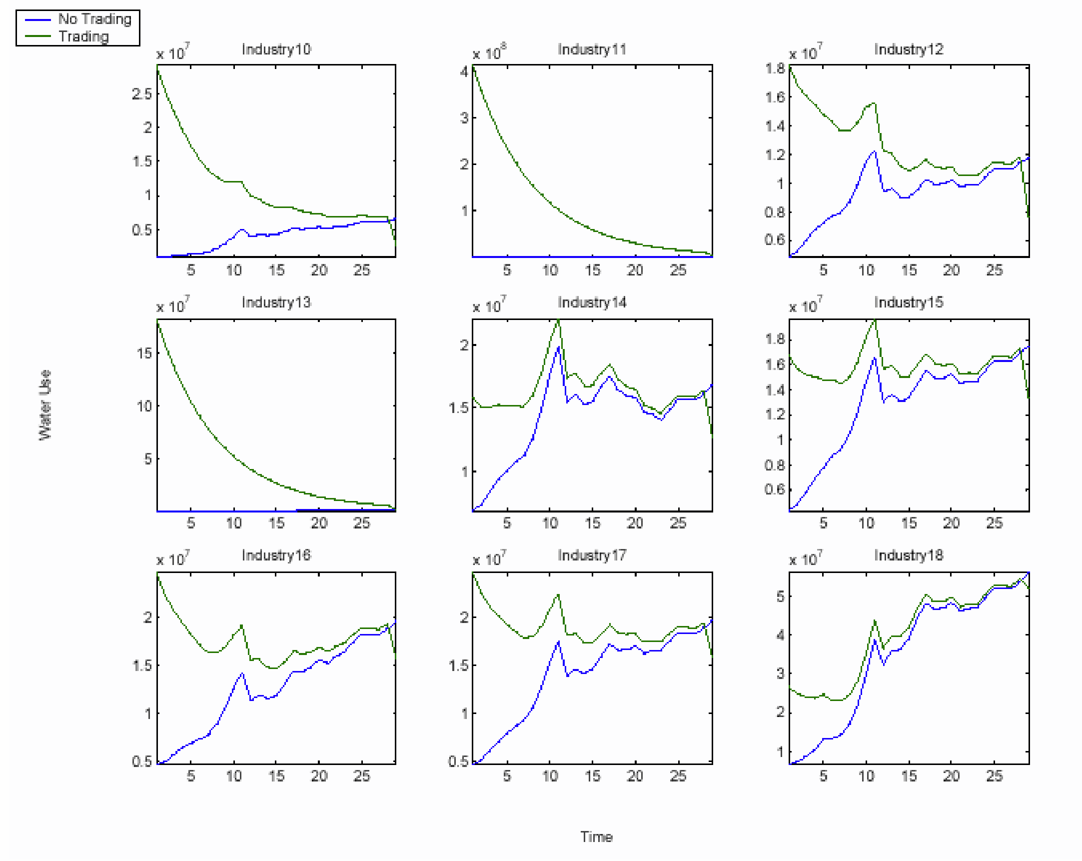

Figure 5 Water Allocation Under Trading and Non Trading Regimes: Sector 10-18

The main findings from this analysis may be summarized as follows. The first industry (that, on average, consumes up to 45% of water) finds it optimal to reduce its consumption of water to the profit of other industries that receive very low quantities of water (industry and service, starting from industry 9). Industries 2 through 6 do not find it beneficial to trade water (under the current model). Notice that at the end of the period, the results of the model seem to match the observed water use. This is has to do with the forward-looking feature of the model and, using any discount rate, the future is less important that the present over a long period of time.

In this model, we assume that the decision is made in 1970 for the future, and thus assumes perfect knowledge about all future water availabilities. A better way to solve this model would be to use recursive techniques (Bellman's equation), where at each period the decision-maker re-evaluates prior decisions, such as whether he decided optimally in the previous period, and by solving this model recursively, the results reflect a more reasonable approach to water allocation decision-making. However, applying those methods is demanding and requires far more data.

Integration with the Northeast Brazil Macroeconomic Model

In this section, the major focus was to link some of the formulations described in the previous section with the econometric-input-output model for the Northeast Brazil economy. Once again, yearly data for the period 1970-1998 were used together with input-output coefficients for 35 sectors for 1992.[3] The analysis used employment data $\left(L_{i,t}\right)$, water use $\left(w_{i,t}\right)$, and value of production $\left(X_{i,t}\right)$ in 1992 prices. With $P_{i,92}$ the price in industry i base 1992, and A_i a technology coeffecient, then using the historical data, we can estimate at 90% confidence interval the parameters of the following model for each industry separately.

$$X_{i,t} = P_{i,92} A_i w_{i,t}^{\alpha} L_{i,t}^{\beta} \tag{17}$$

The above model is linearized using the log(.) operator to become:

$$\log\left(X_{i,t}\right) = \beta_1 + \beta_2 \log\left(w_{i,t}\right) + \beta_3 \log\left(L_{i,t}\right) + \eta_{i,t} \tag{18}$$

The algorithm used for regression (18) seeks values for $\beta_1, \beta_{2,}$ and β_3 without sign restrictions; the elasticity of the value of production to water inputs is for most industries $\beta_2 \approx 1$. With $\gamma = -\beta$, equation (17) can be rewritten as:

$$\begin{aligned} X_{i,t} &= P_{i,92} A w_{i,t}^{\alpha-\gamma} \frac{w_{i,t}^{\gamma}}{L_{i,t}^{\gamma}} \\ &= P_{i,92} A w_{i,t}^{\alpha-\gamma} \left(\frac{w_{i,t}}{L_{i,t}}\right)^{\gamma} \end{aligned} \tag{19}$$

From (19), if $\beta > 0$ then (18) is a Cobb-Douglas production function with *water* and *labor* as inputs, but if $\beta < 0$ then it is a Cobb-Douglas production function with *water* as input, the ratio *water per worker* is of relevance, in either cases the elasticities are given by β_2 and $\beta_{3,}$,

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[3] Recall that the input-output coefficients are endogenously adjusted annually; see Israilevich *et al*., (1997)

The results of the regression in (18) show the existence of increasing returns for some industries. In fact for some industries we have $\beta_2 \approx 1$, with for some industries β_2 slightly greater than one, for details on the values of β_2, and β_3 see figure 6.

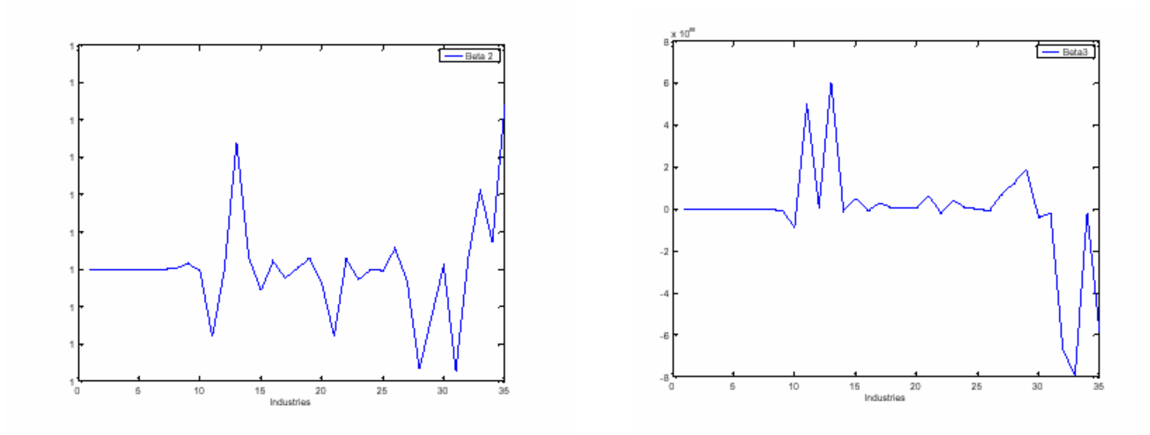


Figure 6 Values of β_2 and β_3 by Industry

The initial integration process is presented in figure 7.

