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**The Impacts of Water Management Policies on
Agricultural Production in Australia
- An Economic Analysis**

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Abstract

In the Australian Murray-Darling Basin (MDB) the combination of severe and prolonged droughts and historic water management decisions to divert water for cultivation stressed water resources in such an intensive manner that wetlands went dry and rivers are now far from a natural flow. More appropriate water management policies must be implemented to restore ecological function. However, with 39 % of Australia's total value of agricultural production, transitions in use need to be managed to minimise economic and social impacts on basin communities while they adjust. Recent studies estimate that industries with high water usage but lower or more volatile value products will be impacted more than higher value products. Therefore, this study's focus is to analyse different water management policies and their impacts on agricultural production, particularly changes in production of water low value and water high value crops and agricultural water consumption. By applying the Water Integrated Market (WatIM)-Model, benefits and costs of water management policies can be evaluated by identifying changes in quantities, prices and economic welfare, such as consumer and producer surplus. The WatIM-Model is a multi-market model combining water low and water high value crop markets and the water market with its supply and demand. Since the MDB is a complex system with different types of agriculture and water sharing rules in each catchment, economic variables are aggregated in the WatIM-Model to examine overall trends and changes in the MDB. By the assumption that policy decisions on one market cause reactions on prices, supply and demand on other markets, market interdependencies can be derived. With these results, the merit of shifting production from water low value crops to water high value crops is examined and advantages and disadvantages of water management policies can be determined. This enables refinement of water management policies to optimise social, economic and environmental outcomes.

Keywords: Water market, water management policy, agriculture, sustainable water allocation

1 Introduction

On the one hand, by 1982 it was already reported that three to four year periods of particularly low annual rainfall and drought periods were a common feature of the Australian climate (Rees, 1982). But drought and water scarcity did not result in a sufficient adaptation of agricultural habits to address environmental requirements. Water became permanently overused resulting in unsustainable and unhealthy conditions of the Basin's rivers, wetlands and floodplains. For instance, the median annual flow to the sea of the river Murray in South-East Australia is now only 27% of the pre-development, natural flow (Qureshi et al., 2009). The Murray's water resources have been constrained to support agricultural areas. Climate change will increase drought conditions and substantially less precipitation especially in Eastern Australia (World Water Assessment Program, 2009). For instance, the MDB marked a six year continuing period of lower rainfall than average since 2001. Water resources must be protected and seem not to be available under the same conditions for water intensive agricultural production as in the past.

As reported by the Garnaut Climate Change Review, major declines in agricultural production may occur by mid-century under a no global climate change mitigation strategy. Particularly affected is irrigated agriculture in the MDB where half of its annual output would likely be lost. This development would have huge impacts on food exports as well as depopulation of rural areas. Further presumptions under climate change state the end of irrigated agriculture by the end of the century caused by increasing frequency of drought, decrease of median rainfall and a nearly complete absence of runoff in the MDB if no mitigation of greenhouse gases takes place. Otherwise, there is a 10% chance of wetter conditions under a no-mitigation case in Australia. In this case, the northern part of the MDB would have a 20-30% increase of rainfall by 2050. Irrigated agricultural production would be less than 1% greater than with no human-induced climate change in the MDB (Garnaut, 2008). Accordingly, a 90% chance for a drier climate would affect irrigated agriculture in the MDB tremendously.

On the other hand, Australia is one of the biggest exporters of agricultural products in the world. For instance, in 2007 Australia was quantitatively the second largest exporter of meat-cattle boneless beef, as well as of raw sugar, and the fifth largest wine and cotton exporter. An export of 14,684,211 tons of wheat in 2007 brought Australia to number three of the biggest wheat exporters in the world and to number 18 of the world's major commodity exporters

(FAOSTAT, 2007). For such large-scale production, vast inputs of arable land are needed, and in the case of irrigated crops, water must be applied for production.

We seek to examine the impacts of water management policies on agricultural production and the economy in a partial equilibrium model framework using the Water Integrated Market Model (WatIM-Model).

After providing background information about irrigated agriculture, growing areas and water consumption of selected crops in the MDB in section 2, we outline the analytical framework in section 3. Section 4 describes the data we use to estimate the model. Section 5 describes the calibration method. Section 6 reports on the scenario analysis and section 7 concludes with a brief discussion and further steps to take.

