Impacts of Reallocation of Resource Constraints on the Northeast Economy of Brazil

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Abstract

There is a growing recognition in the economic development literature that one of the major impediments to growth and development in the next 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-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 results revealed that water re-allocation played only an important role directly on the agricultural sectors, the major consumers of water in the Northeast of Brazil. Re-allocation was driven by an objective to maximize value added. Over the period 1999-2012, the impact on the six agricultural sectors was to reduce their output and employment by of 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% on average, over 1 million jobs annually.

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.

Key Words: Brazil, water, input-output, stochastic linear programming.

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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 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-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 report 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. Section 4 provides a summary evaluation and section 5 indicates some future directions for this research.

2. Background

2.1 Resource Constraints and I-O Models

In this section of the report, 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.

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:

$$\begin{bmatrix} X^c \\ \hdashline X^a \end{bmatrix} = \begin{bmatrix} B_{cc} & \vdots & B_{ca} \\ \hdashline B_{ac} & \vdots & B_{aa} \end{bmatrix} \begin{bmatrix} f^c \\ \hdashline f^a \end{bmatrix} \tag{2.1}$$

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:

$$R = WX \tag{2.2}$$

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):

$$R = \left[W^c \; \vdots \; W^a \right] \begin{bmatrix} B_{cc} & \vdots & B_{ca} \\ \hdashline B_{ac} & \vdots & B_{aa} \end{bmatrix} \begin{bmatrix} f^c \\ \hdashline f^a \end{bmatrix} \tag{2.3}$$

or in more compact form:

$$R = WBf \tag{2.4}$$

Subsequently, they developed unweighted water multipliers:

$$\bar{M} = \bar{W}^{-1} V^{*/} = \left[\bar{M}^c \; \vdots \; \bar{M}^a \right] \tag{2.5}$$

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:

$$\bar{\bar{M}} = \begin{bmatrix} \Delta f^c & \vdots & 0 \\ \hdashline 0 & \vdots & \Delta f^a \end{bmatrix} \begin{bmatrix} V^c \\ \hdashline V^a \end{bmatrix} \tag{2.6}$$

where V^c, V^a are the partition of 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 sector 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.

The challenges in the present time period focus on multiple objectives and the need to explore alternative time phasing of programs. These are challenges that cannot easily be accomplished with an input-output system alone. In the next section, a review of some water allocation models will be provided prior to the presentation of the model used in this study in section 3.

2.2 New Developments in Water Resources Allocation Models

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. In general, the available methods can be classified as follows:

1. Linear Programming (LP), including chance-constrained LP, stochastic LP, and stochastic programming with recourse.

2. Dynamic programming (DP), including incremental DP (IDP), discrete differential DP (DDDP), incremental DP and successive approximations (IDPSA), stochastic DP, reliability-constrained DP, differential DP (DDP), and the progressive optimality algorithm.

3. Nonlinear Programming.

4. Simulation.

Combinations of several of the above methods have also been reported in the literature.

Stochastic linear programming has been one of the widely used techniques in water resources management. In the deterministic mode, i.e., stream flows and precipitation are taken to be equal to the mean seasonal inflows or from the historical critical period. However, virtually all of the hydrologic model parameters are uncertain; when important variables are uncertain, a comprehensive analysis needs to evaluate both expected performance of the system for random events and the magnitude of loss for system failure (Yeh, 1985). Although the uncertainties of some parameters may be taken into account through a sensitivity analysis, the procedure does not explicitly consider these uncertainties and may not lead to satisfactory results.

2.2.1 The Model of Stochastic LP

Stochastic programs are mathematical programs where some of the data incorporated into the objective or constraints are uncertain (see Zafiriou, E., 1991 and Brige and Louveoux ,1997). Uncertainty is usually characterized by a probability distribution on the parameters. The two main ways of handling stochastic programming problems are split into chance constrained models, (Kall and Wallace,1994), and recourse models.

Models with chance or probabilistic constraints are models that produce a solution that ensures a set of constraints will hold with a certain probability. A typical chance constrained stochastic programming problem has the following form:

$$\begin{aligned} &\min_x f(x) \\ &s.t \;\; g_1(x) \le 0 \\ &\qquad \Pr\{g_2(x) \le 0\} \ge a \end{aligned} \tag{2.7}$$

where $Pr\{A\}$ denotes the probability of A occurring and $g_2(x)$ has some parameters that are stochastic. With this formulation, the constraint is not completely binding since violation is allowed with some probability.

Recourse problems find a solution that minimizes the expected costs of the consequences of that solution in the future. Stochastic programming problems that only look into the next "stage", are called two-stage stochastic programming problems with recourse. These problems are written as:

$$\begin{aligned} &\min_x \; f(x) + Q(x) \\ &s.t. \quad g(x) \leq 0 \end{aligned} \tag{2.8}$$

where $Q(x)$ is the recourse function that reflects the future consequences of a decision in the present. The usual form of $Q(x)$ is the following:

$$Q(x) = \sum_i p_i Q_i(x) \tag{2.9}$$

where Q_i is the value of the recourse function using a realization of a discretized distribution of the stochastic parameters. The probability of the realization of the parameters used in Q_i is denoted as p_i. Thus, $Q(x)$ is a sum of the future consequences of a decision, weighted by the probability of the occurrence of the consequence. This method uses a discretized version of the probability description and thus only approximates the uncertainty of the system.

To summarize the theories of stochastic programs, it should be emphasized that the main task in decision making under uncertainty is to derive a deterministic equivalent of the stochastic program . If this step is successful, then a standard optimization solution procedure can be used. If a deterministic equivalent cannot be found because of the enormous size of the practical problem, Monte Carlo simulation in combination with parallel computing techniques appears to be the most viable approach.

2.2.2 Solving Stochastic LP

A number of different algorithmic approaches have been proposed for solving two-stage stochastic LPs of types (A1) and (A2) (see Kall, 1976; Wets, 1974; and Wets, 1983 for an investigation of the recourse problem). In general, the available approaches can be listed as follows:

1. Applying Benders' decomposition using expected-value cuts, representing an outer linearization of the expected second-stage costs or the recourse function, (Van Slyke and Wets, 1969).

2. Using row and column aggregation schemes to approximate a stochastic program, (Birge, 1984).

3. Same as 1 but using multiple cuts, where a different cut with respect to each scenario is computed and the expected-value calculation is carried out in the master problem, (Birge and , Louveaux, 1985).

4. Using classical approximation scheme for solving two-stage stochastic LP with stochastic right-hand sides which is to calculate lower and upper bounds via the inequalities of Jensen, (Frauendorfer, 1988).

5. Using a separable piecewise linear upper bound for the case that evaluation of the recourse function involves the solution of a network problem, (Birge and Wallace, 1988).

6. Using "Progressive Hedging," in which non-anti capacity constraints are enforced via Lagrangian penalty terms in the objective, and in which a two-stage or multi-stage program is solved for each scenario in each iteration, (Rockafellar and Wets, 1989).

7. Employing interior-point linear programming solvers (Lustig et al., 1991)

8. Using Barycentric Approximations, Frauendorfer (1992)

The recent widely used technique to solve two-stage stochastic LP is proposed by Infanger and Dantzig (1994). This approach, that combines Benders decomposition and Monte Carlo importance sampling, is as follows. Using dual (Benders) decomposition, the stochastic LP is decomposed in to a master problem (the first-stage problem) and series of subproblems (the second-stage problems). Each of the subproblems corresponds to a scenario—that is, a certain combination of outcomes of the uncertain parameters in the model. Then, the master problem is solved iteratively to obtain a first-stage trial solution for the problem and a series of subproblems to evaluate that trial solutions, that is, to obtain the expected second-stage costs and their sensitivity with respect to the trial solution. The second-stage is passed to the master problem in the form of Benders cuts, and an updated trial solution is obtained in each Benders iteration. The algorithm terminates when a particular trial solution can be declared optimal. To avoid the enormous size of computation of solving all possible subproblems, Monte Carlo importance sampling is used to estimates the expected future costs and their sensitivity. Using this approach, the large-scale test problem, in the deterministic equivalent formulation with 4.5 billion constraints and variables, has been able to be solved by using a PC.

2.2.3 Implications for the Northeast Brazil Application

Considerable uncertainty exists about the level and location of future investments designed to either manage exiting water resources or to enhance (capacity expansion) the supply of future resources. Further, the region is often subject to periodic droughts, some of which may extend for several years. Hence, some exploration should be made of the possibility of using stochastic programming options, at least for a small set of the constraints. With the wider availability of algorithms to solve such problems, Monte Carlo search procedures can be adopted to add some degree of uncertainty into investment decisions, weather and climate and even factors such as export demand and tourism growth.

3. The NE Brazil Model

The modeling system employed draws on some prior work contracted between the BNB and the University of São Paulo, who in turn cooperated with REAL in the estimation of the system and its transfer to a user-friendly software environment. For this application, the individual state detail was not employed; the resource constraint system was linked with the aggregated (Northeast as a whole) model.

3.1 Major Water-Consuming Sectors

We picked 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:

- Industrial crops 45.5%
- Grains 22.0%
- Fruits 8.5%
- Cattle 14.3%
- Poultry, Hog and Pig 5.5%
- Other agricultural products 2.8%

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. Figures 1, 2, and 3 show respectively the % water use, water use in m3, and volume of output for each of the above industries.

