Do water markets bring efficiency?
Water market impacts on grape productivity in the Murray-Darling Basin, Australia

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Abstract:

Water markets emerged as economic tools to deal with water scarcity. By reallocating existing water resources instead of using costly engineering projects to extend the existing supply, they are expected to increase efficiency in water resources allocation. The Murray-Darling Basin in Australia hosts some of the most advanced water markets in the world (Grafton, 2011). Although the theoretical literature dedicated to the potential of water markets is rich, very few studies focused on measuring the empirical impacts of established water markets, often in the absence of a sufficient market activity. In the years following 2007, a massive increase in transactions occurred within the Australian water allocation markets. We use this opportunity and attempt to fill the gap. A database on agricultural production, climatic influences and market activity was gathered in order to measure the impacts of water trades occurring between 2009 and 2014 on agricultural productivity in the grape production sector. When applying a Cobb-Douglas as well as a Translog production function to the production, we find no significant impact of water markets on agricultural productivity. Part of an explanation could be that efficient irrigators purchase their water to reduce their own risk, without using it to extend their cultivated surface as noticed by Bjornlund (1999).

Introduction

In 2016, the World Economic Forum held in Davos published the Global Risks Landscape 2015[1]. Among all the risks presented, the report rank water crisis as the most important risk in terms of potential impact. Behind this acknowledgement, a fact: demographic pressures and the expected impacts of climate change endanger the balance between water supply and demand, while the means of increasing water supply become more and more expansive.

In this context, water markets have emerged as a potential tool to deal with water scarcity. Such markets can be defined as "a system of formal rules and regulations that govern the buying, selling and leasing of water use rights (…) that are ideally traded independent of land titles" (Debaere et al., 2014). They can be used in a given sector, as agriculture; or they can allow inter-sectoral trades, as in the case of rural to urban transfers. By reallocating water to the most productive activities (Hodgson, 2006), from low-value to higher valued uses (Dinar et al., 1997), markets are expected to foster a more efficient use for water. Instead of increasing the available supply, they are expected to reallocate water in a more efficient way.

Australia is a perfect example of such a situation. The South-eastern corner of the Australian territory is subject to significant physical water scarcity, according to the UN (2012): in their words, water resources development is approaching or has already exceeded sustainable limits. Australia has developed water markets since 1994, when a cap on total water extractions was introduced, in parallel with a separation between land titles and the water resources that were previously bundled to it. Historically, water markets appeared first within the Murray-Darling Basin (MDB), located within the South-eastern corner of Australia. It developed through progressive reforms, and experienced a massive increase in transactions after 2007. Grafton et al. (2011), in a comparative study of water markets in different parts of the world, described water markets in the Murray-Darling Basin as the most advanced water markets currently in place.

This context strengthens the interest of studying water markets in this area, as the global occurrence of water stress is likely to increase in the coming decades: Australia, and the Murray-Darling basin in particular, form a laboratory to the use of economic and market tools to face a situation of water scarcity. The aim of this study is to question the impact of such

[1] http://reports.weforum.org/global-risks-2015/top-10-infographics/, as of 26/01/2016 at 15:12 pm

tools on agricultural productivity, through water allocation efficiency. We based our analysis on agricultural, climatic, and market data. Did the recent increase in transactions on water markets in Australia foster improvements in the efficiency of water use, and thus in agricultural productivity? In other words, did the market reallocate water to the highest value-producing users? The approach chosen to address this question is to analyze the impact of water markets using production functions in the grape production sector.

Literature review: water market impacts on water allocation efficiency

Markets have been praised in the early literature as a feasible alternative to central water management, described as limited in its ability to reallocate resources efficiently. In this perspective, it focuses on the benefits expected from water transfers. Resorting to the private sector in the field of water allocation decisions was for example advocated by Milliman (1959), or Hartman and Seastone (1970).

Different empirical studies dedicated to water market impacts simulate their existence to estimate potential benefits. Vaux and Howitt (1984) simulate interregional water transfers in California. Using a general equilibrium approach, the authors compared the costs of such transfers to those of a gradual supply extension in water's area of arrival to meet the expected demand. The net benefits estimated from the transactions for buyers and sellers amount to $66 million for the year 1980. Besides, Vaux and Howitt expect these benefits to increase to $220 million for the year 2020. Geographically close to this first study, Dinar and Letey (1991) estimate profit functions for farmers in the San Joaquin Valley and simulate the ability to trade water in their model. Their results show better abilities to invest in irrigation technology, decreased environmental pollution and a potential reallocation of water towards the urban sector. Whittlesey and Willis (1998) analyze different alternatives aimed at maintaining a minimum flow in the Walla Walla River Basin (State of Washington, USA). Using a model predicting agricultural behavior and stream flows in the basin, they compare the cost of resorting to the market to other alternatives (storage, extraction restrictions, and loss reduction) with the same objective. The market strategy is found to be the most cost-effective approach. In Australia, Peterson et al. (2005) use the general equilibrium approach to introduce the ability to trade water in the Australian economy. Their results indicate important gains in Regional Domestic Product where water is traded with a positive global impact on

Australia's GDP. This impact is described as particularly important in years of drought ($555 million in a year subjected to important water scarcity, and $201 million in a year subject to a relative abundancy), suggesting water markets might alleviate the economic effect of droughts on the Australian economy.

Another section of the empirical literature attempting to measure water market's economic impacts analyzes actual transaction data at a microeconomic level. Hearne and Easter (1997) choose this approach and analyze transactions from water markets in Chile in the agricultural sector. They compare water values determined by crop budget analysis (i.e. by estimating how much irrigators actually paid for water) to prices included in water trades. They find gains from trade varying from $1000 per share to $10 000 per share, depending on the time and location of trades. In Australia, Bjornlund (1999) focuses on transactions in two specific areas of the Murray-Darling Basin, and relates them to the characteristics of the irrigators involved in the trade. He finds that water is in average moving towards more efficient buyers that were also growing higher-valued crops. However, he does not find evidence showing that the buyers use their newly acquired water to increase their cultivated area. Finally, Brooks and Harris (2008) analyze data from three trading zones in northern Victoria to determine consumer and producer surplus. They find surpluses averaging $20 000 a week in the Greater Goulburn area.