2 Irrigated agriculture in the Murray-Darling Basin

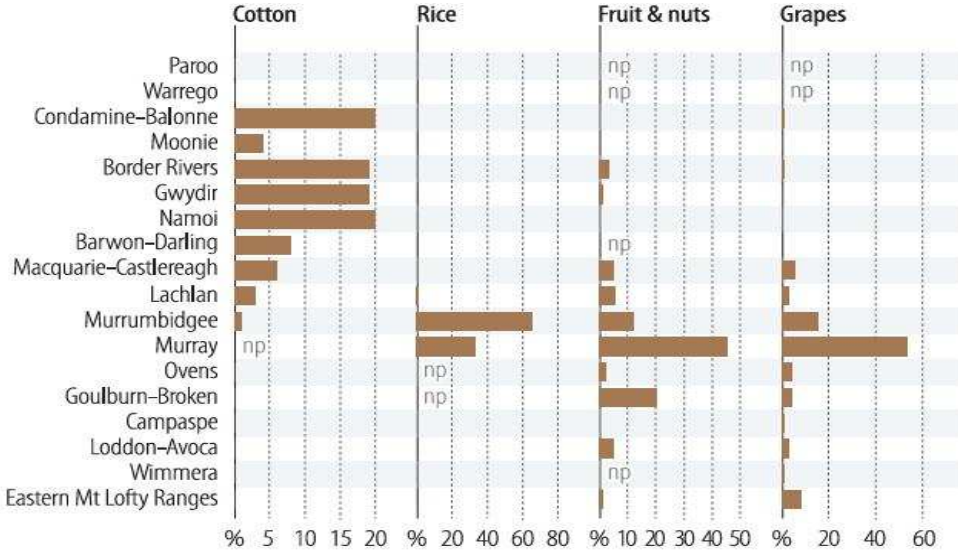
In 2008/09, a total area of 409,000,000 ha was used for agriculture, of which 1,761,000 ha were irrigated using up 6,500,577 ML in Australia (ABS, 2010a). More than half of this amount of irrigation water is used in the Murray-Darling Basin (MDB) where 39 % of Australia's total value of agricultural production is derived (ABS, 2008). The MDB covers an area of 1,059,000 km², where 100% of Australia's irrigated rice production, 90% of Australia's irrigated cotton production, and 60% of Australia's irrigated grapevine production takes place (ABS, 2010b).

More than 80 per cent of land used for cotton, rice, grapes and vegetables is irrigated. Without irrigation, some of these crops could not be produced at the present level. Irrigation allows year round production in the Basin. It enables cropping in summer when temperatures and evaporation are high. In a wet year like 2010, much less irrigation has been needed to grow crops because of the nourishment of natural rainfall.

The volume of water used varies to a great extent between industries (Bell et al., 2007). Cotton farms used the most irrigation water for cultivation by consuming 2,599 GL (1,574 GL) in 2000-01 (2005-06) followed by rice 2.418 GL (1,252 GL). In contrast, irrigation water used for vegetables was 166 GL (152 GL) in 2000-01 (2005-06) (ABS, 2008).

As shown in Figure 1, crop producing areas are quite diverse. For instance, the dominant irrigated crop in southern Queensland (Border Rivers and Condamine-Balonne) and northern New South Wales (Namoi and Gwydir) is cotton. Rice is cultivated dominantly in New South Wales Central Murray and Murrumbidgee; same as grapes, fruits and nuts which are mainly produced in a number of locations in the Murray region.

Figure 1 Region shares of total Murray-Darling Basin GVAP for selected crops



Source: ABS/ABARE/BRS, 2009

Considering a comparison of crop markets such as rice, cotton, grapes, vegetables and fruits as performed in the Water Integrated Market (WatIM)-Model, observed regions must comprise all crops cultivated. All of these crops are water intensive crops, but the amount of irrigation water consumed and value produced by cropping vary widely. Therefore, we divide crops into water high value and water low value crops in which water high value crops’ ratio of Gross Value of Irrigated Agriculture Production¹ (GVIAP) to the applied water is higher than \$1,500 per ML.

Rice and cotton are representatives of water low value crops² since ratio of GVIAP to water applied is less than \$1,500 /ML (cotton \$673 /ML and rice \$274 /ML in 2007-08). That means less than \$700 of GVIAP can be derived by an investment of 1 ML irrigation water. On the contrary, water high value crops such as grapes, fruits and vegetables have a ratio of GVIAP

¹ “GVIAP refers to the gross value of agricultural commodities that are produced with the assistance of irrigation. “ (ABS , 2010c)

² Note that we derive the definition for low values not from GVIAP in proportion to capital investigated (return on investment would be higher) but from GVIAP in proportion to quantity of used water for production.

to water applied which is higher than \$1,500 /ML (grapes \$3,091 /ML, fruits \$4,093 /ML and vegetables \$6,901 /ML in 2007-08) (ABS, 2010c).