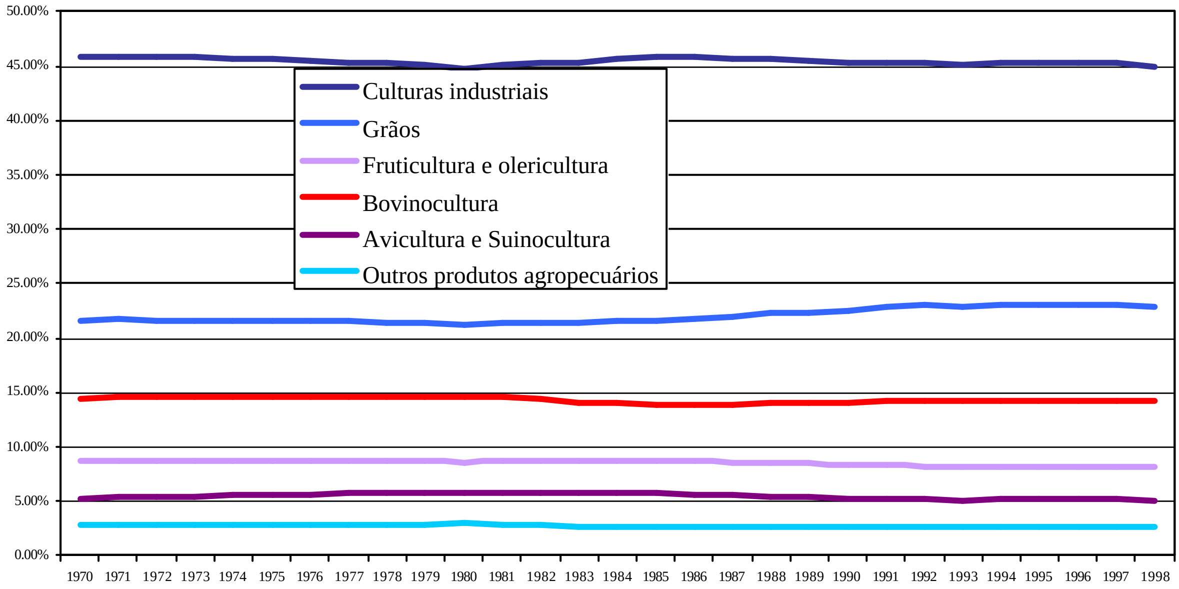

Figure 1 Water use by Industry 1970-1998

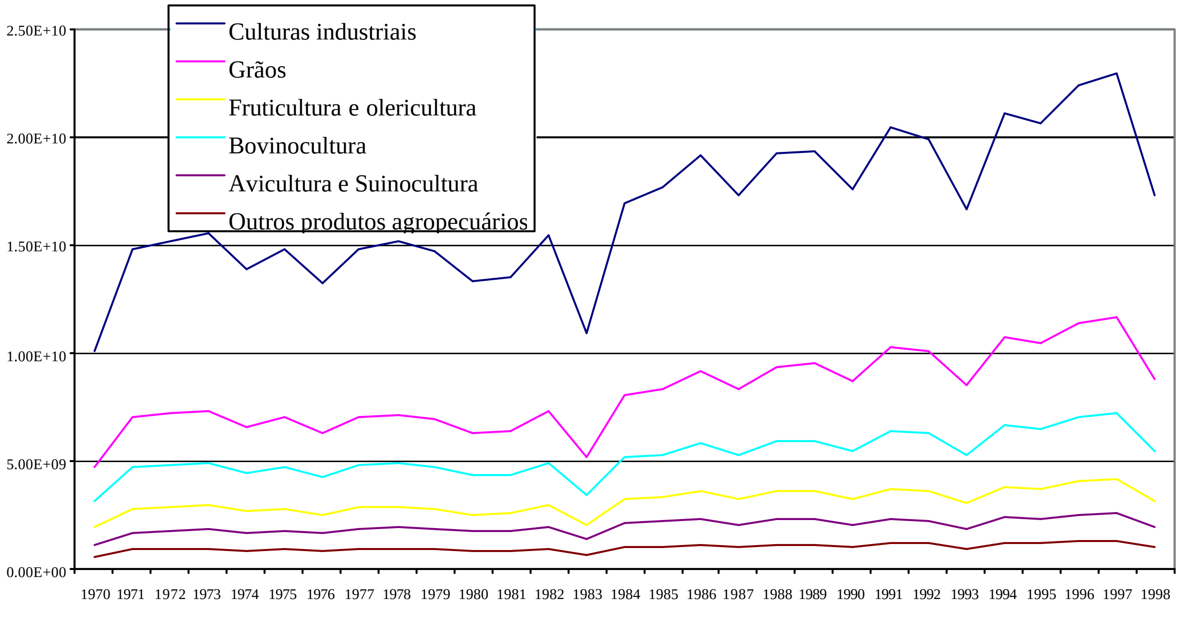

Figure 2 Water use in m^3

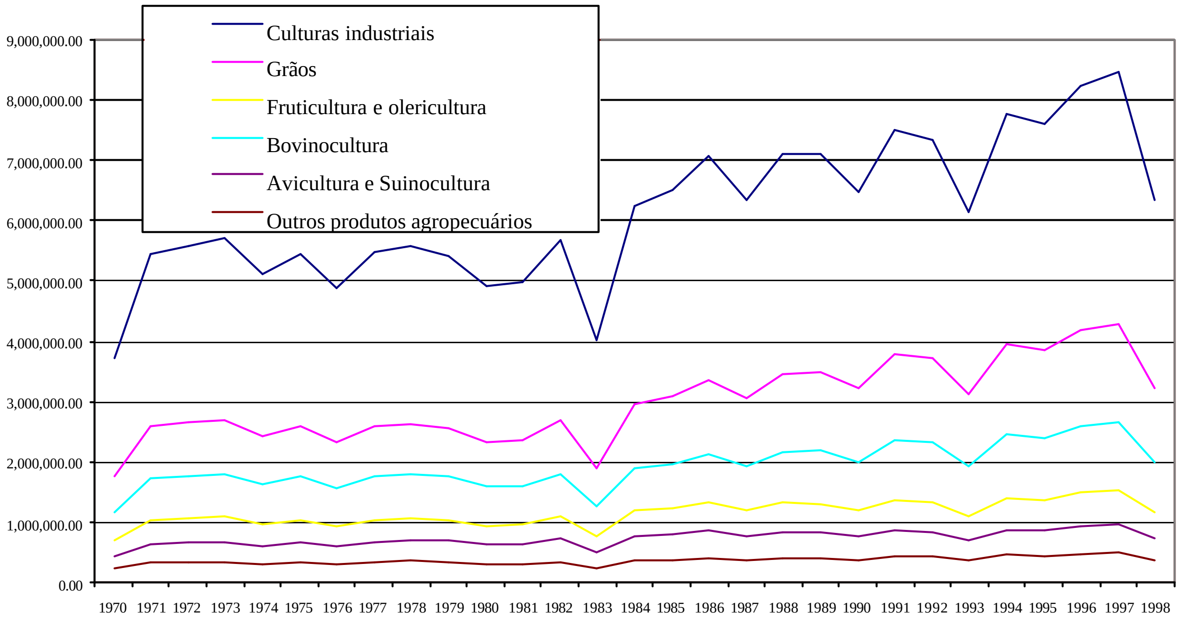

Figure 3 Output by Major Water-Consuming Sectors

Over the period shown in figures 1 through 3, 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. The shares of each sector are shown in figure 4 and figure 5 provides the actual totals.