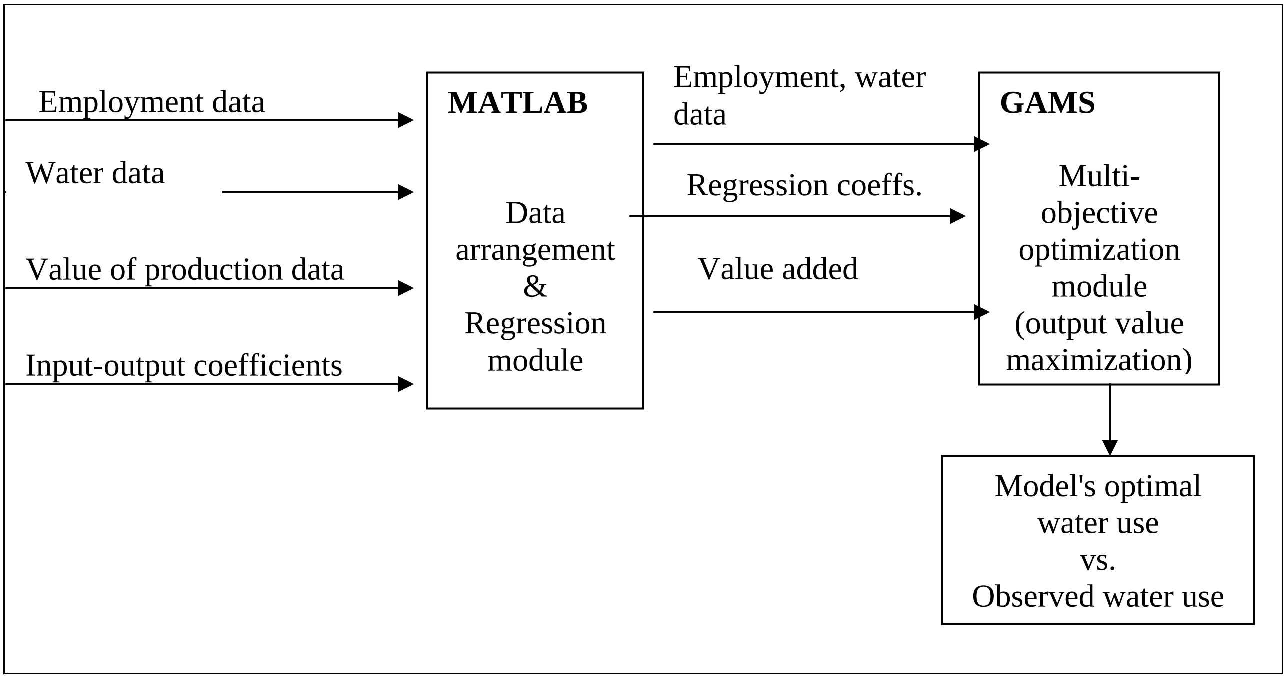


Figure 7 Initial Model Integration

What we obtain is a set of relations linking water use with the output value of each sector, $\hat{X}_{i,t} = f_i(w_{i,t}, L_{i,t}), \forall i,t$. We then determine a new water quota $\hat{w}_{i,t}$ for each period to maximize a convex combination of industries output values.

$$\begin{aligned} &\max_{\hat{w}_{i,t}\ge 0} \sum_i \lambda_{i,t} f_i\left(\hat{w}_{i,t}, L_{i,t}\right) \\ &\text{s.t.} \quad \sum_i \hat{w}_{i,t} \le \sum_i w_{i,t} \end{aligned} \qquad \forall t \tag{20}$$

The program in (20) is a multi-objective maximization program where with $va_{i,t}$ being the value-added, the weight coefficients are $\lambda_{i,t} = va_{i,t} / \sum_i va_{i,t},\ \forall t$ so that greater importance in water rationing is given to industries with higher added-value.

For a better visualization, we will graphically represent the quantity $\hat{w}_{i,t} - w_{i,t}$ for all the industries over time. If $\hat{w}_{i,t} - w_{i,t} > 0$, then the industry needs more water than what has been used historically, and if $\hat{w}_{i,t} - w_{i,t} < 0$, then the industry is using more water than should be efficiently allocated. A sample is provided in figures 8.

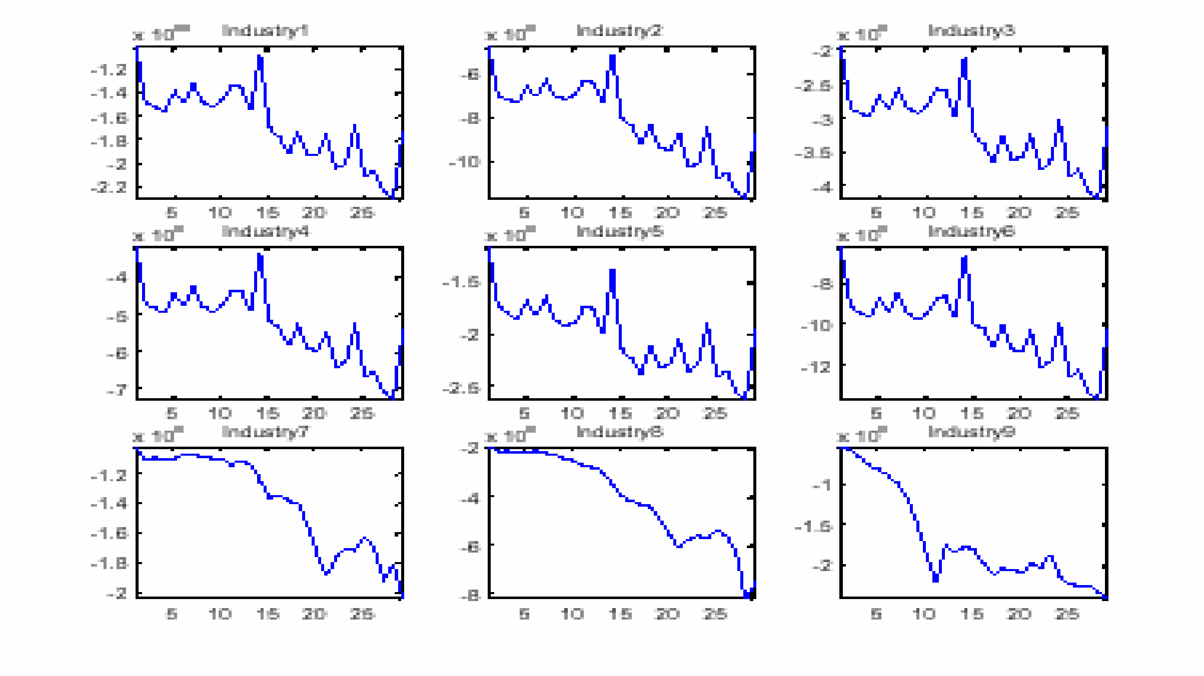


Figure 8 Results for Sectors 1-9

The next step is to provide projections of water use through formal integration with the econometric-input-output model. Using the last available data about water availability and labor in 1998, we seek to solve the below multi-objective problem to find the projected water uses $wp_{i,t}$:

$$\min_{wp_{i,t}\geq 0} \sqrt{\sum_i \frac{1}{\lambda_{i,t}} \left(X_{i,t} - f_i \left(wp_{i,t}, L_{i,98} \right) \right)^2}$$

$$\text{s.t.} \qquad \forall t = 1999,\ldots,2012 \qquad (21)$$

$$\sum_i wp_{i,t} \leq \sum_i w_{i,98}$$

where $X_{i,t}$ are values of output projections for $t = 1999,\ldots2012$ in the water unconstrained model (produced by MERIP-NE 2001).