In parallel to these empirical estimates, limits to the use of water markets that could prevent them to improve efficiency in the use of water resources have been widely commented, in a context of limited market development. Classical limits to the use of markets are often amplified in the case of water: as water is a massive resource, the costs raising from moving the resource can be high (Turner et al., FAO 2009). Some of the transaction costs related to water trading are analyzed by Colby (1992) in the western United States, who concludes that the administrative costs are not to be considered as 'overly burdensome' to transactions in the western United States water markets around 1990.

Moreover, the potential for externalities is important. Besides the gains potentially obtained by the buyer and the seller, other actors are impacted by the reallocation of water. Changes in streamflows, return flows and impacts on water's area of origin are frequently cited in that matter and can mitigate the gains obtained by the buyers and sellers (Garrido Fernandez, 2016). Another aspect analyzed by the literature is the 'stranded asset' problem (Chong and Sunding, 2006; Heaney et al., 2006; Bjornlund, 2008; Frontier Economics et al., 2007): as irrigation water use requires heavy investment in infrastructures, these infrastructures are often shared by different users. If one of these users decides to sell his or her water entitlement, the maintenance costs of the infrastructure will be supported by the remaining users, who generally compete with the leaver. Furthermore, when an irrigator sells his rights permanently, the lack of maintaining work on his property can bring weeds and increase disease risk for the neighbors (Frontier Economics et al., 2007; Bjornlund, 2008) or even cause soil erosion (Chong and Sunding, 2006).

Moreover, different authors notice the very limited development of water markets in terms of transaction between 1980 and 2000. Some attempt to explain this phenomenon, as Rosen and Sexton (1993) who suggest the low level of transactions is due to a lack of cooperation between market actors and operational institutions actually owning the water. Saliba et al (1987) also question the limited amount of water trade that was undertaken at the time, as compared to the potential benefits that could be realized from it according to Vaux and Howitt (1984). They conclude that the interdependencies and the public good characteristics of water make perfectly competitive markets purely infeasible in practice.

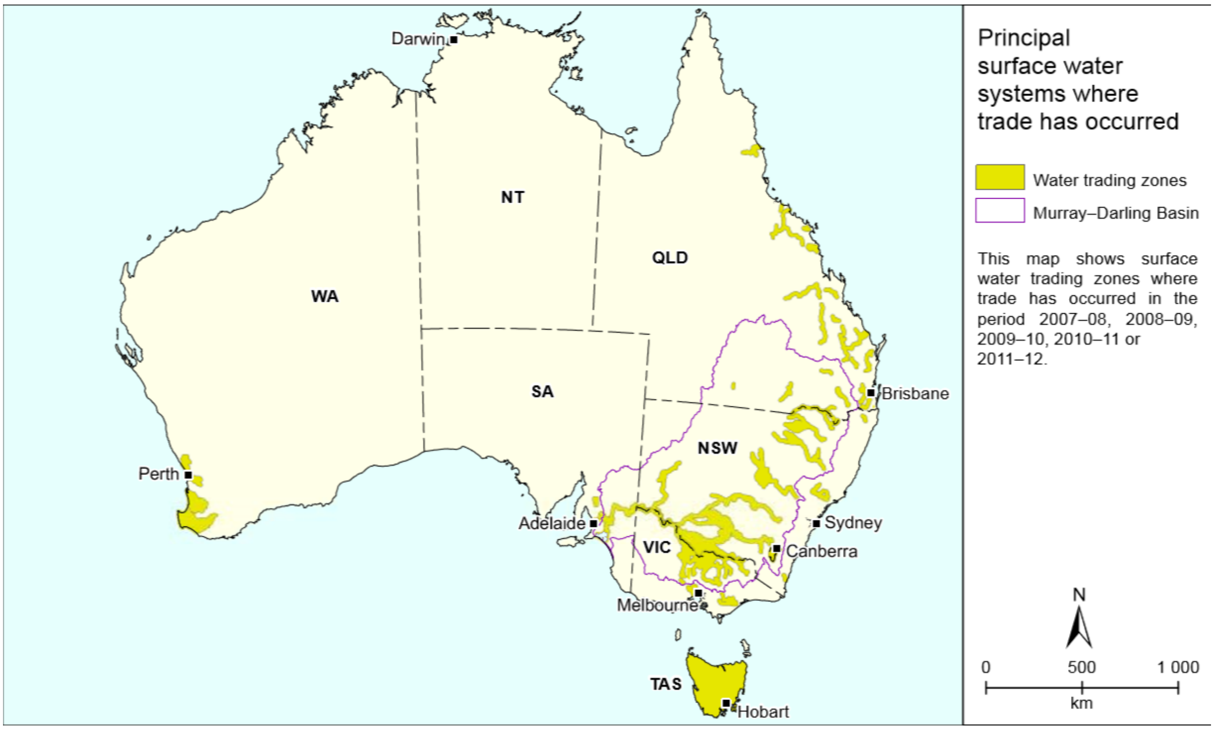
Although the literature analyzing market potential impacts and their limits through their simulation or at a micro-economic level is quite rich, the empirical analysis of regional impacts of water trade is very limited. An important reason for this is the lack of transactions that has affected markets in many countries. In the years following 2007, however, a massive increase in transactions occurred in the Murray-Darling Basin (NWC 2012). This increase followed different regulations meant to improve the functionality of water markets in the MDB: after the initial Cap and the separation of land and water rights decided in the 1990s, the National Water Initiative (2004), the Water Act (2007) and the Murray-Darling Basin Plan (2012) reformed the institutions governing water markets in Australia and attempted to reduce transaction costs. This phenomenon provides an opportunity to measure the global economic impacts of increased water transfers in a hydrologic Basin, while basing the analysis on transactions actually taking place in the Australian water markets. However, we found no article addressing this challenge. This study constitutes an attempt to fill the gap, by using the existing Australian market data, along with data obtained on the Australian agricultural production, water use, and climatic conditions.