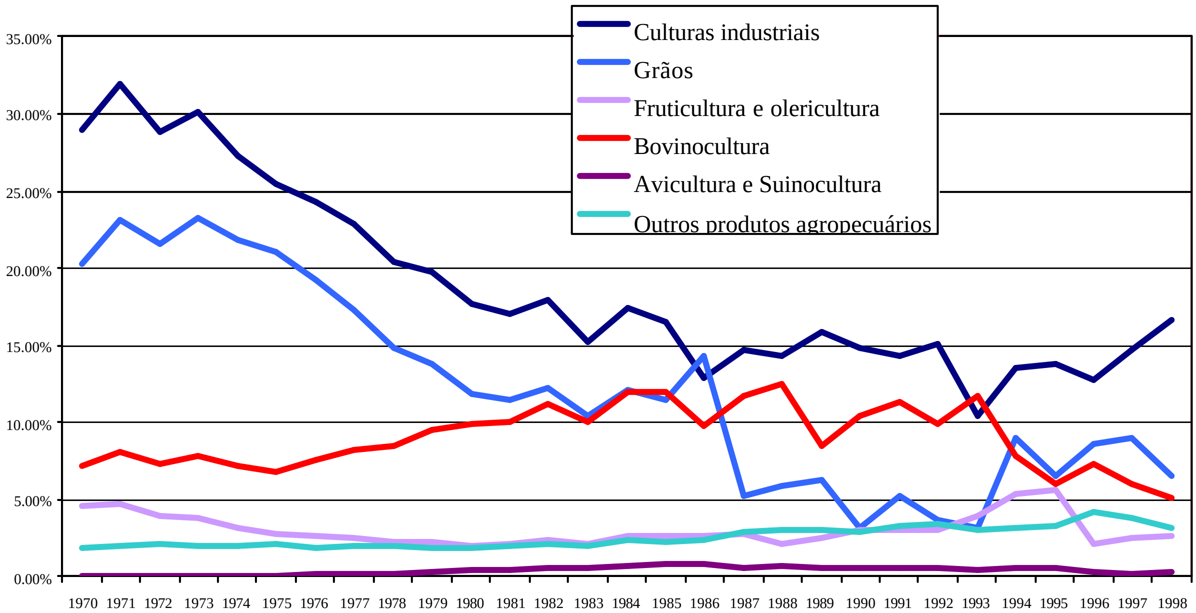

Figure 4 Employment Shares by Industry, 1970-1998

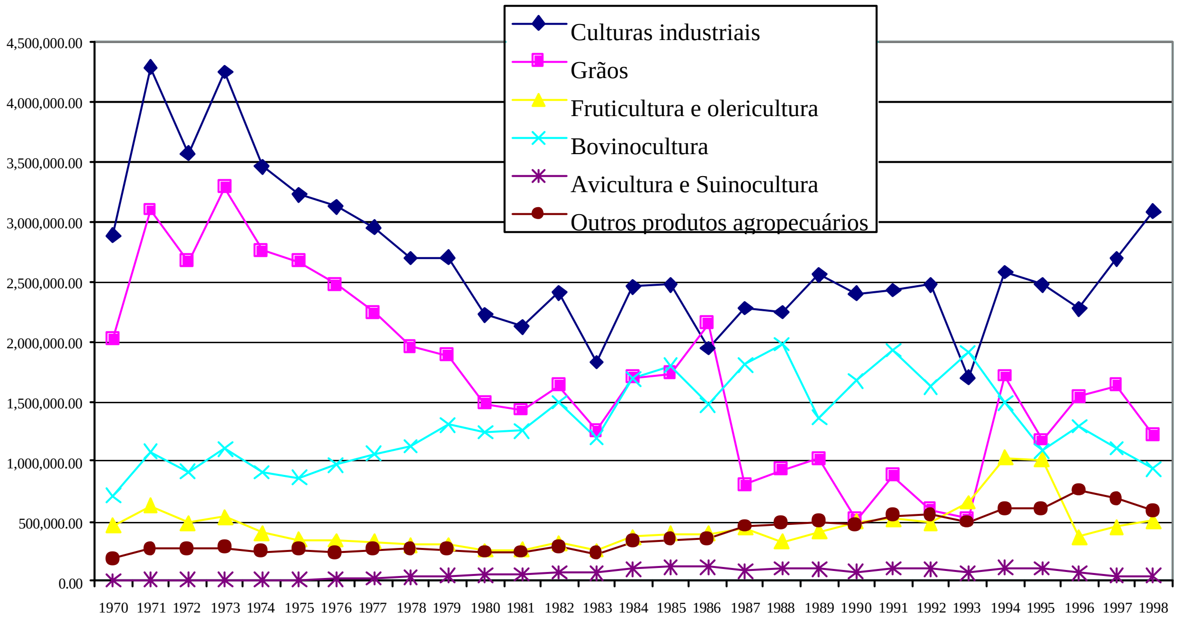

Figure 5 Employment Totals by Industry, 1970-1998

3.2 The Model Specification

3.2.1 Initial Specification

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.

$$X_{i,t} = P_{i,92} A w_{i,t}^{a} \tag{3.1}$$

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

$$\log\left(X_{i,t}\right) = \log\left(P_{i,92} A\right) + a \log\left(w_{i,t}\right) + h_{i,t} \tag{3.2}$$

So the model to estimate using OLS is now:

$$\log\left(X_{i,t}\right) = b_1 + b_2 \log\left(w_{i,t}\right) + h_{i,t} \tag{3.3}$$

The results of the regression show the existence of increasing returns to water inputs for many industries. In fact for some industries we have $b_1 = a \approx 1$, with for some industries b_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 fig 6. (Increasing returns poses convergence problems in the next step by it seems that the results obtained are good enough)

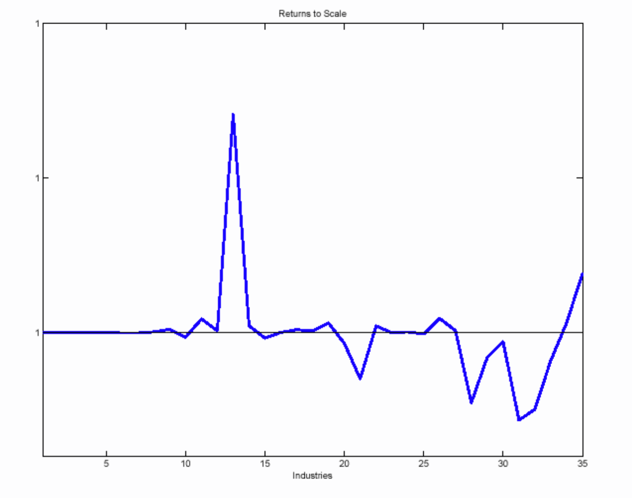

Figure 6 Returns to Scale

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 new water quota for each period, such 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.

$$\begin{aligned} &\min_{\hat{w}_{i,t}\geq 0}\left(\sum_i l_{i,t}\left(X_{i,t} - f_i\left(\hat{w}_{i,t}\right)\right)^k\right)^{1/k} \\ &\text{s.t.} \qquad\qquad \forall t \\ &\qquad \sum_i \hat{w}_{i,t} \leq \sum_i w_{i,t} \end{aligned} \tag{3.4}$$

For our purpose we chose $k = 2$ and the weight coefficient $l_{i,t} = \frac{L_{i,t}}{\sum_i L_{i,t}}, \forall t$, 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.

A comparison of historic water use and optimized water use is given in figure 7, 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 sectors in industry and services are depicted in curves similar to figure 8 , 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), where historically employing increasing proportion of the work force and also producing higher values of output.

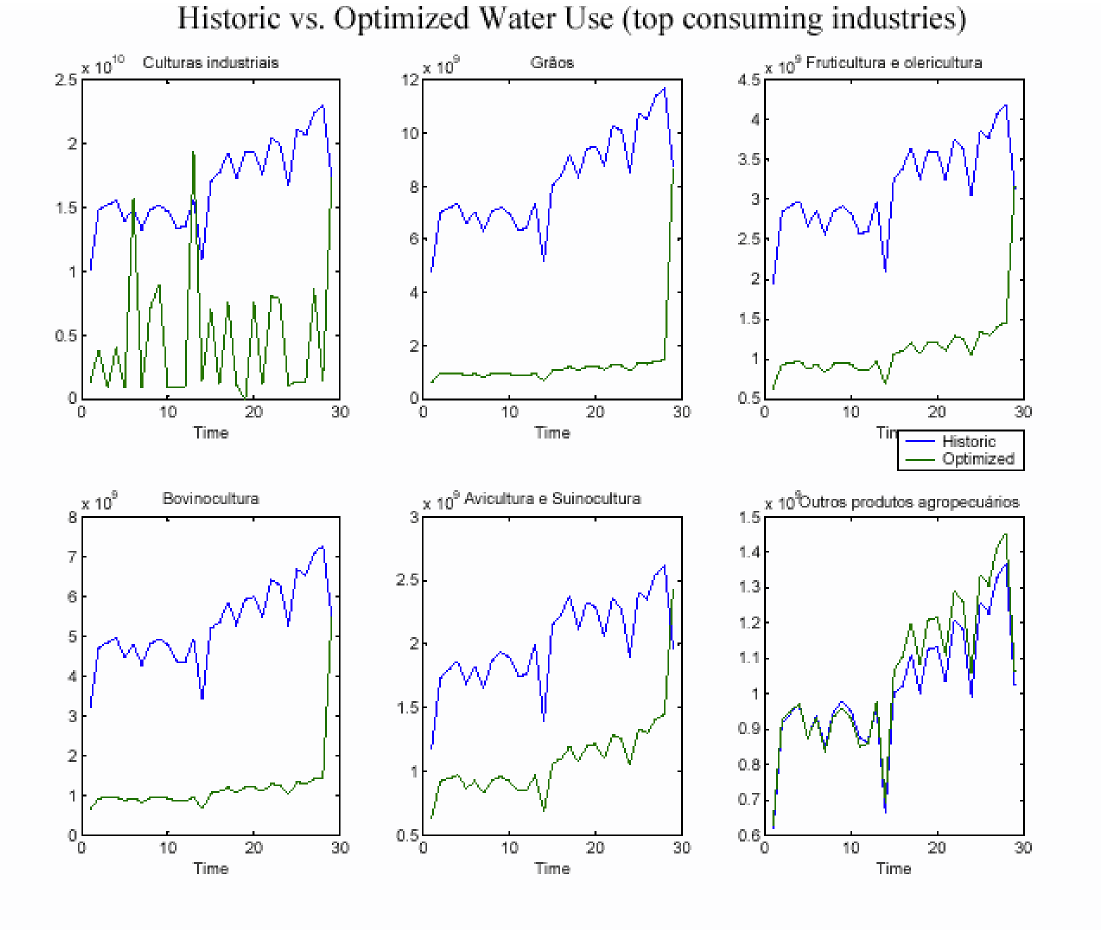

Figure 7 Historical versus Optimized Allocation of Water for Major Water-Consuming Sectors

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 legislations water rights transfer is not allowed, and water rights are attributed on a use-it-or-loose-it basis, which gives incentives for firms to use all their water quota even inefficiently to avoid a revision of the quota level in future periods.