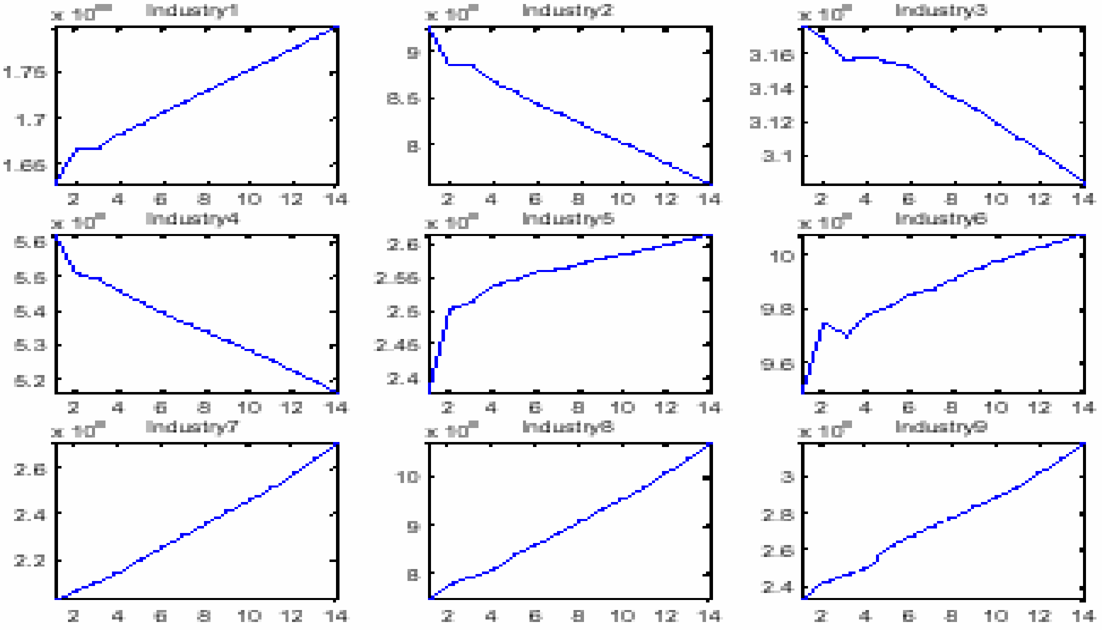


Figure 9 Forecast Results for Sectors 1-9

The optimal quantities for $wp_{i,t}$ are given in figure 9; the optimal use of the available water resources to meet the growth objectives entails a large sacrifice in the first six industries, namely, all the agricultural activities.

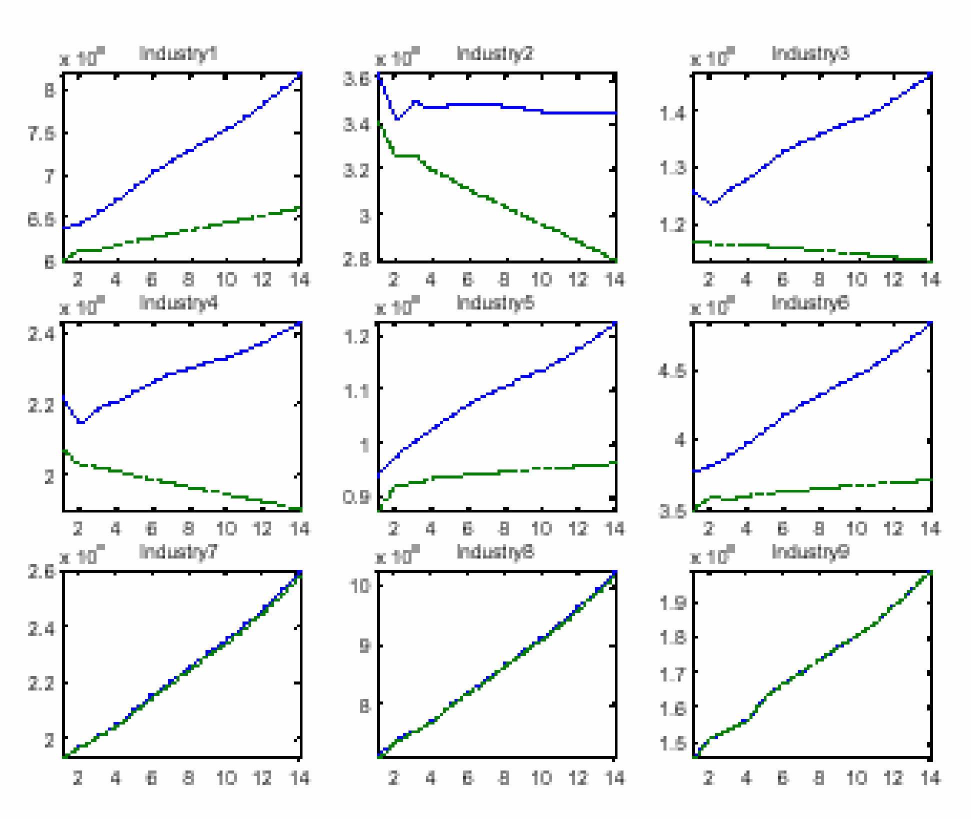


Figure 10 Relationship between Constrained and Unconstrained Water use for Sectors 1-9

Starting from industry sector 9, the projection is perfectly matched; however, this is not the case for the first six industries – the major water-consuming sectors (see figure 10). For industries with discrepancies, the blue curves are the projections of water use without constraints and the green curves depict the consumption under an optimal allocation program derived from equation (21). The process by which the model calculates the re-allocations is shown in figure 11.