Context

Water markets in Australia

There is no global water market in Australia. Water trade occurs in distinct markets spread around the country. Water trade is, for logistical and juridical reasons, only possible between hydrologically connected zones[1]. In particular, the Murray-Darling Basin (MDB) represents more than 60 % of the Australian irrigated surface and over 80 % of the Australian water trade (NWC 2011). The market was historically created around the agricultural sector in the MDB (Maziotis et al., 2013) and it is where water trade is the most developed and established, as illustrated by the National Water Commission (NWC):

Figure 1: Occurrence of water trading in Australia, 2007-08 to 2011-12

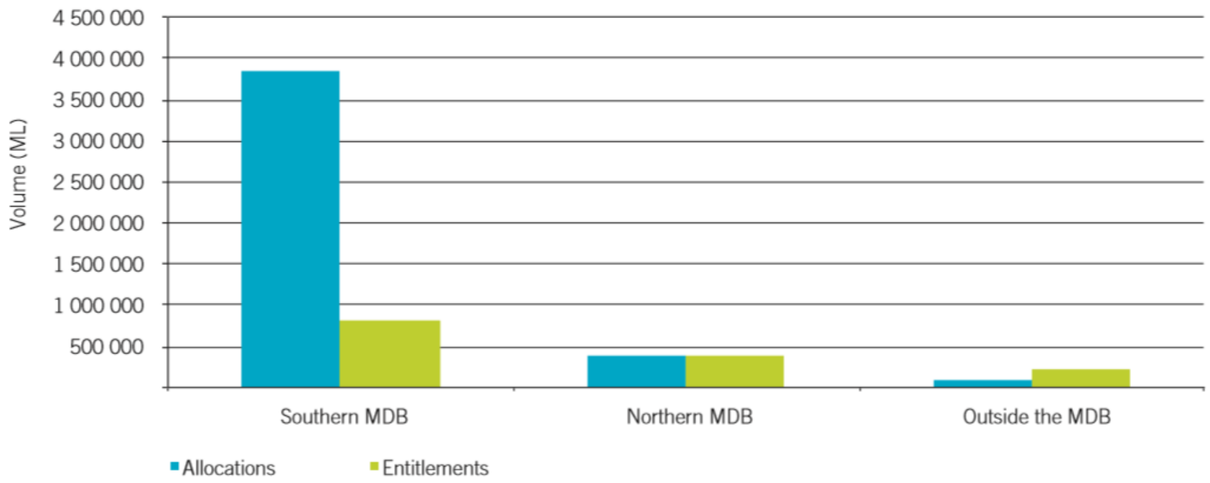


Source : NWC 2013, Figure 1.6

The basin is represented here as the area within the continuous line in the South-East corner of Australia. It involves parts of four Australian States: New South Wales, Victoria, Queensland, and South Australia. It also includes the Australian Capital Territory. As the basin is subject to a climate favoring irrigated agriculture in comparison with the semi-arid climate found northwards, agriculture covers 67% of its territory. The MDB is clearly facing a water scarcity situation. In 2015, the ratio of water demand to available water resources was superior to 0.4 in most of the basin's area, defining a "high" water stress (UN Water report 2015[2]). This and the prevalence of irrigated agriculture contribute to explain the emergence of water markets in the area: as noted by Debaere et al. (2014), a market for water resources potentially appears when water demand approaches water availability.

Different water market regions are defined by the National Water Commission "Water market reports" in Australia (NWC 2013). Inside the Murray-Darling basin, the southern-connected MDB region is the most active water trading area in the country. It is represented by the green area in the southern half of the MDB in Table 1. The northern half of the basin contains the northern MDB region, graphically represented in Table 1 as well. The third region is a gathering of different areas where water trade is occurring. The dominant market region, in terms of volume traded, is undeniably the southern MDB segment, as suggested by the following table published by the National Water Commission:

Figure 2: Water trade in three market regions, 2011-12



Source: reproduced from figure 1.7 in NWC (2013)

The important volume of water trade occurring in the southern MDB brought Grafton et al. (2011) to describe water markets in the Murray-Darling Basin as the most advanced in the world.

80% of the world's water is consumed by agriculture (UN, 2009), and the MDB is no exception to this phenomenon. As a result, water markets were historically meant to reallocate

[2] Source : UN Water report 2015, cited by Le Monde (March 20th, 2015)

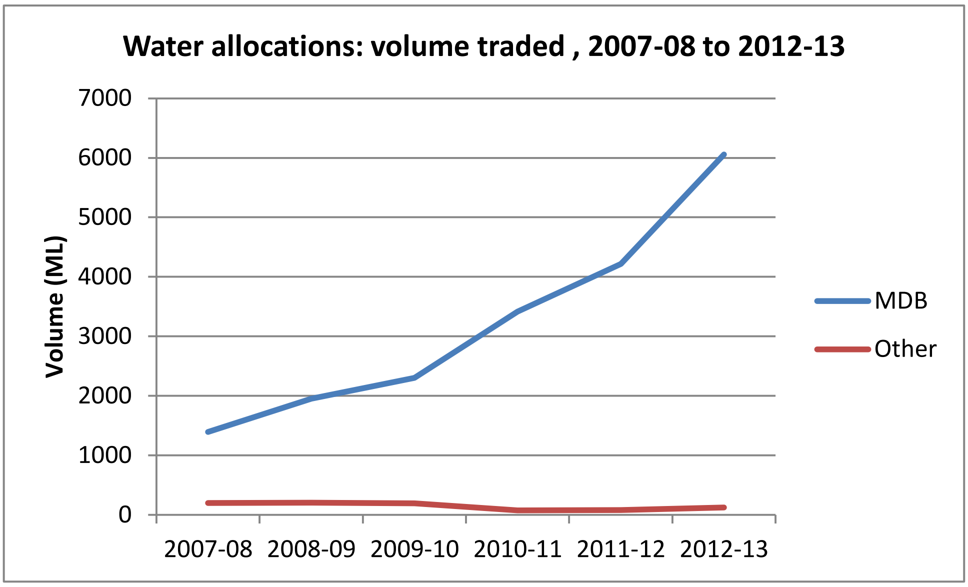
water resources in the agricultural sector, and the most important actors of water trade are irrigators. However, a number of other actors are involved in the process of exchanging water rights in Australia. This includes water brokers who provide market information and trading platforms to irrigators, federal and national authorities who launched an important buyback program destined to restitute water to the environment, and Irrigation Infrastructure Operators (IIOs) who typically own blocks of water rights on behalf of irrigators, and redistribute these rights to their members. All of these actors trade under federal, national and sometimes local regulations that have been progressively adapted to increase irrigators' participation to water markets.

The process historically establishing Australian water markets implied different steps, the most important being the following:

- In 1995, a cap was established on total water extraction in the Murray-Darling Basin. This decision set the maximum level of water extraction in the basin at the 1994 extraction level. This step caused a large increase in the water traded on the market, as additional needs for water had to be fulfilled through the market.
- In 2004, the National Water Initiative (NWI) precisely defined the generic terms 'entitlement' and 'allocation', common to all Australian States, in an effort to unify the existence of many different water markets. It recognized the need for better designed water markets to improve efficiency in water uses, in a context of low participation to such markets.
- In 2007, the national 'Water Act' took additional steps to decrease barriers to trade.
- In 2012, finally, the Murray-Darling Basin Plan defined freedom of trade as the norm and restrictions to trade in the Basin as exceptions, while establishing an authority in the Basin responsible for the management of water resources.