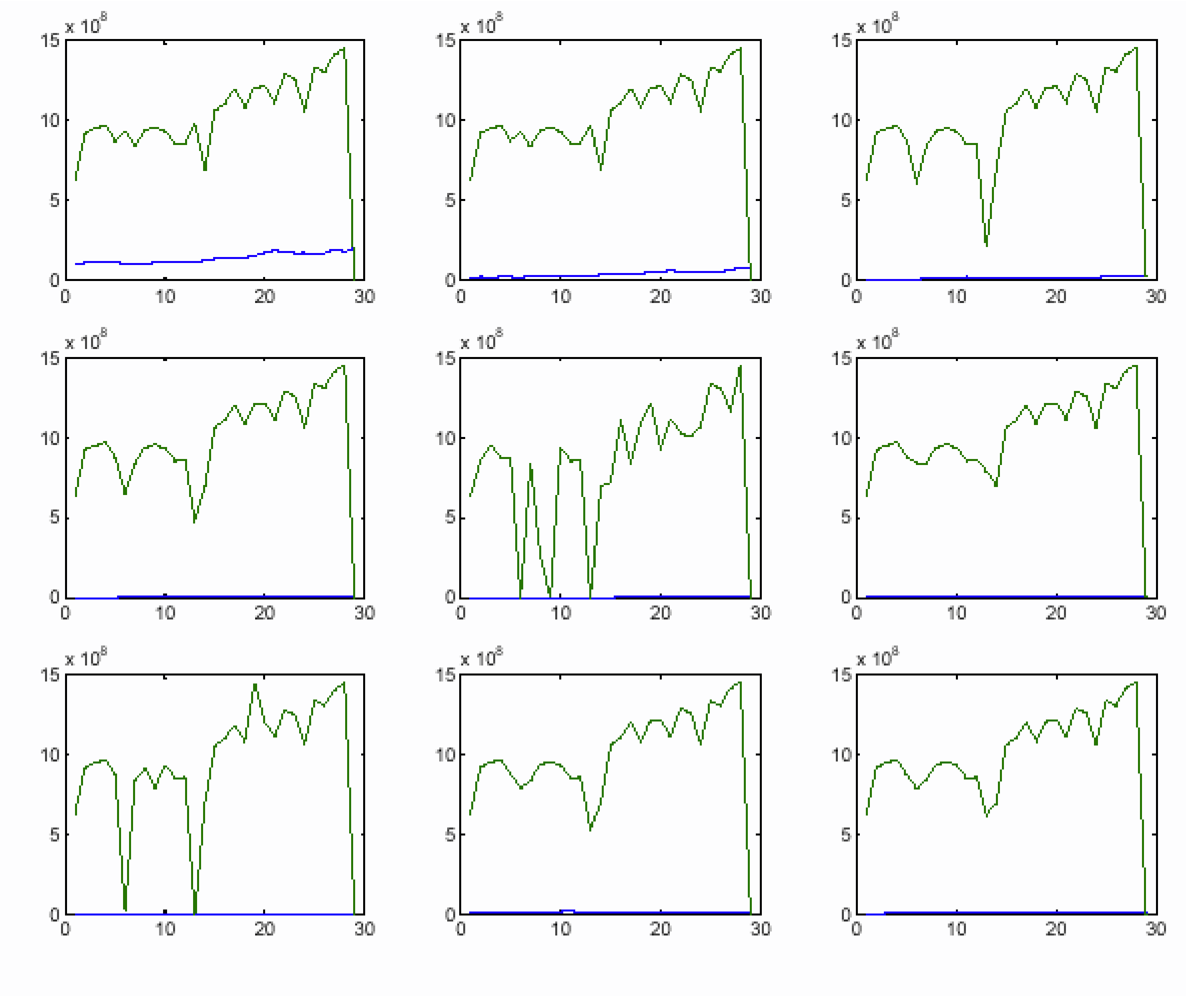

Figure 8 A Sample of Water Use in Non Major Water-Consuming Sectors

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 worry about the resulting behavior of the industry and not the micro behaviors, aggregation oblige):

$$\max_{\{q_{i,t}\}_{t=1}^{T}} \sum_{t=1}^{T} q^{t-1}\left(f_i\left(w_{i,t} + q_{i,t}\right)\right) \quad \forall i \qquad (3.5)$$

s.t.

$$0 \le q_{i,t} + w_{i,t} \quad \forall i \qquad (3.6)$$

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 case $q_{i,t} < 0$, then the volume of water lent cannot exceed the available amount quota at that period. Also, no concerns are to be considered about changes in the value of output from changes in price since we are using a fixed price (base year 1992). In the above program the discount rate is $q = \frac{1}{1+r}$, 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 (3.5)-(3.6), 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):

$$\sum_{i=1}^{n} q_{i,t} = 0 \quad \forall t \tag{3.7}$$

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 (3.5)-(3.6) for each industry and (3.7) is transformed into the Pareto allocation problem:

$$\max_{\{q_{i,t}\}_{t=1}^{T}} \sum_{i=1}^{n} \sum_{t=1}^{T} q^{t-1} \left(f_i \left(w_{i,t} + q_{i,t} \right) \right) \quad \forall i \tag{3.8}$$

s.t.

$$\sum_{i=1}^{n} q_{i,t} = 0 \quad \forall t \tag{3.9}$$

$$0 \le q_{i,t} + w_{i,t} \quad \forall i \tag{3.10}$$

Figures 9 through 12 show the results of the above program.

[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).