The WatIM-Model is a multi-market model combining the water low value crop markets for rice and cotton as well as the water high value crop markets for grapes, vegetables and fruits. With the examination of these five markets, we are able to see the effects of water management policies on each of the assessed markets. Therefore, it is possible to detect different developments in the cultivation of water high and water low value crops under water scarcity.

3 Conceptual framework

To identify the benefits and costs of different water management policies we develop a multi-market model, following the microeconomic modelling approach of Kirschke and Jechlitschka (2002). Changes in quantities, prices and economic welfare such as consumer and producer surplus as results of water management policies, can be derived. The WatIM-Model is a partial equilibrium multi-market model observing water low value crop markets (rice, cotton) and water high value crop markets (grapes, vegetables, fruits). In order for the WatIM-Model to work, we assume that policies such as protection policies are not given. We can therefore assume that world market prices equal domestic prices within liberal markets in the WatIM-Model.

The supply function is:

$$q_m^s(p_n^s) = a_m (1 + f) \prod_{m,n=1}^5 (p_{mn}^s)^{\varepsilon_{mn}^s}$$

with $m, n = 1, \dots, 5$. (1)

Each of the five markets, rice, cotton, grapes, vegetables and fruits, has its own supply function $q^s(\cdot)$ and demand function $q^d(\cdot)$ depending on prices p in all markets. The parameter q^s is the quantity supplied.

The non-linear WatIM-Model of the Cobb-Douglas type takes account for quantity changes on market m due to price changes on all other markets n . Each market is influenced by itself and the other four markets by the use of appropriate own-price and cross-price elasticities ε_{mn} . In this way, market interdependencies can be derived.

Where ε_{mn}^s is the supply elasticity and f is the exogenous shift parameter which is used to simulate price policies in the first step (see section 5 for further explanation).

a is the supply constant, defined for the initial equilibrium as:

$$a_m = \frac{q_m^s}{\prod_{m,n=1}^5 (p_{mn}^s)^{\varepsilon_{mn}^s}} \quad (2)$$

Just as the supply function, the demand function is dependent on prices p in all markets m and income y :

$$q_m^d(p_n^d, y) = b_m \prod_{m,n=1}^5 (p_{mn}^d)^{\varepsilon_{mn}^d} y^{\eta_m} \quad (3)$$

With $m, n = 1, \dots, 5$.

Where ε_{mn}^d is the demand elasticity, η_m is the income elasticity of demand on market m and b is the demand constant, defined for the initial equilibrium as:

$$b_m = \frac{q_m^d}{\prod_{m,n=1}^5 (p_{mn}^d)^{\varepsilon_{mn}^d}} \quad (4)$$

The cost function of each market m is defined as:

$$C_m = p_m^s q_m^s (1 + f) - a_m (1 + f) \prod_{\substack{m,n=1 \\ n \neq m}}^5 p_m^s \varepsilon_{nm} \prod_{n=m}^5 \frac{p_m^s \varepsilon_{nm} + 1}{\varepsilon_{nm} + 1} \quad (5)$$

with $m, n = 1, \dots, 5$.

The shift parameter f is treated equally as in the supply function (1).

The inverse Cobb-Douglas demand function would be infinite, as the integral value is ∞ . We define a fictitious intersection of the demand curve with the price axis and cut off the integral at an adequately high price³ p_m^{d0} . Therefore, evaluating the level of total benefit and other

³ This price is set at such a high level that it can not be achieved in terms of stable currencies (this would not be true in hyperinflationary conditions).

functions which are based on total benefit such as consumer and producer surplus must be done with caution (Kirschke and Jechlitschka, 2002).

The total benefit is defined as:

$$TB_m = p_m^d q_m^d + b_m \prod_{\substack{m,n=1 \\ n \neq m}}^5 p_m^{d \varepsilon_{nm}} \prod_{\substack{m,n=1 \\ n=m}}^5 \left(\frac{p_m^{d_0 \varepsilon_{nm} + 1} - p_m^{d \varepsilon_{nm} + 1}}{\varepsilon_{nm} + 1} \right) y^{\varepsilon_{ym}} \quad (6)$$

with $m,n=1, \dots, 5$.