In parallel to this process, transactions in the MDB increased in a major way between 2007-08 and 2012-13. The following figure illustrates the trend in allocation trading, the exchange of temporary rights to water:

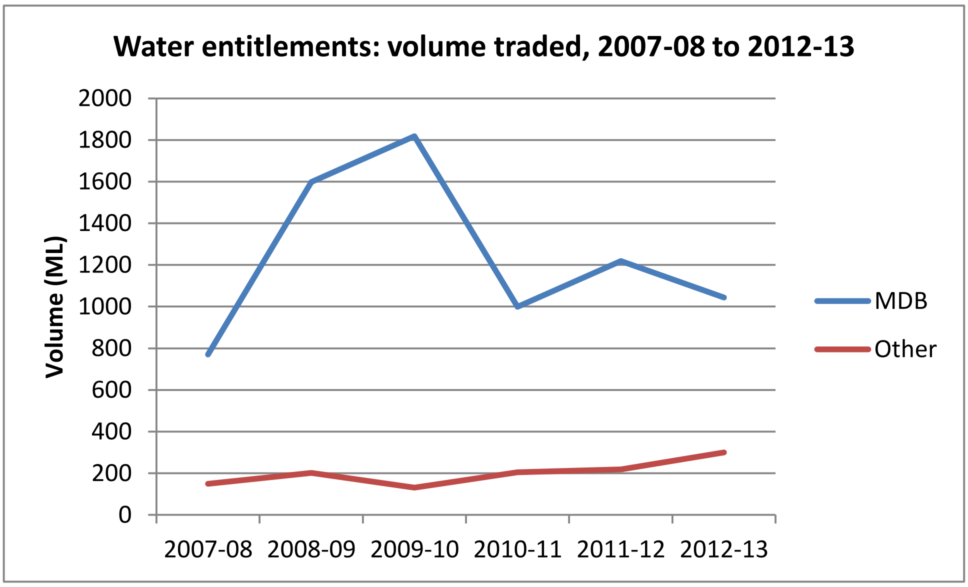
Figure 3: Allocation trade in Australia, within and without the Murray-Darling Basin



Source: adapted from data in NWC (2014)

While allocation trading remained at a similar level between 2007-08 and 2012-13 outside of the MDB, it constantly increased in the Basin to reach a total of 6058 ML traded in the year 2012-13, more than four times its initial value of 1393 ML traded. In the entitlement market, which is the exchange of permanent rights to water, volumes traded did not follow the same pattern:

Figure 4: Entitlement trade in Australia, within and without the Murray-Darling Basin



Source: adapted from data in NWC (2014)

Although the Murray-Darling basin still distinguishes itself by the level of water trading that occurred, the precedent trend towards higher trading volumes is not as strong in the entitlement market, suggesting there is less change in permanent ownership than in temporary ownership for water in the agricultural sector.

There is therefore a massive increase in market activity following the year 2007/08 in the Murray-Darling Basin allocation markets. This change, mainly occurring in the southern connected part of the Basin, was largely intended by federal and national authorities, as water markets were established in the aim to increase efficiency in the allocation of water resources: markets are expected to allocate water towards those creating the most value with it. This can be explained by the water scarcity phenomenon affecting the Basin in the 2000s. As the Millennial Drought hit Australia in the years following 2004, with effects lasting until 2010 for certain areas in the MDB, the authorities undertook the establishment of water markets in an effort to reallocate water resources more efficiently. The aim of our study is to determine whether rising transactions in water markets actually fostered such a change between 2007-08 and 2013-14.

Specifically, we chose to focus on the grape production sector. Grapes are produced in all Australian States and Territories and constitute one of the major commodities produced in Australia. This allows for comparisons between different areas across the country, and we will use this opportunity. Secondly, grape production necessitates a constant access to water throughout the year, meaning that it is an almost exclusively irrigated crop. It is therefore impacted by the water market when such a market is available, as irrigators are the most active participants to the water market. Finally, grape production in Australia is produced in a relatively constant way between 2009-10 and 2013-14, our period of study. The consistency of the output's quantity enables a more robust analysis of agricultural productivities, while making reallocations of water within the grape production sector possible.

Methodology and data

The data

The data analyzed in the next sections was obtained through different sources. Most of the data available is defined at a regional level: the 54 Australian Natural Resource Management Regions, as defined by the ABS, form the geographic basis of our analysis. The following sections will present the data used in this research, along with the justification for its use in our matter of interest.

Agricultural data

To analyze the efficiency of water use in the grape production sector, we chose to use data relating to the value of agricultural production in the sector and to the amount of water used to generate this production. The Australian Bureau of Statistics (ABS) was the main source for this required data. The ABS reports 'Agricultural Commodities', 'Water Use on Australian Farms' and 'Value of Agricultural Production' for each year between 2009-10 and 2013-14 provided annual data on grape production, in tons and value generated for each NRM region in Australia, as well as water use in the grape production sector in the same time-period. As the cultivated area is an important factor explaining agricultural production, it has been included in our database and is expected to induce a higher level of production. The agricultural labor productivity was also derived for the year 2013-14, by relating the total agricultural production to the number of permanent agricultural employees in the agricultural sector. This indicator was used in order to control for the potential correlation between the global agricultural labor productivity and its counterpart in the grape production sector. As we could find no evidence of such a correlation, however, this variable was not used in the results presented.

Climatic data

Climate has been described as the most important determinant of agricultural productivity, mainly through its influence on temperature and water regimes (Kang et al, 2009). We therefore use rainfall and potential evapotranspiration in our analysis, in order to take these determinant influences into account. As estimates of rainfall or temperature at a NRM region level are not available, the data has been computed based on the rainfall, latitude and temperature of individual stations across Australia. The computation procedure varies according to the concerned data, and is described in the following sections.

Rainfall

The procedure used to obtain estimates of the annual rainfall for each of the 54 NRM regions between 2009-10 and 2013-14 is the following:

Step 1: 10 hydrographic stations have been defined for each region. These stations have been chosen in order for them to cover most of the region's territory, although this choice was constrained by the limited number of stations available. A list of the available stations can be found on the Australian Bureau of Meteorology's website[3].