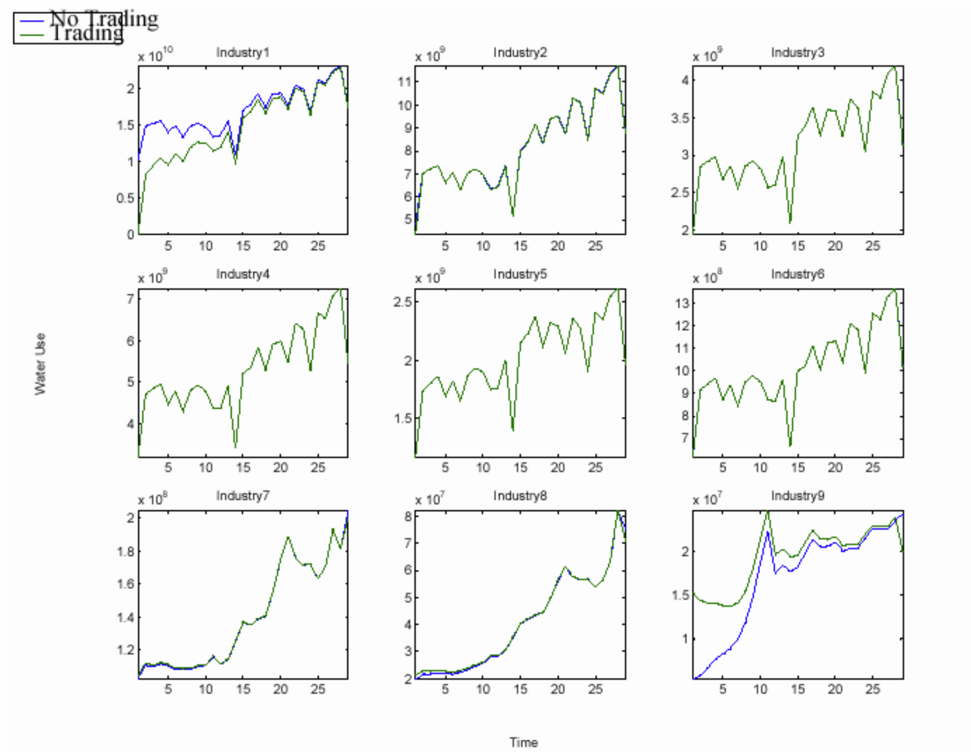

Figure 9 Water Allocation Under Trading and Non Trading Regimes: Sector 1-9

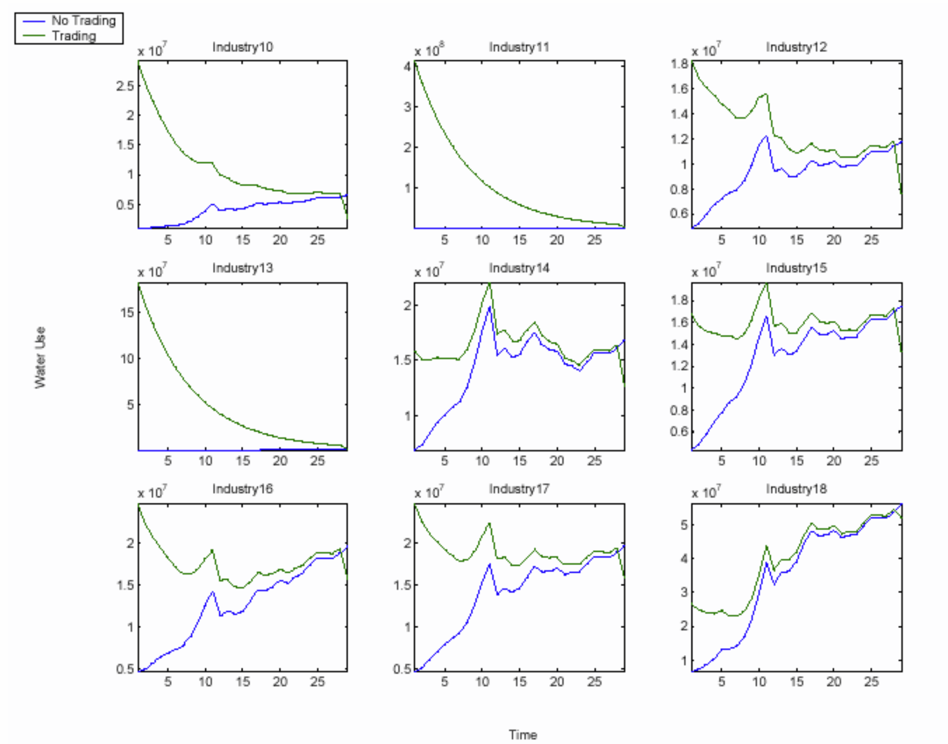

Figure 10 Water Allocation Under Trading and Non Trading Regimes: Sector 10-18

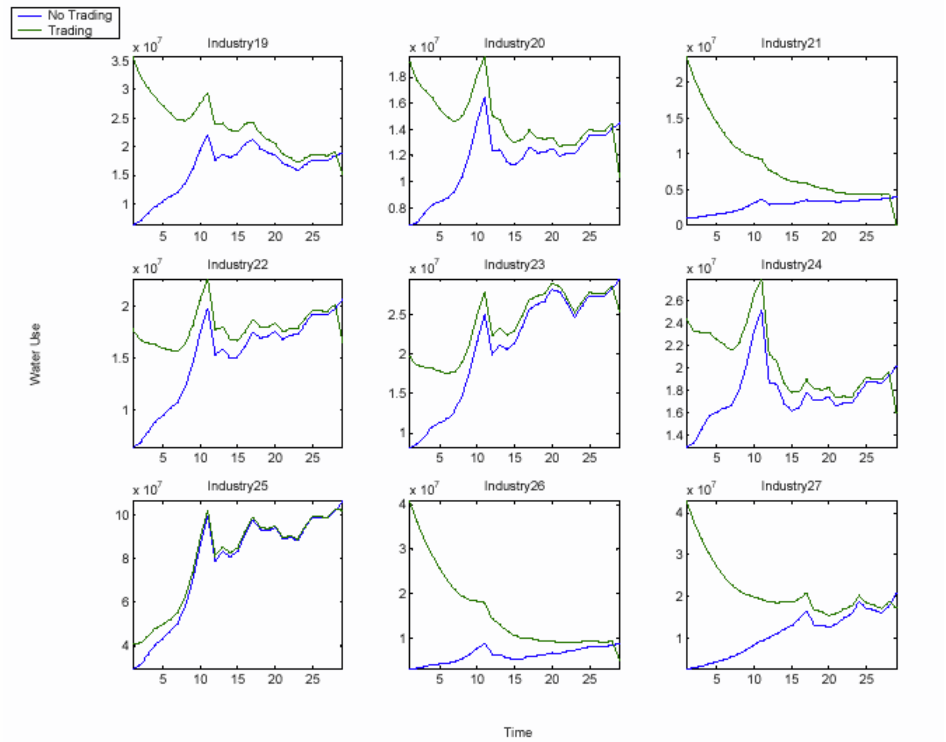

Figure 11 Water Allocation Under Trading and Non Trading Regimes: Sector 19-27

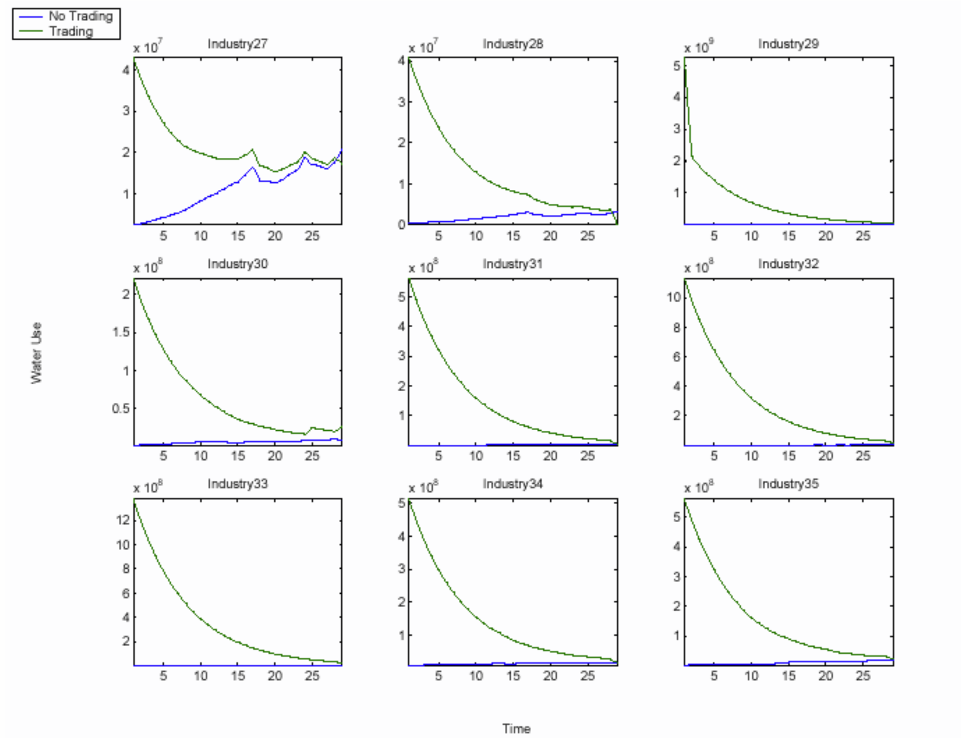

Figure 12 Water Allocation Under Trading and Non Trading Regimes: Sector 27-35

The main findings from this analysis may be summarized as follows:

The first industry (in 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)

One can 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.

3.2.2 Integration with the NE Brazil Macroeconomic Model

In this section, the major focus was to link some of the formulations described in section 3.2.1 with the econometric-input-output model for the NE Brazil economy. Once again, yearly data for the period 1970-1998 were used together with input-output coefficients for 35 sectors for 1992. 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,

$$X_{i,t} = P_{i,92} A_i w_{i,t}^{a} L_{i,t}^{b} \tag{3.11}$$

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

$$\log\left(X_{i,t}\right) = b_1 + b_2 \log\left(w_{i,t}\right) + b_3 \log\left(L_{i,t}\right) + h_{i,t} \tag{3.12}$$

The algorithm used for regression (3.12) seeks values for $b_1, b_2,$ and b_3 without sign restrictions; the ela

With $g = -b$, equation (3.11) can be rewritten as:

$$X_{i,t} = P_{i,92} A w_{i,t}^{a-g} \frac{w_{i,t}^{g}}{L_{i,t}^{g}} = P_{i,92} A w_{i,t}^{a-g} \left(\frac{w_{i,t}}{L_{i,t}} \right)^{g} \qquad (3.13)$$

From (3.13), if $b > 0$ then (3.10) is a Cobb-Douglas production function with *water* and *labor* as inputs, but if $b < 0$ 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 b_2 and $b_{3,}$,

The results of the regression in (3.12) show the existence of increasing returns for some industries. In fact for some industries we have $b_2 \approx 1$, with for some industries b_2 slightly greater than one, for details on the values of b_2 see figure 13, for details of the values of b_3 see figure 14.

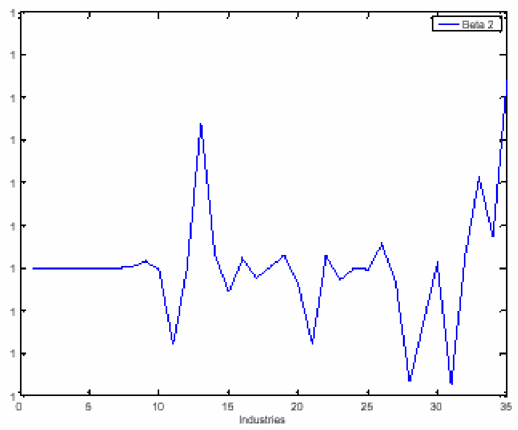

Figure 13 Values of b_2 by Industry

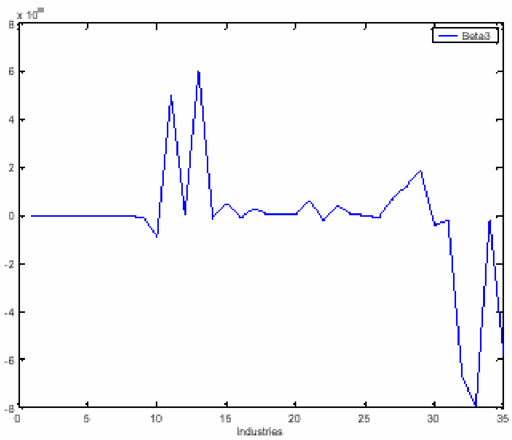

Figure 14 Values of b_3 by Industry

The initial integration process is presented in figure 15.

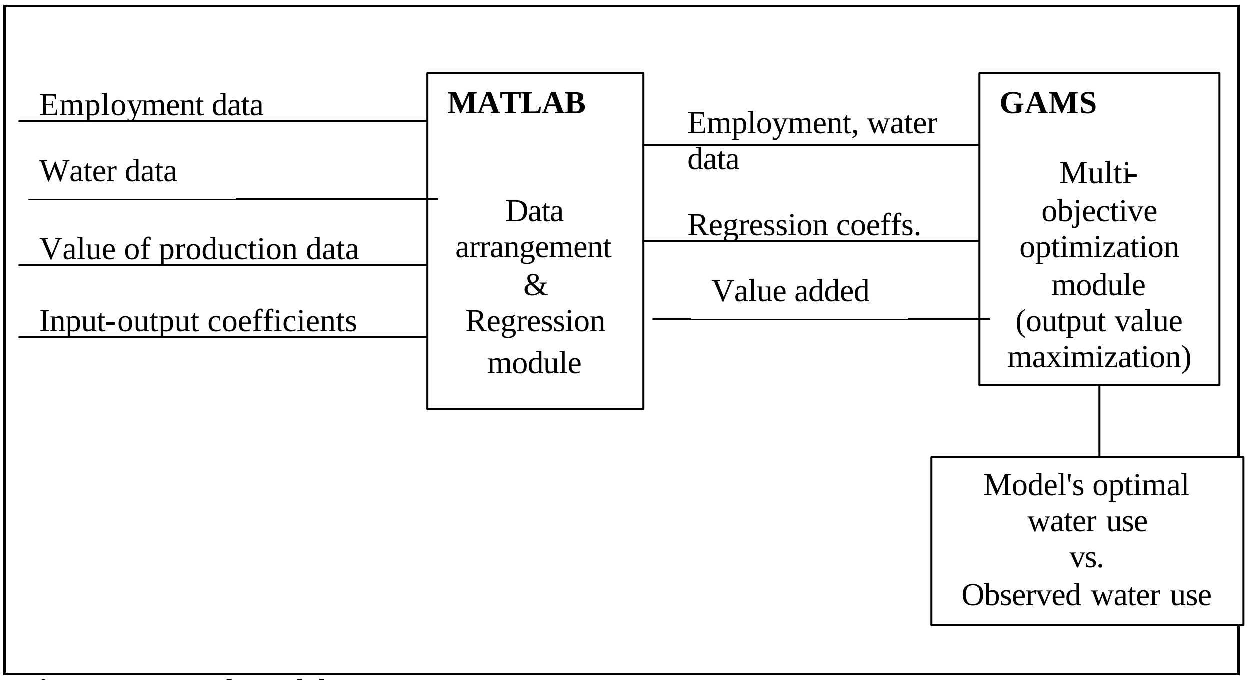

Figure 15 Initial Model Integration

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 new water quota $\hat{w}_{i,t}$ for each period, such as to maximize a convex combination of industries output values.

$$\max_{\hat{w}_{i,t}\geq 0} \sum_i l_{i,t} f_i\left(\hat{w}_{i,t}, L_{i,t}\right)$$
$$\text{s.t.} \qquad \forall t \qquad (3.14)$$
$$\sum_i \hat{w}_{i,t} \leq \sum_i w_{i,t}$$

The program in (3.14) is a multi-objective maximization program where with $va_{i,t}$ being the value-added, the weight coefficients are $l_{i,t} = \dfrac{va_{i,t}}{\sum_i va_{i,t}}, \forall t$ so that greater importance in water rationing is given to industries with higher added-value.