We define the foreign exchange (FE) as exported quantity derived by subtracting quantity demanded from quantity supplied multiplied by world market prices p^w for each market m :

$$FE_m = (q_m^s - q_m^d) p_m^w \quad (7)$$

Further, we gain welfare for each market by applying:

$$W_m = TB_m - C_m + FE_m \quad (8)$$

Total welfare is consequently: $TW = \sum_{m=1}^5 W_m$

$$\text{Total expenditures are } TEP^d = \sum_{m=1}^5 p_m^d q_m^d \quad (9)$$

$$\text{Total revenue is } TRV^s = \sum_{m=1}^5 p_m^s q_m^s \quad (10)$$

$$\text{Consumer surplus is total benefit less expenditures: } CS_m = TB_m - EP_m \quad (11)$$

$$\text{Producer surplus is revenue less costs: } PS_m = RV_m - C_m \quad (12)$$

Economic variables are aggregated in the WatIM-Model to examine overall trends and changes in the MDB since the MDB is a complex system with different types of agriculture and water sharing rules in each catchment. Therefore, prices and quantities supplied and demanded are portrayed as mean values across the total MDB.

4 Data collection

To evaluate the different effects of water management policies on water high and water low value crop industries, data is required for rice, cotton, grapes, vegetables and fruits as well as for the water market. The area of observation in the WatIM-Model is the MDB. Data is

collected for the period 2000 to 2006. Production quantities for all crops are retrieved from the Australian Bureau of Statistics (ABS) and the Australian Government Department of Agriculture, Fisheries and Forestry (DAFF), partly released for the MDB (periods 2000-01 and 2005-06) (ABS, 2008), partly set into relation to Australian quantity supplied published in the Australian food statistics 2006 (DAFF, 2007).

Demand quantities for all crops except cotton are extracted from the Food and Agriculture Organization of the United Nations (FAO) statistic FAOSTAT Food Balance Sheets and then set into relation to the population of the MDB. The GAIN reports Australia, Cotton and Products from 2000 to 2010 of the United States Department of Agriculture (USDA) are used to define the quantity demanded of cotton (USDA, 2010a).

Australian producer prices and world prices for all five crops are taken from the FAO FAOSTAT producer price statistics. Transport charges are not included (FAOSTAT, 2010). We define world prices as the mean of all producer prices of all countries available at FAOSTAT for the five observed crop markets.

Data about water quantity consumed by crop industries in the MDB is derived from the ABS, for the period 2000-01 to 2004-05 as a proportion of Australia's water consumption, for 2005-06 to 2007-08 we use available data of the MDB. For the sake of simplicity we assume that the quantity consumed is the available quantity of water for observed industries. Therefore, quantity supplied and quantity demanded is the same in the first step. The price for water is estimated on the basis of the ABS's Water Account 2008/09 which releases the expenditures on distributed water of agriculture, forestry and fishing for the periods 2004-05 and 2008-09 (ABS, 2006).

To integrate interdependencies of markets, producer's own-price and cross-price elasticities were taken from Bell et al. (2007). Since the estimates are short run in character, they are applicable for our statistic model which makes no long run projections for the future. Cross-price elasticities are set to zero for our first scenario (see section 6).

In addition, we use the Australian demand elasticity for cotton and the Australian income elasticity from the 1996 ICP data derived by the USDA's Economic Research Service (USDA, 2010b).

We derived the share of costs for water from the 1999-2000 Corrigendum Agriculture for cotton, fruits and vegetables (ABS, 2002). The values for rice and grapes are approximated since no data is available.

The price for water we use for our scenario is \$114/ ML derived by total expenditures on distributed water in relation to the total physical use of distributed water (ABS, 2010d).

5 Model Calibration

For data error correction we calibrate the WatIM-Model. The calibration is taken into account in the model by applying the supply function's constant a and the demand function's constant b (see section 3). In the first step, we determine quantities of supply and demand with $a=1$ and $b=1$. In this way we achieve model internal derived quantities which must be constrained to real demanded and supplied quantities. By dividing the real value by the internal value we determine the constant of the supply function a and the constant of the demand function b in the second step. After this step, a and b are kept constant for all scenarios and policy analyses.