Step 2: Monthly rainfall data between July 2009 and June 2014 was extracted for the 540 stations through the Australian Bureau of Meteorology (BoM) online database, and estimates for annual rainfall were computed from these monthly estimates.

Step 3: Annual rainfall for a given NRM region was defined as the average of the annual rainfall found in the 10 stations defined in step 1.

The estimates of annual rainfall used in this study are therefore based on daily observations made in 540 different stations across Australia's 54 NRM regions, between July 2009 and June 2014. Rainfall has an ambiguous impact on agricultural productivity: on one side, it increases a crop's access to water, therefore facilitating its development. On the other side, it increases disease risk and therefore decreases crop yield. This second effect was described as dominant in the grape production sector by Webb (2006).

Temperature

The procedure used to obtain temperature estimates is similar to the one described earlier. However, as individual stations providing temperature observations are not as commonly available as in the case of rainfall, the number of stations selected for each NRM region was sometimes lower. As a consequence, each region is represented by 5 to 10 stations, depending on the existence of hydrometric stations recording temperature in the region and on their location. Besides, temperature is analyzed through two different monthly estimates:

- The mean maximum temperature, defined as the average of daily maximum temperatures in a given month;

[3] http://www.bom.gov.au/climate/data/index.shtml?bookmark=200 , as of January 21st, 2016 at 11:02 am.

- The mean minimum temperature, defined as the average of daily minimum temperatures in a given month

The mean temperature, following Allen et al. (1998), was then defined as:

$$Mean\ Temperature = \frac{Mean\ Max\ Temperature + Mean\ Min\ Temperature}{2}$$

The procedure used to obtain estimates for the mean annual temperature is therefore:

Step 1: Definition of 5 to 10 stations, geographically representative of the NRM region concerned;

Step 2: Extraction of monthly mean maximum and mean minimum temperature data for the given stations through the BoM;

Step 3: Computation of the monthly mean temperature through Equation (3);

Step 4: Computation of the annual mean temperature, defined as the average of all monthly mean temperatures in a given year, for each NRM region in each year of our analysis.

Evapotranspiration

Potential Evapotranspiration (PE) has been calculated from the temperature and latitude in the different NRM regions. Potential Evapotranspiration is a measure of the quantity of water that will evaporate and transpire from the crop, under ideal hydrometric circumstances. It is computed based on temperature and takes into account different additional factors, such as radiations that depend on the latitude of a given area. It is therefore often described as a better predictor than temperature and is widely used in the literature (see Webb, 2006 or Blanc, 2016 for examples). It is expected to increase water use, as it increases the irrigation needs to maintain a constant access to water for a given crop. The effect of evapotranspiration once water use is set constant, however, is difficult to determine.

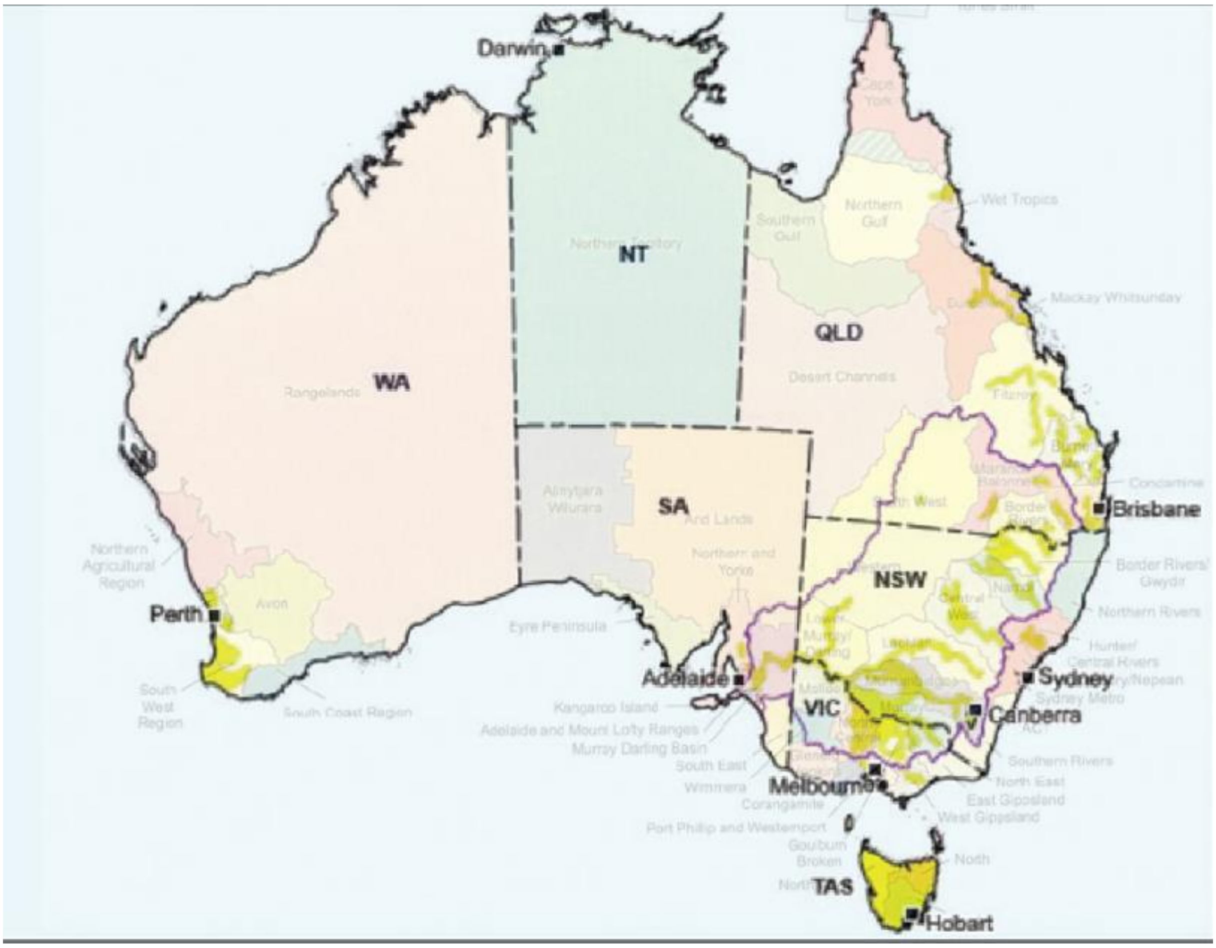
To determine the annual potential evapotranspiration in the different NRM regions we chose to rely on the FAO Penman-Monteith equation, as recommended by the FAO (Allen et al., 1998). Some missing climatic data (wind speed, radiations, etc.) was simulated according to Allen et al.’s advice.