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. The details are available in figures 16, 17, 18, and 19.

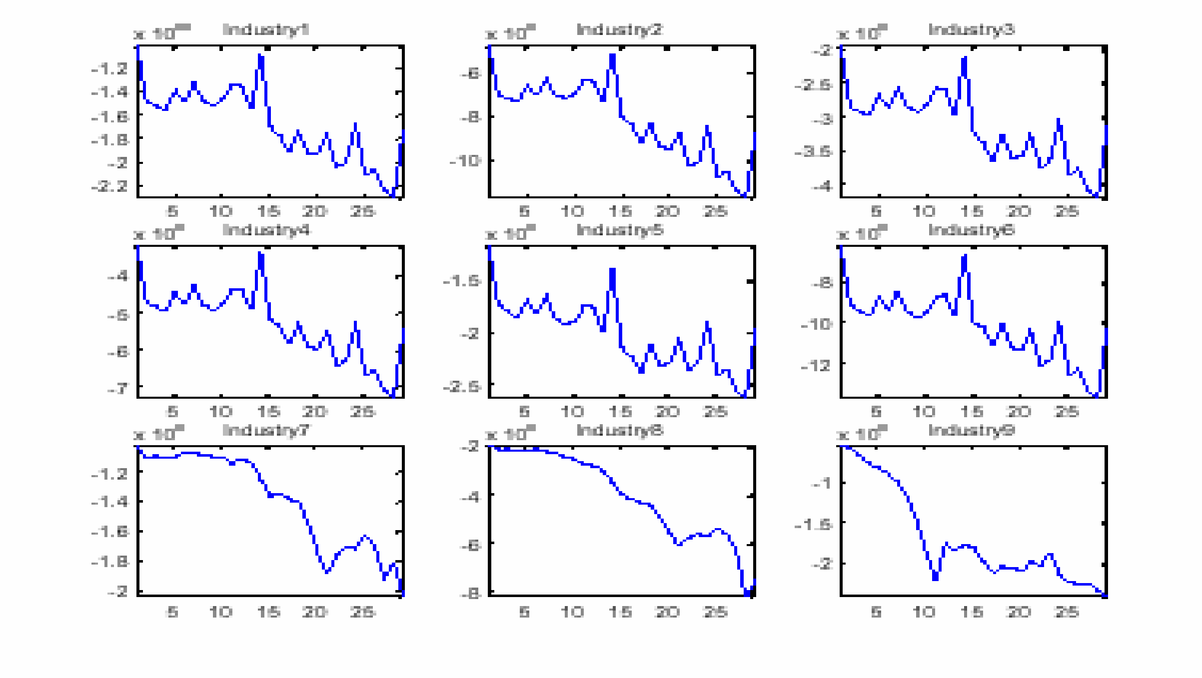

Figure 16 Results for Sectors 1-9

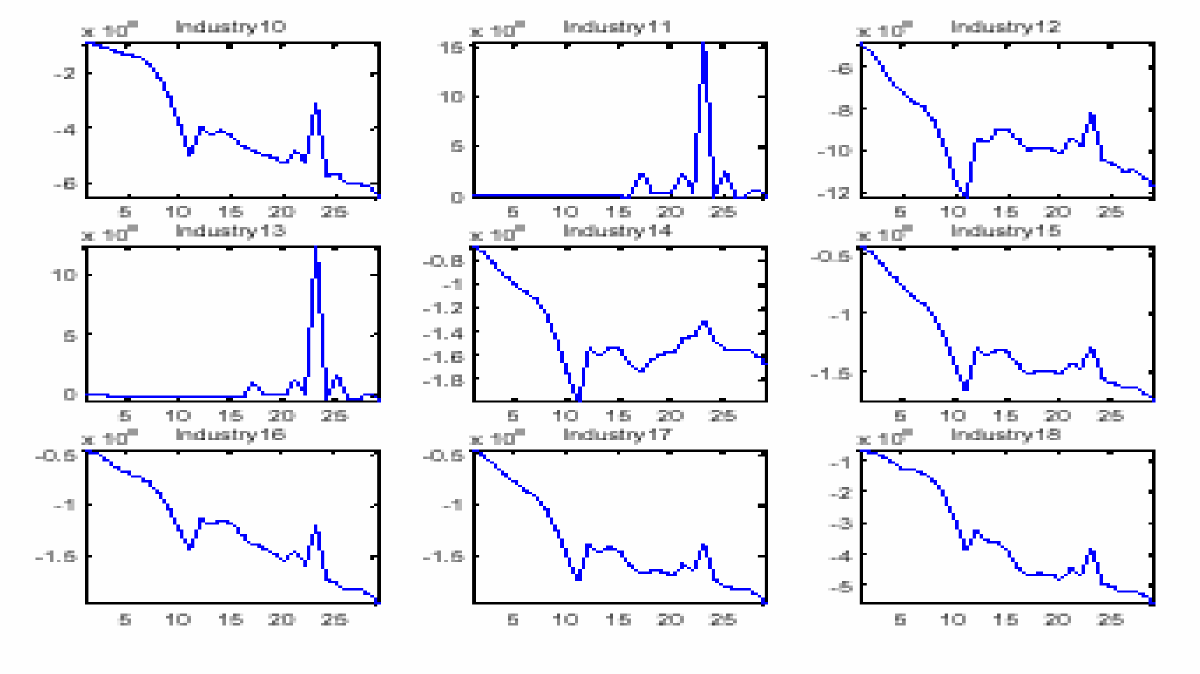

Figure 17 Results for Sectors 10-18

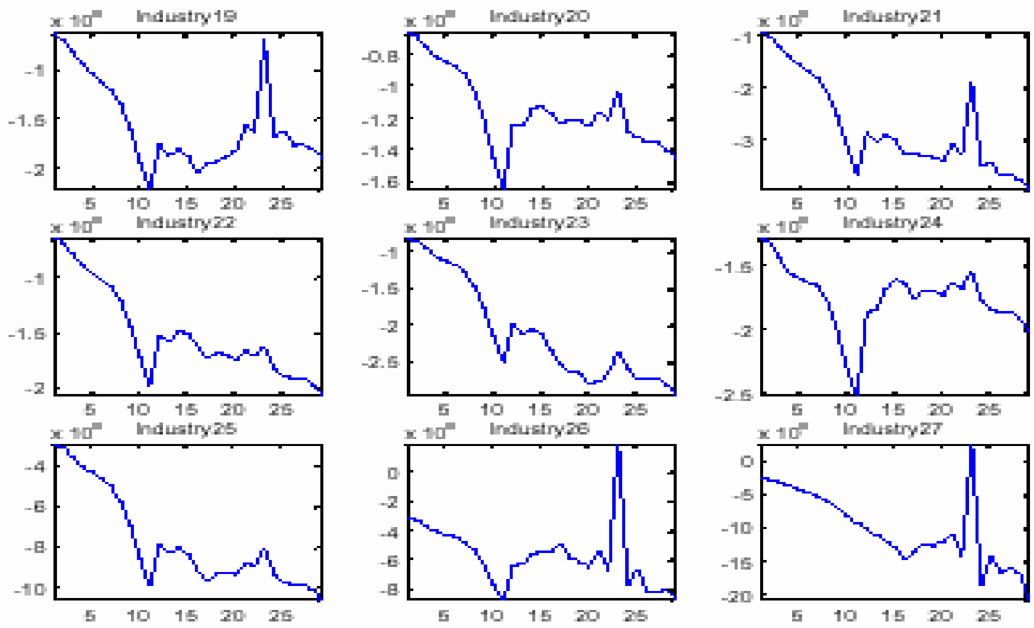

Figure 18 Results for Sectors 19-27

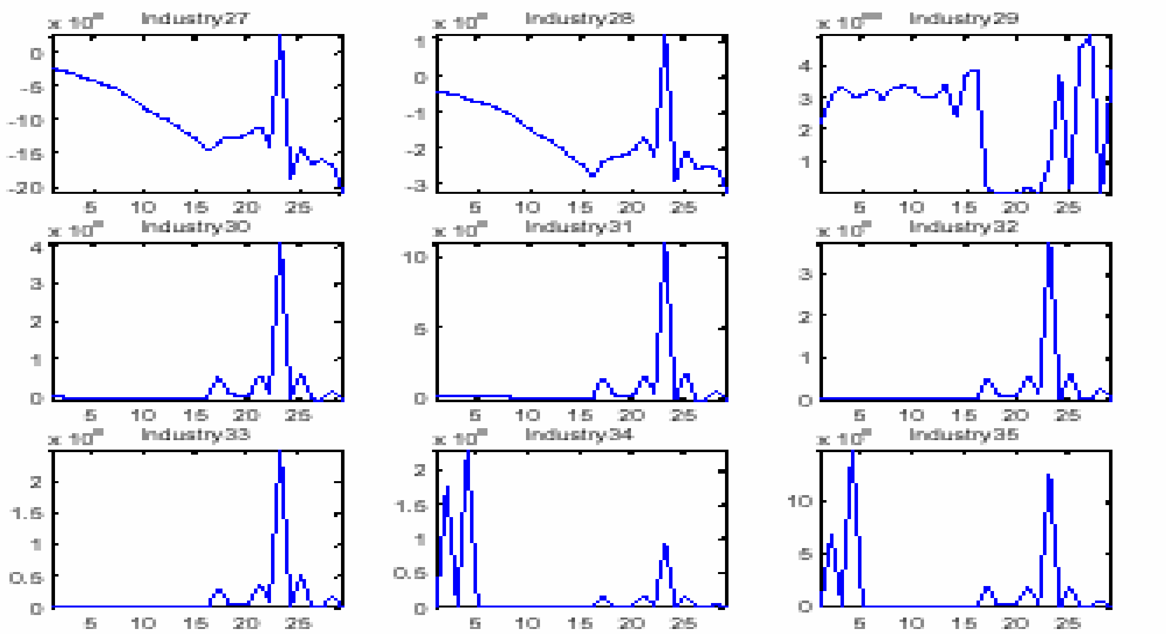

Figure 19 Results for Sectors 27-35

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 $wp_{i,t}$:

$$\min_{wp_{i,t}\geq 0}\sqrt{\sum_i \frac{1}{l_{i,t}}\left(X_{i,t}-f_i\left(wp_{i,t},L_{i,98}\right)\right)^2}$$
$$\text{s.t.} \qquad \forall t=1999,...,2012 \qquad (3.15)$$
$$\sum_i wp_{i,t}\leq \sum_i w_{i,98}$$

where $X_{i,t}$ are values of output projections for $t = 1999,...2012$ in the water unconstrained model (produced by MERIP-NE 2001).

The optimal quantities for $wp_{i,t}$ are given in fig. 20, 21, 22 and 23, 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.