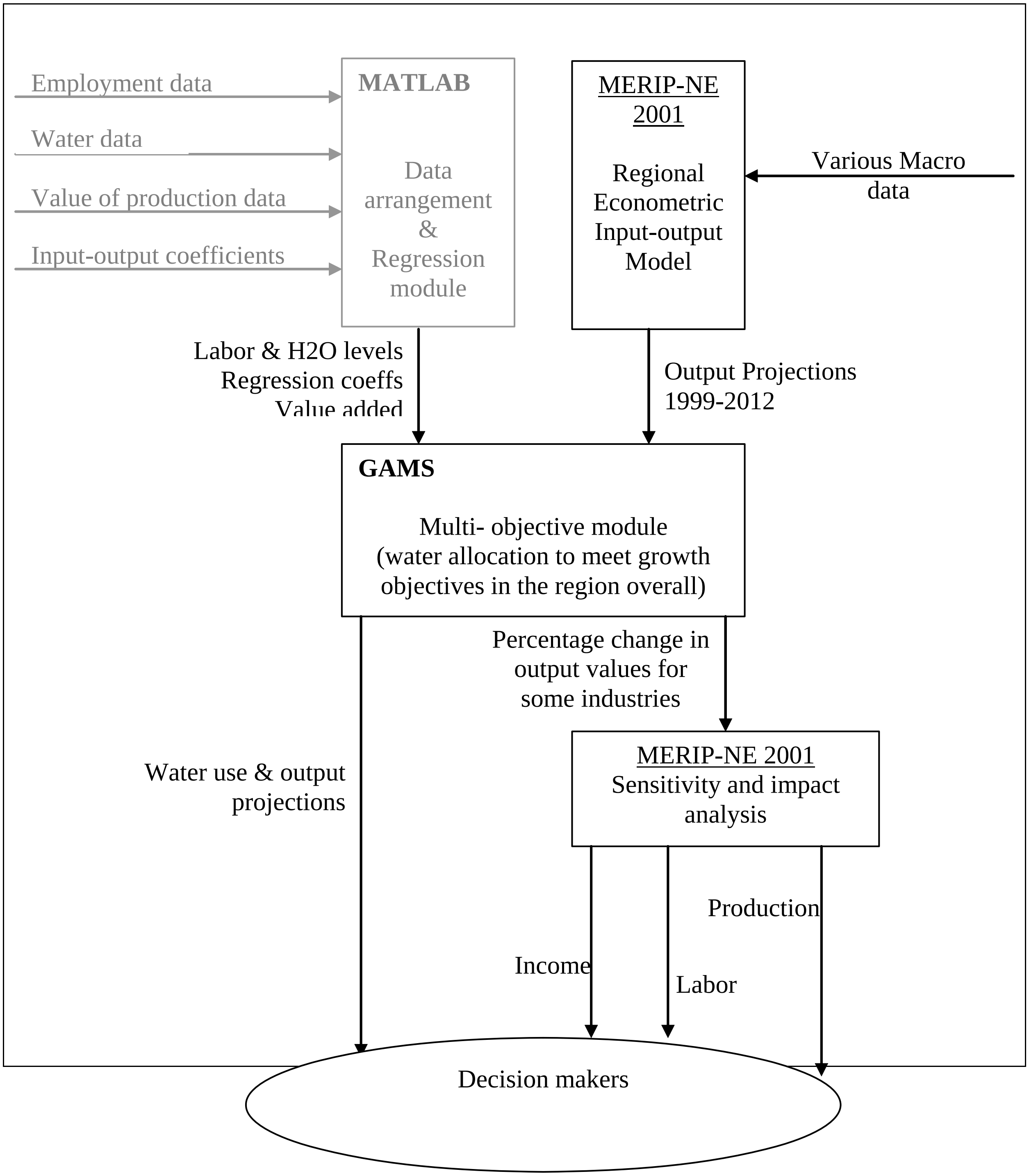


Figure 11 Integration of the Water Allocation Model with the Econometric-Input-Output Model

The percentage of change in the value of output for the two scenarios (constrained and unconstrained) is important only for the agricultural activities and is shown in table 2. For the other industries the targeted projection was met

Table 2: Impact of Water Constraints on Production in Sectors 1-6

Industries	**Percentage of change in output value**
1-CULTURAS INDUSTRIAIS	-12.05%
2-GRÃOS	-12.05%
3-FRUTICULTURA E OLERICULTURA	-14.23%
4-BOVINOCULTURA	-13.77%
5-AVICULTURA E SUINOCULTURA	-13.51%
6-OUTROS PRODUTOS AGROPECUÁRIOS	-14.78%

Table 3 Impact of Water Constraints on the Agricultural Sectors, The Non-Agricultural Sectors and Total Employment

Year	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**
1	-448,470	-444,411	-446,741	-449,152	-451,769	-455,137	-456,225	-456,189
2	-189,631	-172,770	-172,213	-165,871	-161,996	-157,524	-153,404	-148,662
3	-88,883	-86,800	-88,473	-89,508	-90,836	-92,229	-92,989	-93,579
4	-147,984	-148,735	-147,975	-151,426	-151,735	-154,531	-155,272	-156,497
5	-9,863	-10,187	-10,465	-10,698	-10,910	-11,144	-11,304	-11,445
6	-98,519	-99,301	-101,467	-103,794	-106,196	-108,826	-110,763	-112,510
Non-Ag	-220,205	-211,566	-213,035	-212,450	-211,684	-211,848	-210,912	-209,268
Total	-1,203,555	-1,173,771	-1,180,369	-1,182,900	-1,185,127	-1,191,241	-1,190,869	-1,188,149

Year	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**Av. Annual % change**
1	-456,722	-455,990	-457,016	-458,943	-461,292	-463,743	-17.03%
2	-144,124	-139,646	-135,713	-131,952	-128,424	-124,980	-16.07%
3	-94,325	-94,760	-95,595	-96,677	-97,845	-99,052	-19.09%
4	-157,351	-158,179	-159,399	-161,041	-162,779	-164,613	-17.85%
5	-11,608	-11,729	-11,903	-12,111	-12,335	-12,568	-17.96%
6	-114,473	-116,039	-118,120	-120,538	-123,106	-125,762	-19.86%
Non-Ag	-208,106	-206,304	-205,432	-204,880	-204,684	-204,551	-1.13%
Total	-1,186,709	-1,182,648	-1,183,178	-1,186,142	-1,190,465	-1,195,271	-6.39%

Table 3 indicates the losses in employment in these sectors as a result of decreased production caused by lack of water; the final column of this table provides a summary in percentage terms. The focus on employment stems from the important role that the agricultural sectors continue to play in the economy of the Northeast of Brazil. Reductions in production in these sectors reduce employment overall by over 6% on average for the period 1999-2012, representing over 1 million jobs. The losses in the rest of the economy amount to just over 1% on average, generated in large part by the absence of sufficient agricultural products into the food processing sectors and the impacts of losses of wage and salary expenditures on the remaining sectors of the economy.

Integration of water and energy in the system

Once again, yearly data for the period 1970-1998, and 1992 input-output 1992 coefficients for 35 sectors were used. The variables used in the analysis were employment data $\left(L_{i,t}\right)$, water use $\left(w_{i,t}\right)$, energy use $\left(E_{i,t}\right)$ and value of production $\left(X_{i,t}\right)$ in 1992 prices. Attention was directed to industries that have high water consumption over the period 1970-98. The model was re-specified to accommodate energy consumption; with $P_{i,92}$ the price in industry *i* base 1992, and f_i a production function for the whole industry *i*:

$$X_{i,t} = P_{i,92} f_i \left(w_{i,t}, L_{i,t}, E_{i,t}\right) \tag{3.15}$$

We fit the following model:

$$\log\left(X_{i,t}\right) = \beta_1 + \beta_2 \log\left(\frac{w_{i,t}}{L_{i,t}}\right) + \beta_3 \log\left(E_{i,t}\right) + \eta_{i,t} \tag{3.16}$$

Table 4: Results of the regression

	β_1	β_2	β_3
Ind. 1	11.8620	0.3539	0.0487
Ind. 2	12.3770	0.1415	0.1018
Ind. 3	12.6980	-0.0521	0.1446
Ind. 4	9.5425	0.3398	0.1698
Ind. 5	11.8100	0.0016	0.1470
Ind. 6	14.2730	-0.2971	0.0835

The above forms offer more flexibility than a regular Cobb-Douglas production function, depending on the sign of the β it allows for the output of industries to be determined either based on water use, water use per unit of labor, and energy use per unit of labor or to be determined just by water use, labor and energy use. The regression results are shown in table 4 and the elasticities and returns to scale shown in table 5 reveal constant or decreasing returns for all the six industries.

Table 5: Elasticities and returns to scale

	Water	**Labor**	**Energy**	**Returns to Scale**
Ind. 1	1.7113	-1.1694	-0.5419	constant
Ind. 2	1.6048	-0.7762	-0.8286	constant
Ind. 3	1.5141	-1.0670	-0.4471	constant
Ind. 4	1.7113	0.5419	-0.5419	decreasing
Ind. 5	1.4100	0.7979	-2.2079	constant
Ind. 6	0.5200	0.1911	-0.0375	decreasing

For this part the model is run as shown in the figure 21 below:

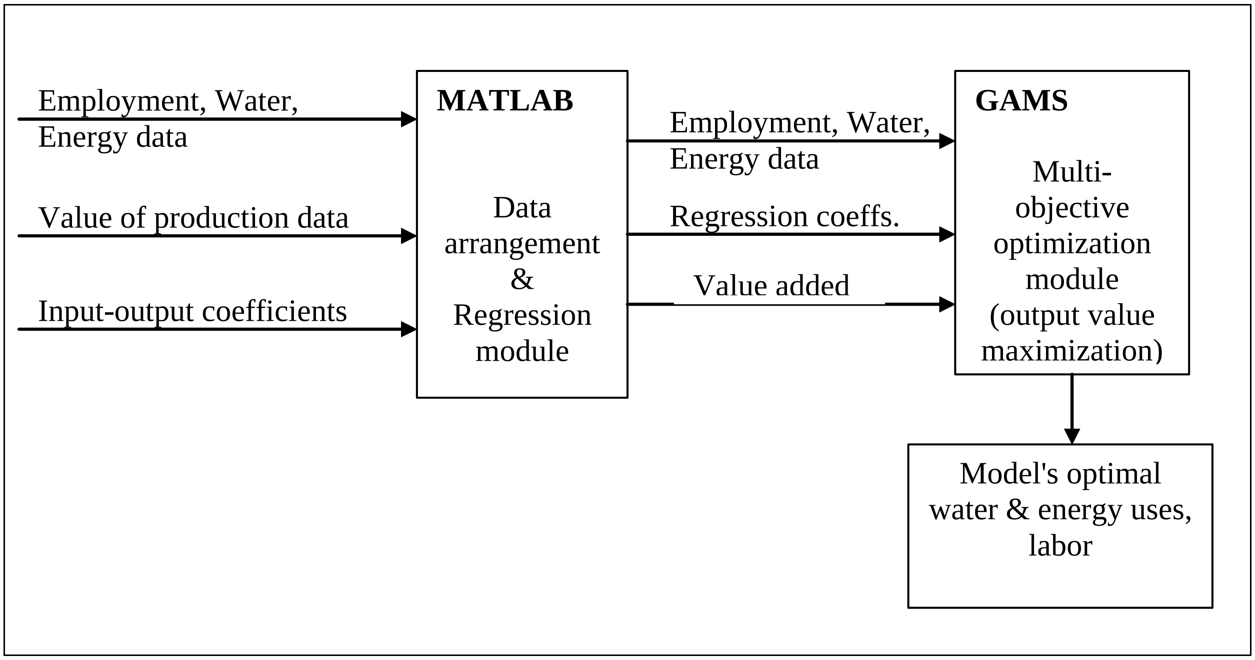


Figure 12: Modeling System Inclusing Energy

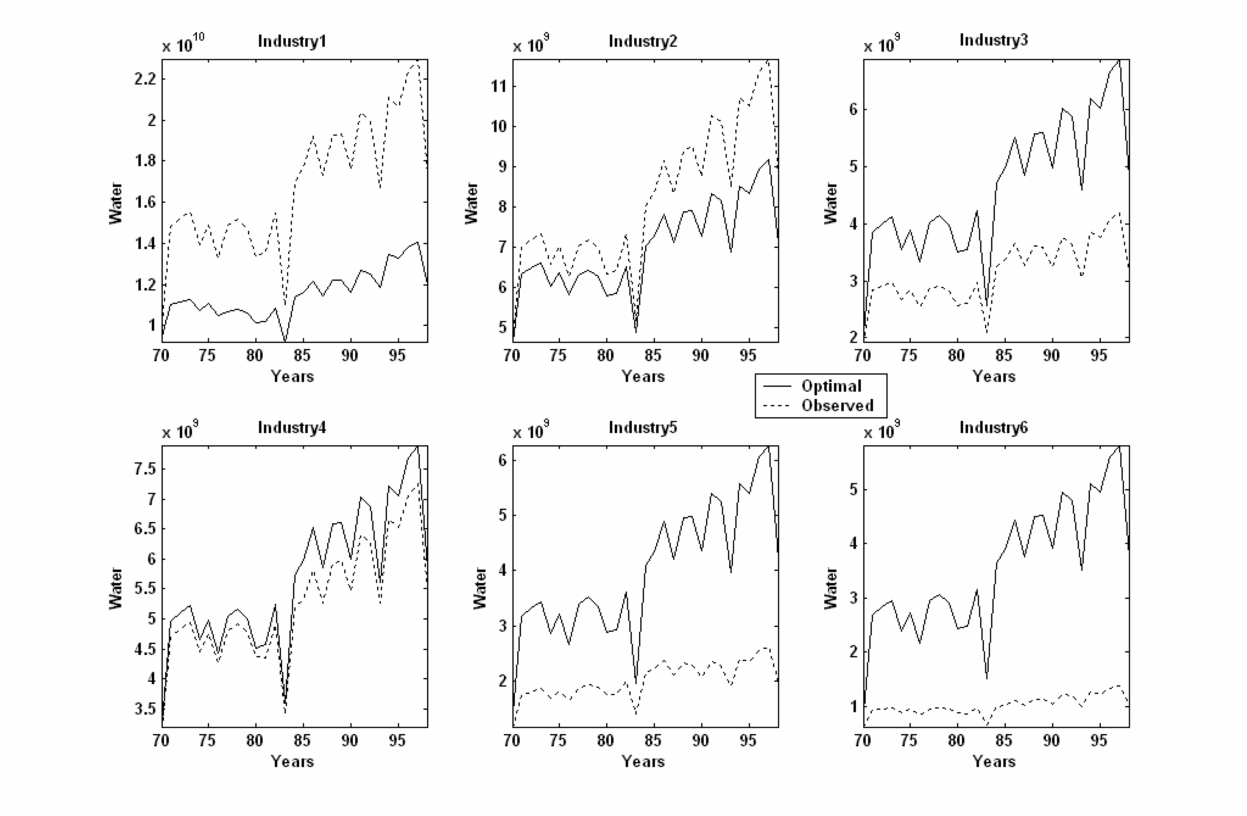
What we obtain from the regression is therefore a set of relations linking water use with the output value of each sector, $\hat{X}_{i,t} = f_i(w_{i,t}, L_{i,t}, E_{i,t}); \forall(i,t)$. We then determine new water quota $\hat{w}_{i,t}$ for each period, such as to maximize the sum of the value-added across the six industries, $\sum_{i=1}^{6} va_i\left(\hat{w}_{it}, \hat{E}_{it}, \hat{L}_{it}\right)$. However, since the following holds:

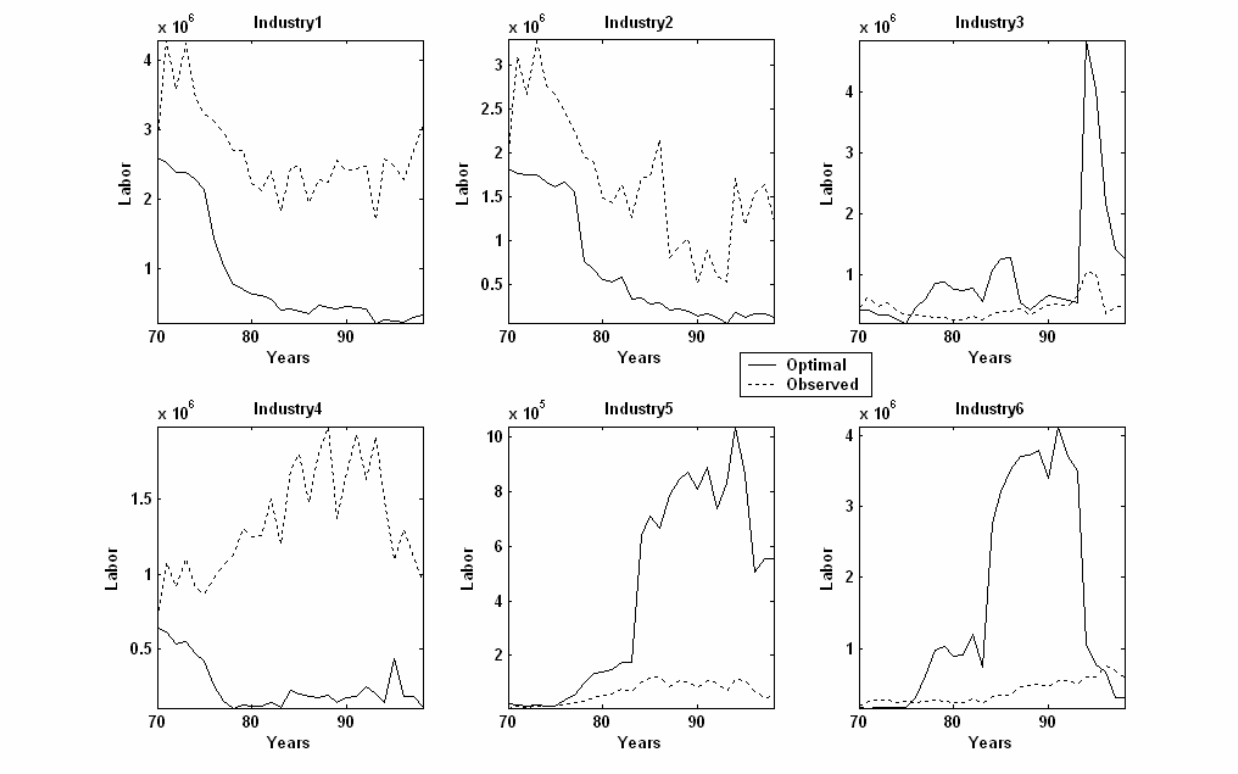
$$
\begin{aligned}
\arg\max \sum_{i=1}^{6} va_i\left(\hat{w}_{it}, \hat{E}_{it}, \hat{L}_{it}\right) &\equiv \arg\max \sum_{i=1}^{6}\left[(1-\sum_k a_{kl}).\hat{X}_{it}\left(\hat{w}_{it}, \hat{E}_{it}, \hat{L}_{it}\right)\right] \\
&\equiv \arg\max \sum_{i=1}^{6}\left[\frac{(1-\sum_k a_{kl})}{\sum_{i=1}^{6} va_{it}}.\hat{X}_{it}\left(\hat{w}_{it}, \hat{E}_{it}, \hat{L}_{it}\right)\right] \\
&\equiv \arg\max \sum_{i=1}^{6} \lambda_i \hat{X}_{it}\left(\hat{w}_{it}, \hat{E}_{it}, \hat{L}_{it}\right)
\end{aligned}
$$