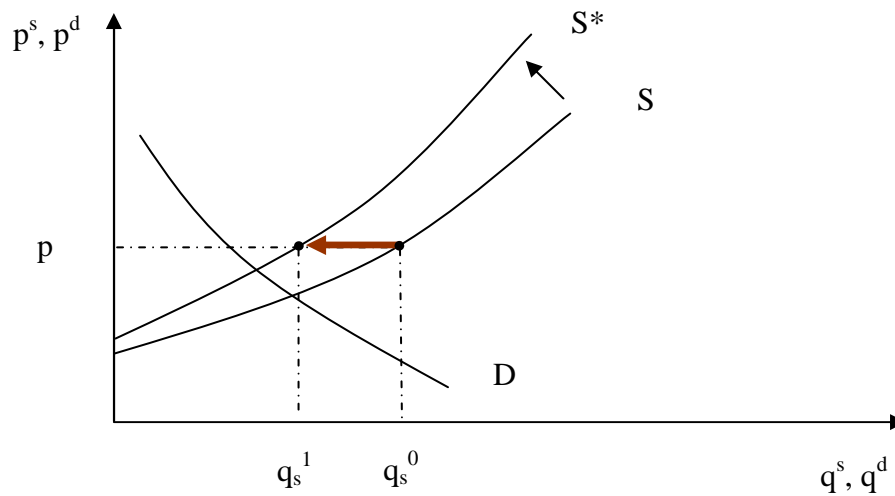
6 Scenario analysis

The main objective is to evaluate impacts of water management policies on agricultural production and to examine different consequences of policies on water high and water low value crop production.

Cross-price demand elasticities are set to zero to analyse impacts of increasing water prices on supply functions. Consequently, demand quantity is constant.

As a first step, we consider five crop product markets and a price rising policy which has impact on the input factor market of water. As shown in the conceptual framework above, the WatIM-Model has no input-markets integrated for this scenario. Therefore, water prices are given exogenously by applying the shift factor f which modifies the level of costs and the level of supplied quantities. We assume total costs to be a result of water costs and all other costs which we keep constant. Hence, a change of costs depends on a change of water prices and the cost share of water. The idea of the shift factor is to integrate an exogenous change in variables. f is negative as a result of increasing water prices. For instance, if the share of costs is 18% for water in cotton production (5 % vegetables, 10% fruits, 13% rice, 7% grapes) and the water price increases by 50%, the shift factor is -0.088 for cotton (-0.024 vegetables, -0.048 fruits, -0.066 rice, -0.033 grapes). With an increase of the price for water by 100%, f is -0.176 for cotton (-0.047 vegetables, -0.096 fruits, -0.132 rice, -0.067 grapes). In this way we are able to examine a shift of supply curve as illustrated in figure 2. If the price of the input factor water increases, the supply curve shifts from S to S^* . Since we keep the product price constant in this scenario, the production quantity q_s^1 is generated on the supply curve S^* after shifting. The demand curve is not affected by the shift and is kept constant.

Figure 2: Supply shifting effects as result of price increasing policies



Source: Own illustration

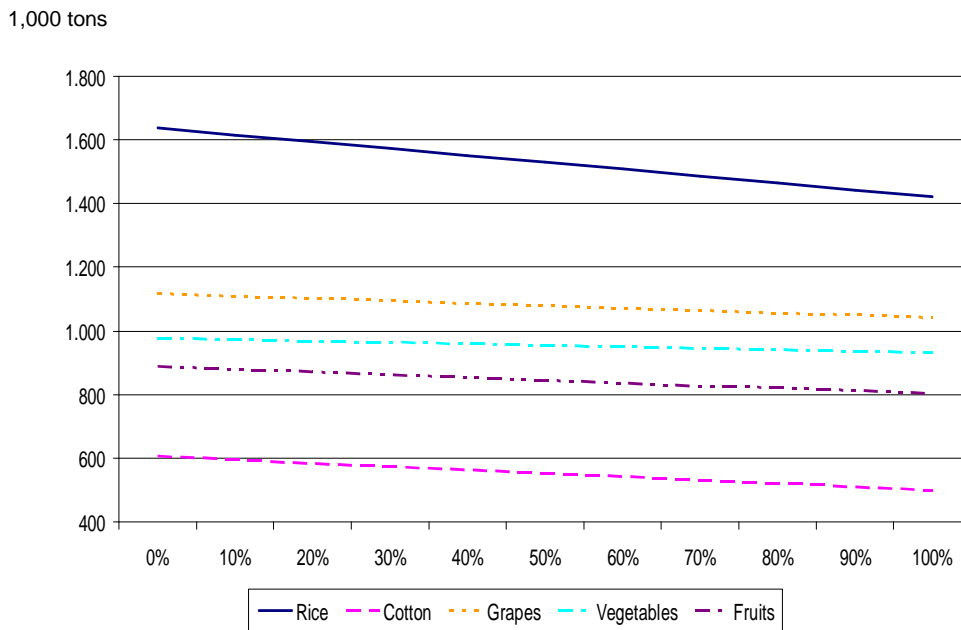
The initial values of production are from period 2000-01 which are also the basis for the model calibration (see section 5). Additionally, we keep the relation of costs for water to total costs constant. In fact, increasing costs would enhance the share of costs for water and therefore reinforce the effects of decreasing quantities produced. As shown in figure 3, quantities produced decrease with increasing price for water.