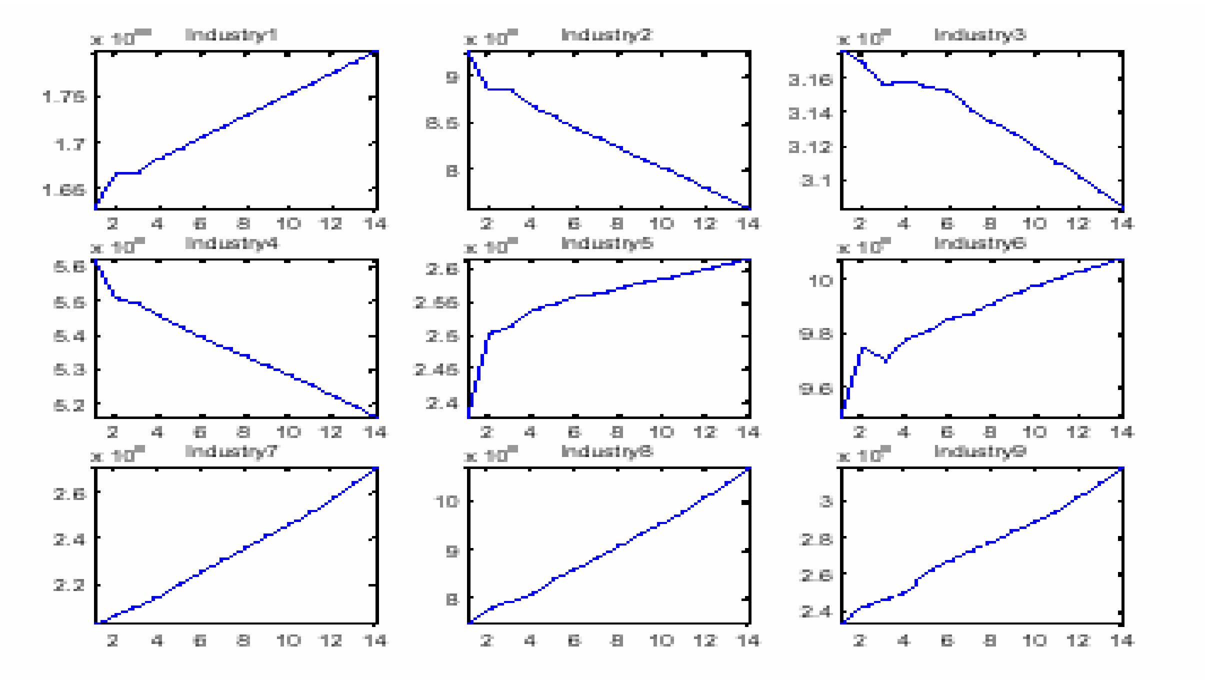

Figure 20 Forecast Results for Sectors 1-9

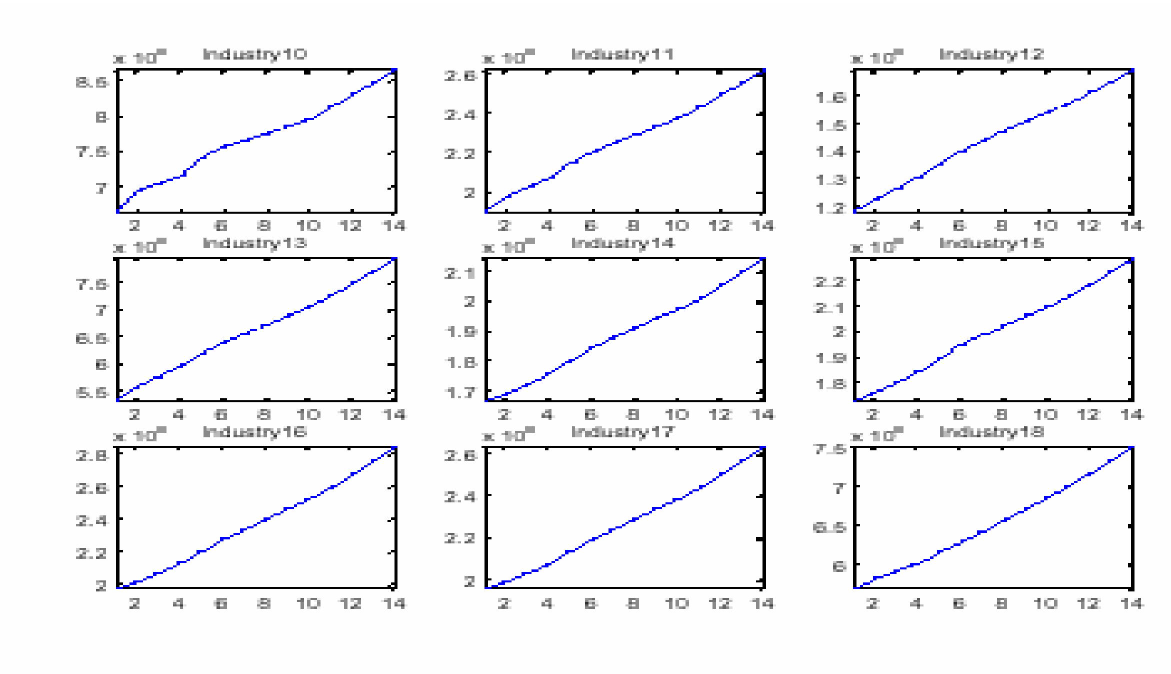

Figure 21 Forecast Results for Sectors 10-18

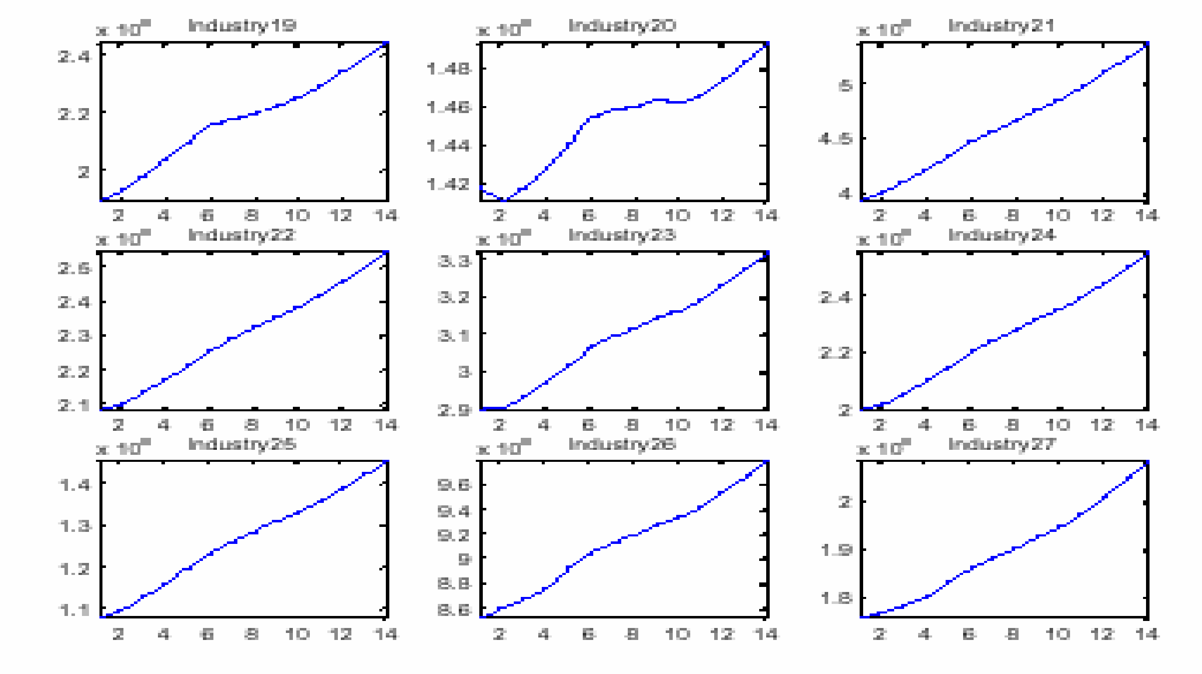

Figure 22 Forecast Results for Sectors19-27

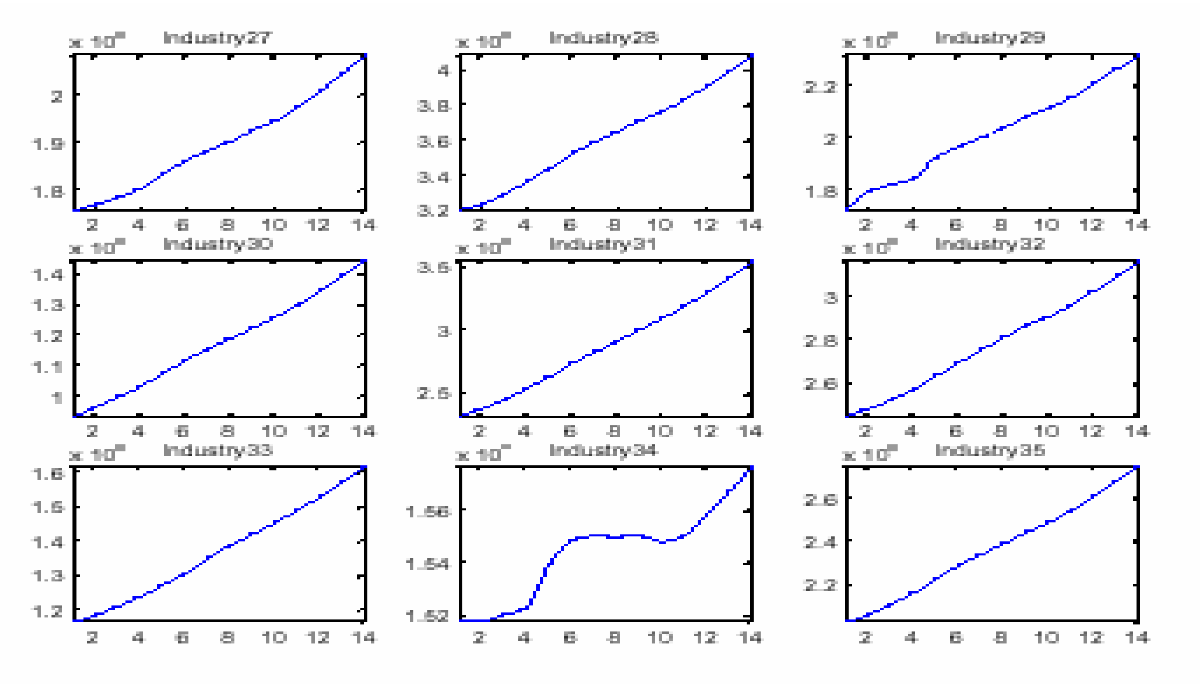

Figure 23 Forecast Results for Sectors 27-35

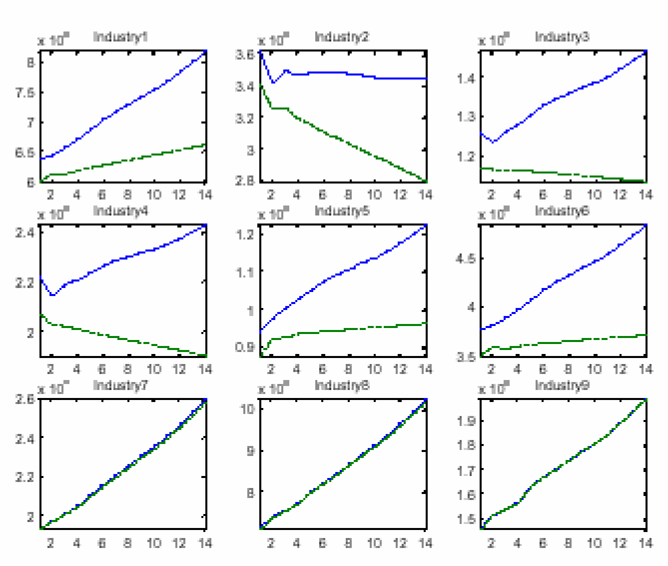

Figure 24 Relationship between Constrained and Unconstrained Water use for Sectors 1-9

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 24). 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 (3.15). The process by which the model calculates the re-allocations is shown in figure 25.

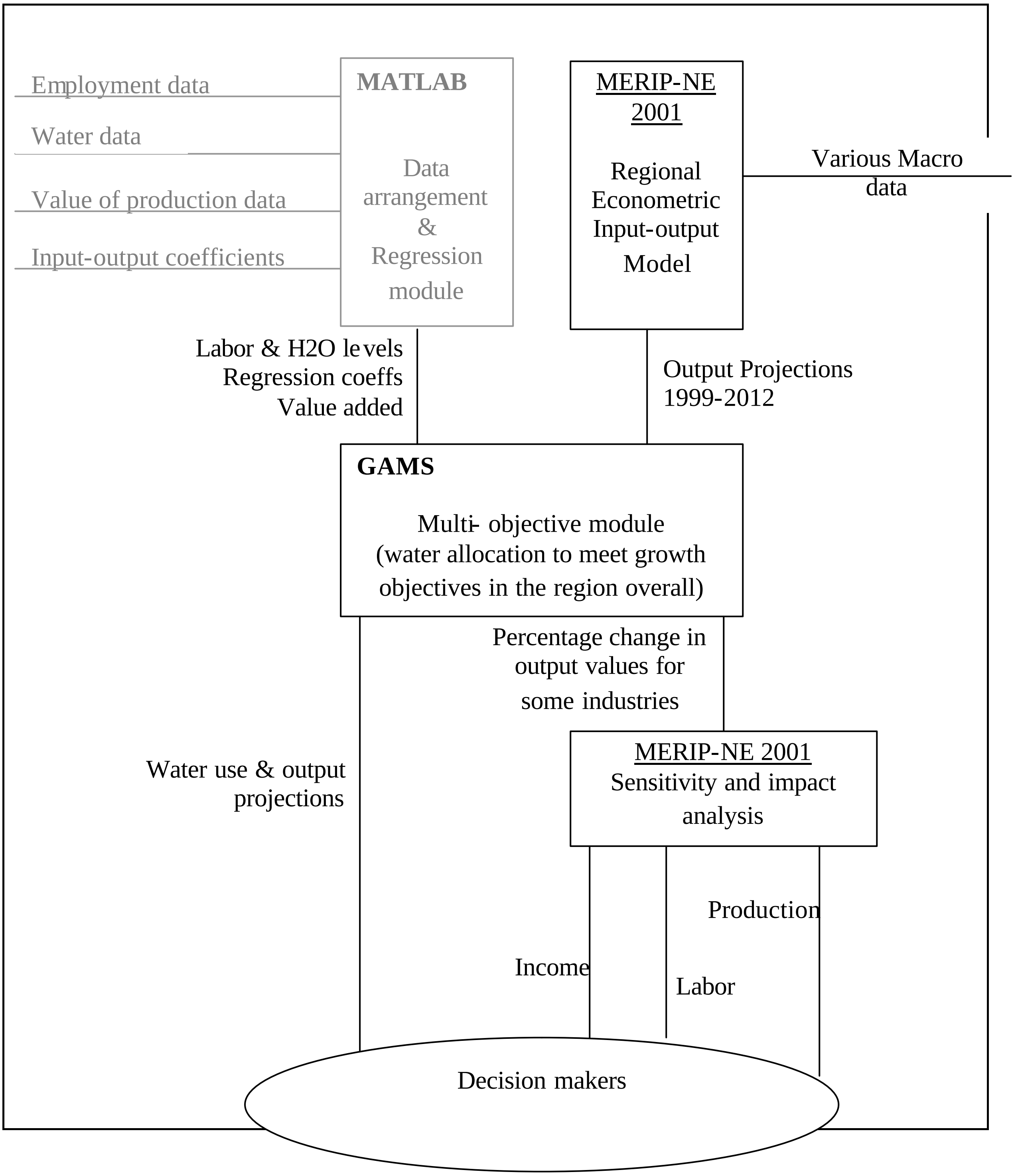

Figure 25 Integration of the Water Allocation Model with the Econometric-Input-Output Model

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 1. For the other industries the targeted projection was met

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

Industries	**Percentage of change in output value**
1-Industrial Crops	-12.05%
2-Grains	-12.05%
3-Fruits	-14.23%
4-Cattle	-13.77%
5-Poultry, hog and pigs	-13.51%
6-Other agricultural products	-14.78%

Table 2 indicates the losses in employment in these sectors as a result of decreased production caused by lack of water. Table 3 provides a summary in percentage terms.

Table 2 Impact of Water Constraints on the Agricultural Sector and Total Employment

Ano	**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
Rest	-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

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

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.

Table 3 Average Annual Percentage Changes, 1999-2012

Sector	Average Annual Percentage Change
1	-17.03%
2	-16.07%
3	-19.09%
4	-17.85%
5	-17.96%
6	-19.86%
Rest	-1.13%
Total	-6.39%

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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