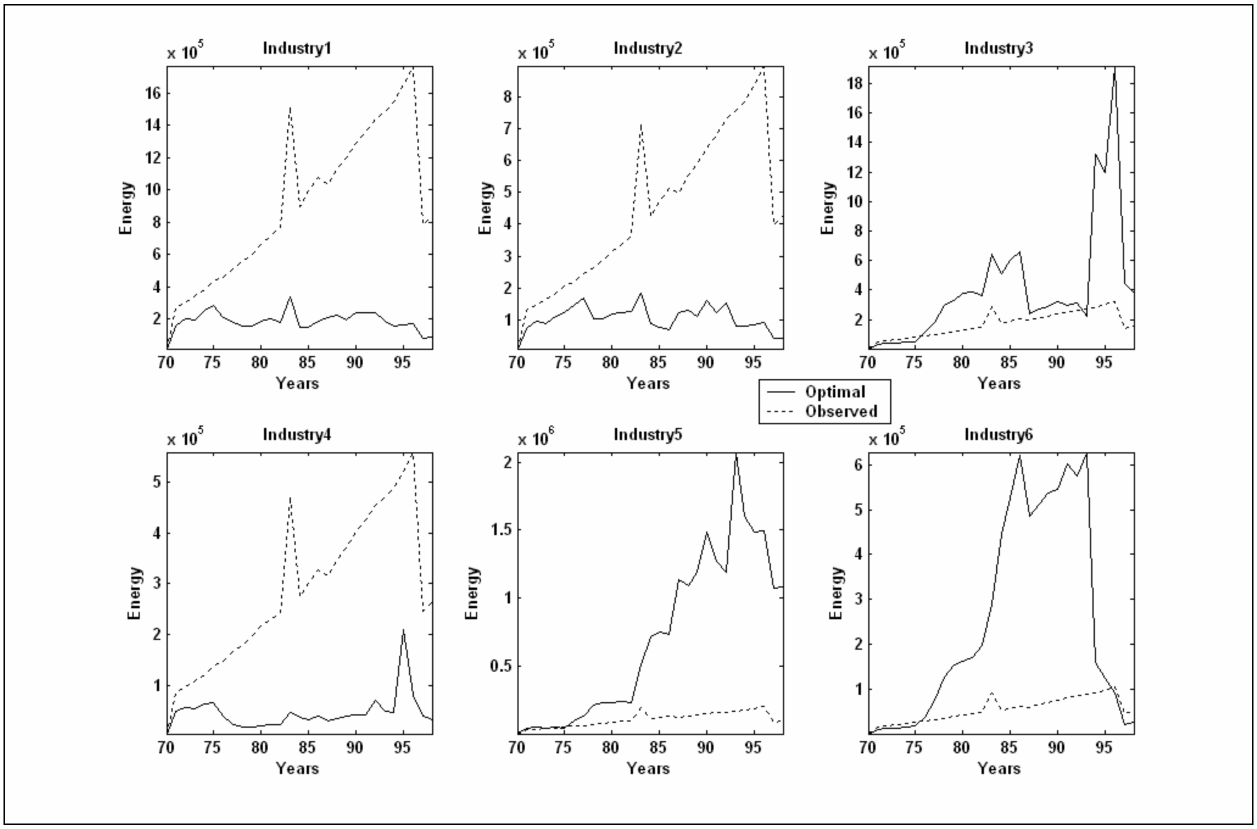
then the problem comes down to maximizing a convex combination of industries output values subject to constraints.

$$
\begin{aligned}
&\max \sum_i \lambda_{i,t} f_i\left(\hat{w}_{i,t}, \hat{L}_{i,t}, \hat{E}_{i,t}\right) \\
&\text{s.t.} \\
&\qquad \sum_i \hat{w}_{i,t} = \sum_i w_{i,t} \\
&\qquad \sum_i \hat{L}_{i,t} \le \sum_i L_{i,t} \qquad\qquad \forall t \\
&\qquad \sum_i \hat{E}_{i,t} \le \sum_i E_{i,t} \\
&\qquad \frac{\hat{E}_{i,t}}{\hat{L}_{i,t}} = \frac{E_{i,t}}{L_{i,t}}; \forall i
\end{aligned}
\tag{22}
$$

The program in (22) is a multi-objective maximization program where with $va_{i,t}$ being the value-added, the weight coefficients are $\lambda_{i,t} = \dfrac{va_{i,t}}{\sum_i va_{i,t}}, \forall t$ so that greater importance in water rationing is given to industries with higher added value. The results are presented graphically in figure 13.


x 10^10
Industry1
x 10^9
Industry2
x 10^9
Industry3
x 10^9
Industry4
x 10^9
Industry5
x 10^9
Industry6
Water
Years
70
75
80
85
90
95
Optimal
Observed


Industry1
x 10^6
Labor
Years
Industry2
x 10^6
Industry3
x 10^6
Optimal
Observed
Industry4
x 10^6
Industry5
x 10^5
Industry6
x 10^6
70
80
90


Industry1
x 10^5
Energy
2 4 6 8 10 12 14 16
70 75 80 85 90 95
Years
Industry2
x 10^5
Energy
1 2 3 4 5 6 7 8
70 75 80 85 90 95
Years
Industry3
x 10^5
Energy
2 4 6 8 10 12 14 16 18
70 75 80 85 90 95
Years
Optimal
Observed
Industry4
x 10^5
Energy
1 2 3 4 5
70 75 80 85 90 95
Years
Industry5
x 10^6
Energy
0.5 1 1.5 2
70 75 80 85 90 95
Years
Industry6
x 10^5
Energy
1 2 3 4 5 6
70 75 80 85 90 95
Years