Mostly impacted are rice and cotton since these crops majorly depend on irrigation water and shares of costs for water are highest in the observed area. Therefore, produced quantities of the water low value crops rice and cotton decrease more significantly than the produced quantities of water high value crops.

As figure 3 illustrates, a doubling of water price does not reduce crop production as significantly as we expected. We suppose, this is caused by the relatively small price of water which is initially \$115/ ML (ABS, 2010d) and that the model is not sensitive enough for these small price changes, since the relation of costs for water to total costs is small.

In this scenario harvest losses caused by severe droughts are not integrated. We assume that all planted crops can be irrigated as required.

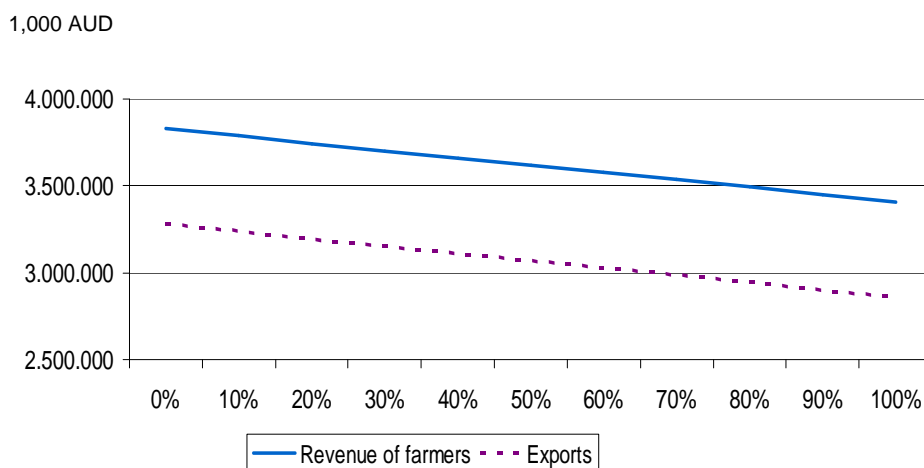
Figure 3: Impacts of increase of water price on quantity produced



Source: Own calculations

Since Australia is a major export country of agricultural products, the excess production decreases, with the result that exports of agricultural products drop as figure 4 shows by the aggregated export curve.

Figure 4: Impacts of price change on revenue of farmers and exports



Source: Own calculations

With a decreasing production and an increase of costs for water, farmers' revenues decline. With this simple scenario we are able to show that the more dependent the industry is on irrigation, the more this industry is affected by increasing water prices.

7 Discussion and further steps

With our scenario we showed that different effects emerge depending on the volume of water consumed. We conclude that the higher the ratio of GVIAP to water of the crop production is, the less vulnerable it is. Under water price increasing circumstances, water high value crop industries such as grape-, vegetable- and fruit production are going to exist longer on the market than water low value crops such as rice or cotton. Hence, water price policies will have an influence on agricultural structure accompanied by a reduction of over-allocation of water. Improvements of sustainable water consumption can be achieved.

Which impacts these effects will have on economies, need to be explored in further research. Our research is at an early stage. The WatIM-Model needs to be developed to integrate water as an explicit input market with interdependencies to the crop markets.

Additionally, water needs to be integrated as an input-factor into the model to see impacts of water management policies not only with the help of an exogenous variable but as a result solved within the model.

The water market of the MDB is very complex. This needs to be implemented into the model by considering water rights and water trade.

The WatIM-Model helps to find out more about advantages and disadvantages of management strategies. Special attention has to be given to limits of available quantities for irrigators and 'the right' price for water. Especially the latter is the key for sustainability because environmental, social and ethical aspects need to be integrated into the actual process of price-setting. For this reason, external, environmental and social costs as well as periodic scarcity of water during droughts need to be internalised within the market price for water.

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