Market data

There are two types of market transactions ongoing in the Australian water markets. Entitlement trading implies the exchange of a permanent water right (i.e. the right to perceive an annual allocation for each year following the trade), while allocation trade implies the exchange of one annual allocation, for a given water year. For both categories, water markets are expected to increase water productivity and thus agricultural productivity as water is sold to the most efficient agents (Hodgson, 2006; Peterson et al, 2005).

Our data relating to market information was limited by the amount of information available, still limited at the time of our study. Nonetheless, the data on transaction volumes in Australian water markets was obtained in the National Water Commission's *Water market reports* (NWC 2013). As there is no sufficient market information available at the Natural Resource Management level, we chose to focus on the presence of water markets as a dummy variable. We therefore do not account for the intensity of market activity. The existence of water market is represented as a binary variable, equal to 1 in presence of water markets and 0 elsewise. To define the presence of water markets in a given NRM region, geographic data obtained through the 2012 National Water Commission's report and a mapped representation of NRM regions in 2006, still in use in the ABS reports as of today, were crossed. As the level of aggregation used by the Australian Bureau of Statistics and the National Water Commission differ, the data was obtained by superposition. The following figure crosses NWC data on the presence of active water markets with the Natural Resource Management regions used by the ABS:

Figure 5: Market presence in NRM regions



Source: adapted from figures in NWC (2012) and FRA (2006); Map created by superposition with the ArcGIS software.

All the areas represented in green relate to zones where water trading occurred at least once between 2007-08 and 2011-12. The Murray-Darling Basin's frontiers appear in purple. The variable describing the existence of water markets was set to be 1 if trading occurred at least once in the corresponding area, and 0 elsewise.

Econometric Model

The approach chosen in this study was to analyze the impact of water markets, particularly in the southern connected Murray-Darling basin, on agricultural productivity in the different Australian NRM regions. To investigate whether water markets induced a higher agricultural productivity of grape production in the regions accessing such markets, we relied on two types of production functions. Such functions have previously been applied in the literature dedicated to the analysis of agricultural production (Bujel and Ghimire, 2006; Quang Long et al.,2013; Akhigir and Shabu, 2011).

Consider the following production function:

$$GPv_{it} = A_{it}F(AREA_{it}, Wateruse_{it})\exp(u_{it})$$

where GPv_{it} is the output, A_{it} is the technological level (or total factor productivity), F is a function of two inputs, land surface $AREA_{it}$ and quantity of water $Wateruse_{it}$, u_{it} is the regression error. We assume that TFP has the following form:

$$A_{it} = A_0\exp(\delta_1 t + \delta_2 Rainfall_{it} + \delta_3 PE_{it})$$

which means that the technological level is decomposed into two parts: an autonomous technological change (δt), on the one hand, and a part related to weather conditions (such as rainfall $Rainfall_{it}$ and potential evapotranspiration PE_{it}) on the other hand.

By applying the logarithm transformation to the production, we obtain

$$\ln GPv_{it} = c + \delta_1 t + \delta_2 Rainfall_{it} + \delta_3 PE_{it} + \delta_4 Market$$
$$+ \ln F(AREA_{it}, Wateruse_{it}) + u_{it}$$

where $c \equiv \ln A_0$. Observe that we have to specify F in order to have a full model for estimation. We can use either a Cobb-Douglas function, i.e. $\ln F(AREA_{it}, Wateruse_{it}) = \alpha \ln AREA_{it} + \beta \ln Wateruse_{it}$, or a more general function such as translog, i.e. $\ln F(AREA_{it}, Wateruse_{it}) =$
$\alpha_1 \ln AREA_{it} + \beta_1 \ln Wateruse_{it} +$
$\frac{1}{2}\alpha_2(\ln AREA_{it})^2 + \frac{1}{2}\beta_2(\ln Wateruse_{it})^2 + \frac{1}{2}\gamma \ln AREA_{it} \ln Wateruse_{it}$.

The model becomes:

$$\ln GPv_{it} = c + \delta_1 t + \delta_2 Rainfall_{it} + \delta_3 PE_{it} + \delta_4 Marketi + \alpha \ln AREA_{it} + \beta \ln Wateruse_{it} + u_{it}$$

in the Cobb-Douglas case, and

$$\ln GPv_{it} = c + \delta_1 t + \delta_2 Rainfall_{it} + \delta_3 PE_{it} + \delta_4 Marketi + \alpha_1 \ln AREA_{it} + \beta_1 \ln Wateruse_{it} + \frac{1}{2}\alpha_2 (\ln AREA_{it})^2 + \frac{1}{2}\beta_2 (\ln Wateruse_{it})^2 + \frac{1}{2}\gamma \ln AREA_{it} \ln Wateruse_{it} + u_{it}$$

in the translog function case.

It should be noted that the problem of endogenous regressors may arise with the specification above. This issue is especially related to the presence of a water market. In this respect, we think that the presence of a water market can be affected by the level of agricultural production, political decisions made by the regulator and other factors that are not included in the model. Omitted variables include other production inputs such as labour and physical investment that are not observed from the data. Consequently, the estimation strategy should properly take the endogeneity of $Market_i$ into account.

We adopt the instrumental variables approach to estimate the model. Alongside the regressors included in the model, we believe two indicators can be used to instrument our Market variable. The total irrigated area within a region increases the pressure on water resources demand and thus the probability of existence of a water market. Moreover, historically, the Murray-Darling basin hosted the first water markets in Australia and has developed an extended juridical framework for the use of water markets. Its markets became the most intensively used markets in the country (see section Context). The affiliation to the MDB is therefore strongly related with the presence of a water market.

The estimation can be sketched briefly as follows. First, we regress $Market_i$ on the whole set of instrumental variables, including $AREAirrigT_{it}$ and MDB_i to form a predictor for $Market_i$. Secondly, we perform the panel regression for the above model where $Market_i$ is replaced by its predictor.