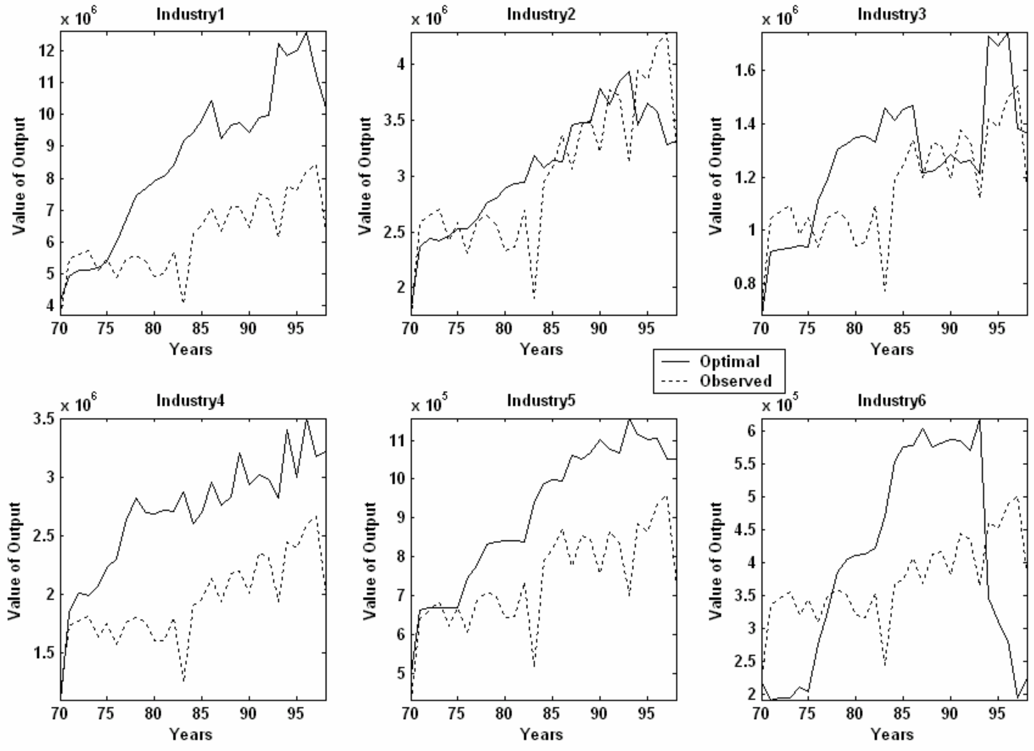


Figure 13: Observed and Optimal Outputs for Extended System using Water and Energy

Projections were made under different the assumption that there was complete *certainty* about the future (figure 13). Using output values projection for the period 1999-2012, we derive coefficients similar to $\lambda_{i,t} = \frac{va_{i,t}}{\sum_i va_{i,t}}, \forall t$. Using Labor projections by industries for 1999-2012, a water constraint limited to the most frequent historic value, and then using the last available data about water availability, labor and energy in 1996 (we use the 1996 value because it is on the growth trend of the energy use), we seek to solve the below multi-objective problem to find the projected water uses $wp_{i,t}$:

$$
\begin{aligned}
&\min_{\substack{wp_{i,t}\ge 0\\ Ep_{i,t}\ge 0}} \sqrt{\sum_i \lambda_{i,t}\left(X_{i,t} - f_i\left(wp_{i,t}, Ep_{i,t}, \hat{L}_{i,t}\right)\right)^2} \\
&\text{s.t.} \qquad\qquad\qquad\qquad\qquad \forall t = 1999,\ldots,2012 \qquad\qquad (3.17)\\
&\qquad \sum_i wp_{i,t} = \overline{W} \\
&\qquad \sum_i Ep_{i,t} \le \sum_i E_{i,96}
\end{aligned}
$$

$X_{i,t}$ are values of output projections for $t = 1999, \ldots 2012$ in the water unconstrained model (produced by MERIP-NE 2001). The optimal use of the available water resources to meet the growth objectives entails a large sacrifice in most of the agricultural industries.

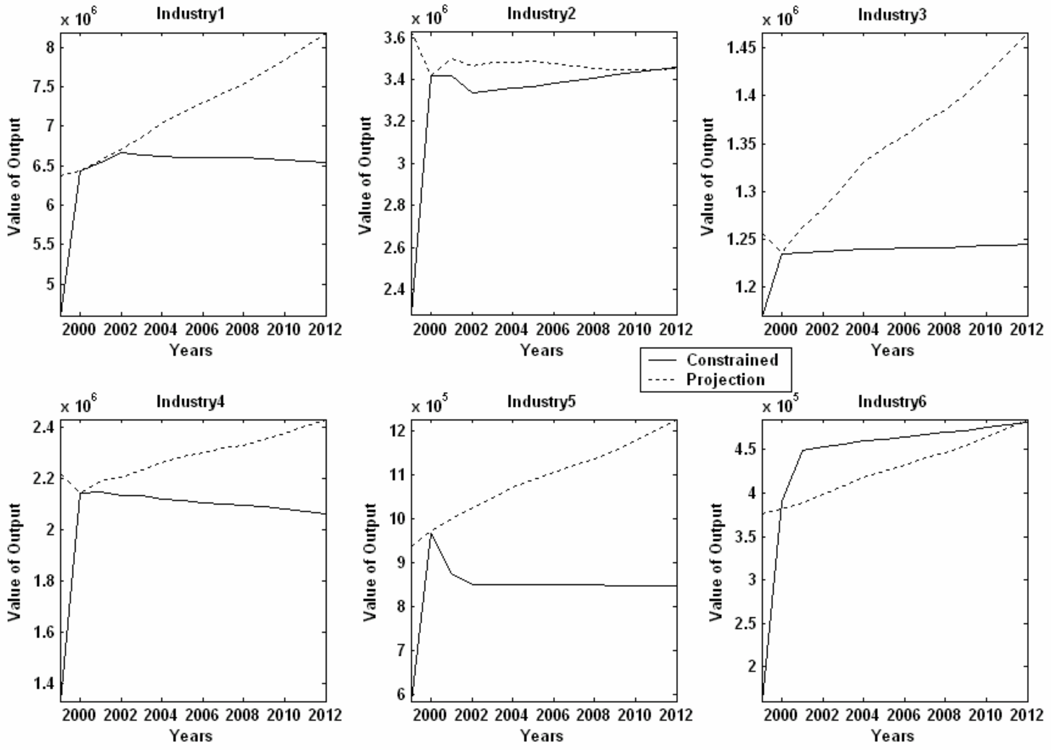


Figure 23: Projections Under Complete Certainty

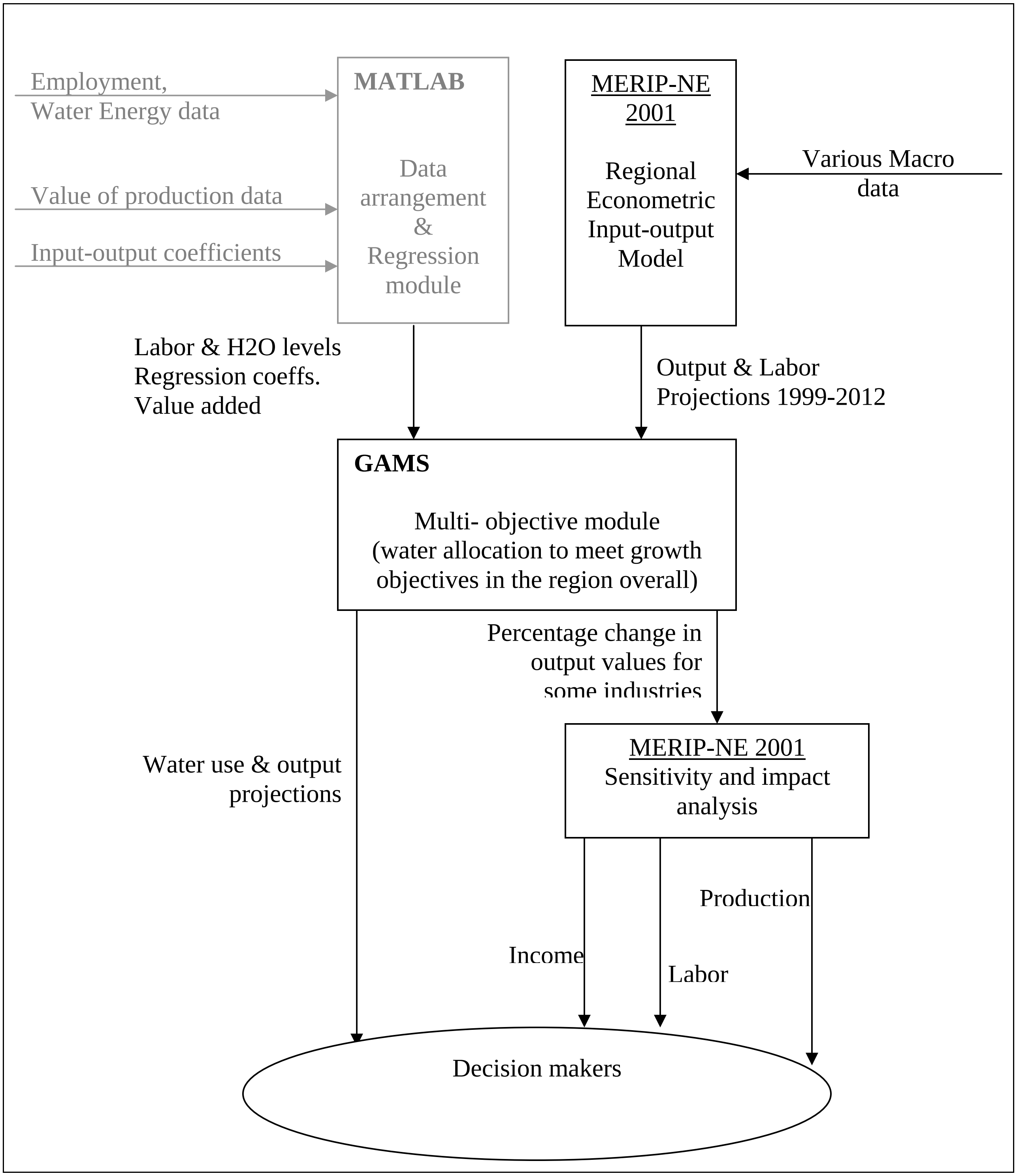


Figure 23: Schematic Model Linkage

The percentage of change in the value of output, is important only for the agricultural activities and it is given in table 6; for the other industries the targeted projection was met.

Table 6: Changes in Output Values under Water and Energy Constrained Case

Industries	**Percentage of change in output value**
1-CULTURAS INDUSTRIAIS	-10.57%
2-GRÃOS	-4.38%
3-FRUTICULTURA E OLERICULTURA	-8.14%
4-BOVINOCULTURA	-10.3%
5-AVICULTURA E SUINOCULTURA	-22.60%
6-OUTROS PRODUTOS AGROPECUÁRIOS	2.12%

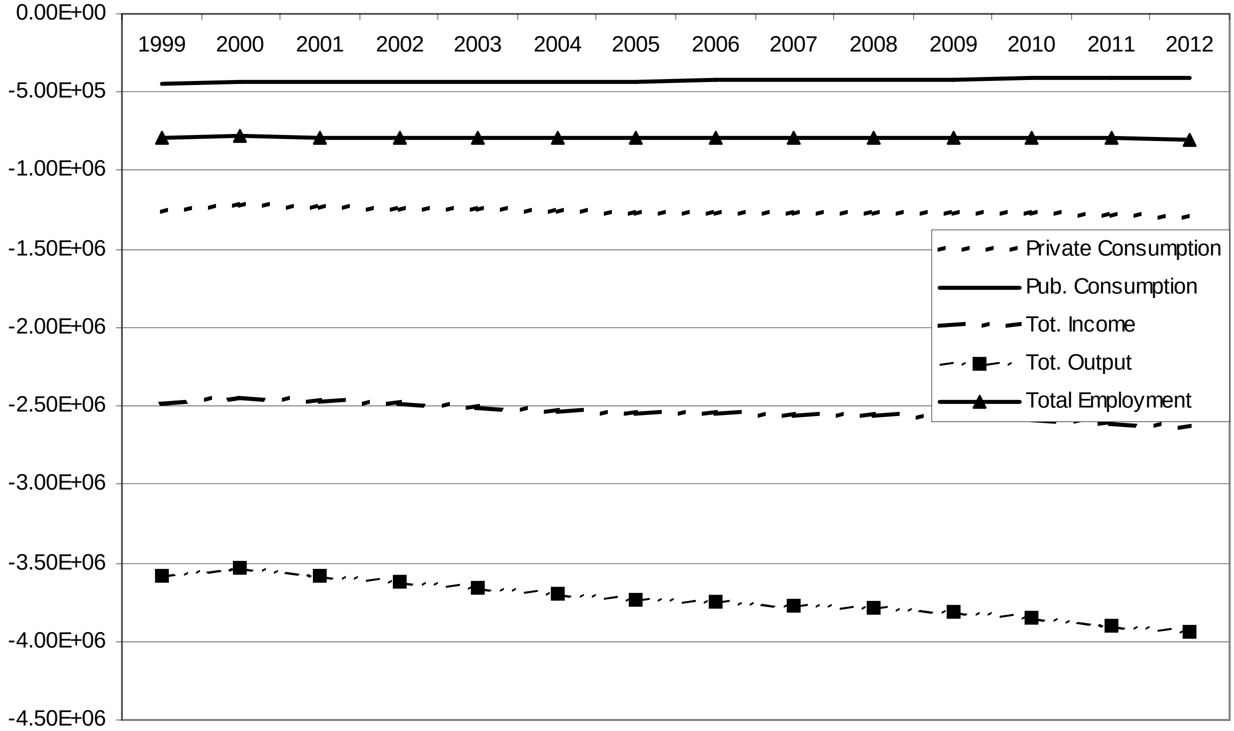


Figure 24: Summary of Impacts on Selected Macro Economic Variables

If we apply those shocks to the NE economy we observe the following summary of the impacts shown in figure 24. There would be a reduction of about 1.25millions R$ in private consumption and R$420,000 in public consumption. Income would decrease by R$ 2.5 million while production would fall R$ 3.5 million. This would translate into a loss of about 780,000 jobs,with the major losses affecting the following sectors: Agro. Products, Grains, Fruits-Olive oil, Bovine, Commerce, Public Administration, & Other Services.

4. Evaluation

These initial results suggest the need for an active link between policy making and economic development when resource constraints are present. Some balance has to be provided between allocation and reallocation on the one hand perhaps driven by concerns with economic efficiency against anticipated losses of employment for part of the labor force with few other alternatives.

The longer run trends, as noted in section 3, have been for employment in agriculture to decline in relative terms but not necessarily in absolute terms. The potential loss of jobs presented here represents one end of a spectrum of possible outcomes – in this case, one driven by market efficiency concerns that seek to maximize an economy’s production. Obviously, there would have to be some balance between this position and one that ignores the problem in the hope that “something happens” to solve the dilemma.

Hence, there is a clear need for the development of some decision-making module that can be linked with systems such as this one to provide assessments of alternative policies on a range of characteristics, such as employment, export activity, enhancing the region’s competitiveness and so forth.

5. Future Developments

The analysis performed here provides only a limited yet vitally important perspective on the integration of water and economic development. In this section, some additional developments will be presented.

5.1 Link energy and water

To what degree is water use for energy and water use elsewhere in the economy complementary or competitive?

5.2 Climate change/water allocation decisions/energy-water conflicts

How do variations in climate affect water supply and year-to-year allocation decisions?

Could the analysis developed between IRI-Columbia University NY and FUNCEME be linked with the model presented in this report?

5.3 Interstate issues – application to a network

How could a representation of water transfers via pipeline be integrated with the model here to explore interstate as well as intersectoral allocation issues?

Could the system be presented with reference to an interregional sectoral flows matrix?

5.4 Pricing

How could pricing systems be introduced into the model to explore market-driven solutions to allocation?

5.5 Micro markets

Could recent work in micro water markets be linked with this macro analysis to explore trade-offs and decision-making at two or more levels in space

5.6 Development of Policy Interface

Could software be developed to provide an interface between policy making alternative development strategies and their economic impacts?

Many of these developments could be conducted simultaneously; each would provide significant value-added to the initial model that has been developed and provide a basis for informed decision-making in the region over the next two decades.

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