Results

The results, using both Translog and Cobb Douglas production function types, appear in the following table:

	Grape production value			
Production function type	**CD**	**CD**	**TL**	**TL**
Temperature variable used	**PEFAO**	**Meantemp**	**PEFAO**	**Meantemp**
Market	0.0121	0.151	-0.0344	0.0920
	(0.02)	(0.26)	(-0.06)	(0.16)
lnAREAG	0.837***	0.893***	1.075***	1.156***
	(8.98)	(9.39)	(3.52)	(3.86)
lnAREAG2			0.0325	0.0216
			(0.57)	(0.39)
lnWateruseG	0.261***	0.228***	0.289	0.237
	(3.82)	(3.34)	(1.62)	(1.35)
lnWateruseG2			0.0635**	0.0569*
			(2.14)	(1.93)
c.lnAREAG#c.lnWateruseG			-0.117	-0.100
			(-1.52)	(-1.32)
PEFAO	0.00144**		0.00123**	
	(2.49)		(2.18)	
Meantemp		0.147***		0.129***
		(3.66)		(3.29)
Rainfall	-0.000212	-0.000171	-0.0000694	-0.0000579
	(-0.73)	(-0.59)	(-0.23)	(-0.19)
SpreadTemp	-0.0916**	-0.0364	-0.0855**	-0.0395
	(-2.12)	(-1.20)	(-1.99)	(-1.32)
Year2010	-0.122	-0.0482	-0.139	-0.0655
	(-0.84)	(-0.34)	(-0.92)	(-0.43)
Year2011	0.0784	0.111	0.0873	0.118
	(0.59)	(0.84)	(0.65)	(0.88)
Year2012	-0.193	-0.130	-0.157	-0.103
	(-1.45)	(-0.99)	(-1.18)	(-0.77)
Year2013	-0.323**	-0.284**	-0.315**	-0.282**
	(-2.47)	(-2.21)	(-2.40)	(-2.18)
_cons	8.263***	5.899***	7.443***	5.406***
	(9.58)	(5.32)	(7.47)	(4.61)
N	187	187	187	187

t-statistics in parenthesis; * p<0.1 ** p<0.05 *** p <0.01

In order to justify the additional use of a translog production function, the null hypothesis that all quadratic and interaction terms are equal to zero was tested against the data. The results reject the null hypothesis in both translog regressions. Additionally, the results were reproduced using an alternative instrument for our market variable (see Appendix 1) and excluding observations subject to specific error levels (see Appendix 2).

The classical components of our production function are behaving as expected: water use and the cultivated surface both have a significant positive impact on grape production. The impact of rainfall on agricultural production is not significant. Rainfall's impact on agricultural productivity has been commented in the literature (see Webb, 2006) as having two contradictory impacts: it is generally expected to have a negative influence on agricultural yield in the case of grapes as it increases disease risk for the crop, while it increases the amount of water available to grapevines, thus favoring their growth. Our result is unconclusive in that matter.

Due to the high correlation coefficient between potential evapotranspiration (PE) and mean temperature (Meantemp), we could not use both in our regressions. Our results are therefore presented using alternatively potential evapotranspiration and temperature. Potential evapotranspiration (PE) has a significant impact in both the Cobb Douglas and the Translog function. Although PE is taken into account in the literature dedicated to agricultural productivity (Blanc et al, 2016), it is generally because of its impact on water regimes. As a consequence, potential evapotranspiration is determinant to agricultural productivity through its impact on water use. Our results indicate that PE might have a significant autonomous impact on agricultural yield, as water use is set constant. The mean temperature also appears as having a positive, significant impact on agricultural production.

Interestingly, our market variable has no significant impact on grape production, everything else set equal. We tested the potential weakness of our instrument by computing the Cragg Donald statistics, but found no weak instrument according to Stock and Yogo's critical values (Stock and Yogo, 2005) in all four regressions. Results for this test can be found in Appendix 3. This suggests that the market as we defined it did not foster a more efficient use of water in the grape production sector between 2009-10 and 2013-14. Bjornlund (1999), in his empirical study of water markets in the Murray-Darling Basin, noticed that water was sold to more efficient farmers in terms of water use and value generated; however, he also observed that the buyers did not use their newly acquired water to increase their cultivated surface. Our results seem to comfort his findings, as the massive increase in water trade in the Murray-Darling Basin in our period of study did not impact water productivity in a significant way within the grape production sector. This would imply that markets benefited to the most efficient farmers, as they used their access to reduce their risk by acquiring additional water, but that it did not increase global water productivity in areas accessing water markets. Transaction costs and third party impacts could also play a role in this matter: efficiency gains might have been prevented by unexpected transaction costs (delays, transmission loss, policy induced transaction costs, etc.), as well as by negative externalities that increase losses in water's area-of-origin.

Conclusion

Water markets emerged in the 1980s as a tool to deal with water scarcity. By reallocating existing water resources, instead of extending the existing supply through massive and costly engineering projects, they are expected to bring more efficiency to the use of water resources. Although the theoretical literature dedicated to water markets is quite rich, the empirical research trying to identify such impacts through the analysis of macroeconomic data is limited. Based on data relative to agricultural production, climate and market activity, our research attempted to fill the gap and could not find any significant impact of the presence of water markets on grape production in a given Australian NRM region. Our results indicate that in the areas where they exist, water markets do not seem to have favorably impacted agricultural productivity through the reallocation of water. Confirmation of this result and further research on the topic would be needed, as the empirical literature does not provide a sufficient explanation for this phenomenon.

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Reports used in the constitution of the data (Source: Australian Bureau of Statistics):

For each year from 2007-08 to 2013-14 included:

‘Agricultural Commodities’

‘Value of Agricultural Commodities Produced’

‘Water Use on Australian Farms’

Appendix 1: Results using an alternative instrument

In order complement our instrumental approach, we used an alternative instrument for our market variable. Instead of using the total irrigated area, the proportion of agricultural area irrigated in a given NRM region was used in the results that appear in the following table:

	Grape production value			
Production function type	**CD**	**CD**	**TL**	**TL**
Temperature variable used	**PEFAO**	**Meantemp**	**Meantemp**	**PEFAO**
Market	-0.852	-0.528	-0.626	-0.950
	(-1.03)	(-0.69)	(-0.79)	(-1.08)
lnAREAG	0.909***	0.958***	1.124***	1.032***
	(9.26)	(9.73)	(3.57)	(3.17)
lnAREAG2			0.0235	0.0365
			(0.40)	(0.61)
lnWateruseG	0.234***	0.204***	0.193	0.244
	(3.38)	(2.99)	(1.06)	(1.30)
lnWateruseG2			0.0511*	0.0580*
			(1.72)	(1.91)
c.lnAREAG#c.lnWateruseG			-0.0872	-0.105
			(-1.13)	(-1.32)
PEFAO	0.00144**			0.00124*
	(2.21)			(1.88)
Meantemp		0.159***	0.143***	
		(3.49)	(3.13)	
Rainfall	-0.0000814	-0.0000390	0.0000986	0.0000825
	(-0.28)	(-0.14)	(0.32)	(0.27)
SpreadTemp	-0.0681	-0.0168	-0.0165	-0.0579
	(-1.40)	(-0.50)	(-0.48)	(-1.17)
Year2010	-0.160	-0.0752	-0.0941	-0.180
	(-1.11)	(-0.53)	(-0.63)	(-1.19)
Year2011	0.0841	0.122	0.129	0.0931
	(0.63)	(0.93)	(0.97)	(0.69)
Year2012	-0.202	-0.132	-0.108	-0.171
	(-1.52)	(-1.01)	(-0.82)	(-1.28)
Year2013	-0.300**	-0.265**	-0.260**	-0.290**
	(-2.30)	(-2.09)	(-2.04)	(-2.22)
_cons	7.887***	5.317***	5.046***	7.360***
	(8.38)	(4.38)	(3.90)	(6.69)
N	187	187	187	187

t-statistics in parenthesis; * p<0.1 ** p<0.05 *** p <0.01

Appendix 2: excluding observations subject to error levels 2 and 3

Excluding observations subject to specific error levels from the ABS data

Our data extracted from the Australian Bureau of Statistics' database is subject to specific error levels, due to the random sampling method used by the ABS. Three error levels were defined based on the classification established by the ABS. Error level 1 corresponds to a standard error of the estimator located between 10 and 25% of the estimator's value. Between 25% and 50%, the error level was set to 2. Finally, standard errors over 50% of the estimator's value define the error level 3. In order to test the effect of these error risks on the validity of our results, we conducted our analysis a second time by only keeping observations subject to an error level inferior to 3. The same test was conducted only with observations subject to an error level inferior to 2. The results are coherent with our main regression and appear in the next page:

	Grape production value							
Production function type	**CD**	**CD**	**CD**	**CD**	**TL**	**TL**	**TL**	**TL**
Temperature variable used	**PEFAO**	**Meantemp**	**PEFAO**	**Meantemp**	**Meantemp**	**PEFAO**	**Meantemp**	**PEFAO**
Market	0.254	0.390	0.492	0.551	-0.252	-0.512	0.122	-0.0848
	(0.47)	(0.74)	(0.90)	(1.03)	(-0.43)	(-0.81)	(0.21)	(-0.14)
lnAREAG	0.694***	0.787***	0.463***	0.561***	1.010***	0.822**	0.702*	0.473
	(6.12)	(6.74)	(4.14)	(4.76)	(3.05)	(2.38)	(1.86)	(1.23)
lnAREAG2					0.0801	0.113	0.0445	0.0829
					(1.18)	(1.58)	(0.64)	(1.15)
lnWateruseG	0.341***	0.276***	0.532***	0.462***	0.391*	0.539**	0.765***	0.947***
	(4.04)	(3.23)	(6.13)	(5.22)	(1.70)	(2.25)	(2.84)	(3.44)
lnWateruseG2					0.0967***	0.113***	0.0313	0.0493
					(2.60)	(2.91)	(0.76)	(1.16)
c.lnAREAG#c.lnWateruseG					-0.199**	-0.246**	-0.105	-0.158
					(-2.04)	(-2.40)	(-1.05)	(-1.54)
PEFAO	0.000858		0.000942*			0.000637		0.000683
	(1.56)		(1.90)			(1.13)		(1.31)
Meantemp		0.114***		0.109***	0.0967**		0.0976***	
		(2.93)		(3.04)	(2.53)		(2.59)	
Rainfall	-0.000404	-0.000412	-0,000672**	-0.000642**	-0.000131	-0.0000515	-0.000492*	-0.000447
	(-1.41)	(-1.47)	(-2.32)	(-2.30)	(-0.42)	(-0.16)	(-1.69)	(-1.44)
SpreadTemp	-0.0861**	-0.0536*	-0.120***	-0.0757***	-0.0367	-0.0546	-0.0646**	-0.0921**
	(-2.19)	(-1.90)	(-3.38)	(-2.94)	(-1.26)	(-1.30)	(-2.46)	(-2.39)
Year2010	-0.125	-0.0693	0.107	0.149	-0.154	-0.231	0.0734	0.000852
	(-0.90)	(-0.51)	(0.78)	(1.11)	(-1.02)	(-1.49)	(0.50)	(0.01)
Year2011	-0.0356	-0.00156	0.0216	0.0317	0.00680	-0.0297	0.0237	0.00539
	(-0.29)	(-0.01)	(0.16)	(0.25)	(0.05)	(-0.23)	(0.19)	(0.04)
Year2012	-0.195	-0.150	-0.0171	0.00517	-0.121	-0.157	0.0335	0.0160
	(-1.54)	(-1.19)	(-0.13)	(0.04)	(-0.95)	(-1.19)	(0.27)	(0.12)
Year2013	-0.184	-0.166	0.0617	0.0762	-0.176	-0.184	0.0781	0.0661
	(-1.48)	(-1.37)	(0.46)	(0.59)	(-1.41)	(-1.41)	(0.61)	(0.49)
_cons	9.303***	7.345***	10.15***	8.110***	6.155***	7.722***	6.644***	8.414***
	(11.34)	(6.63)	(12.64)	(7.36)	(5.05)	(7.35)	(4.85)	(7.19)
N	159	159	107	107	159	159	107	107

t-statistics in parenthesis; * p<0.1 ** p<0.05 *** p <0.01

Appendix 3: Additional tests

The tests for weak identification and the justification for use of the translog model have been computed for our main results. They are presented in the following table :

Production function type Temperature variable used	**CD** **PEFAO**	**CD** **Meantemp**	**TL** **PEFAO**	**TL** **Meantemp**
Weak identification test: H0 = instrumented variable weakly identified				
Cragg Donald statistic	23.46	24.23	22.57	23.48
Critical value	19.93			
H0 rejected?	YES	YES	YES	YES
If no, maximum bias				
Test :H0: quadratic and interaction terms in the translog model are all equal to zero				
H0 Rejected?			YES	YES
p value			0.0734	0.0960