The Effects of Water Markets: Evidence from the Rio Grande[1]

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Abstract

We present the first difference-in-difference analysis of the impact of water markets on production. From 1954 to 2012, we compare the change in crop composition in counties in the Rio Grande water market with neighboring control counties before and after the water market was established in 1971. We show water markets facilitate a shift from low- to high-value crops, or, with our empirical proxies, from less productive crops that generate on average less dollars per unit of water to ones that are more productive. We find that such reallocations are economically significant and especially prevalent in times of drought.

Population growth, economic development, and climate change make water increasingly scarce in many regions of the world. In spite of many reports in the media, water is a renewable resource and the world is not running out of water. There is, however, a need to improve how water is managed, how it is distributed among its competing uses, and also how productively it is used. This need is all the more pressing as there is little appetite to build (environmentally) costly dams, reservoirs, canals, or wells.[2] It is against this background that we study water markets empirically.

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[2] UN (2012) calls for better water management. Zetland (2011) and Griffin (2016) describe the shift from increasing water supply in response to water scarcity to managing demand. Debaere and Kurzendoerfer (2017) documents how the changing composition

Markets should have potential especially for improving water's allocation since water is often in public hands and priced according to political consensus.[3] The price signals that markets send could also trigger a more flexible and decentralized response to droughts and changing environmental and economic conditions, which could make economies more resilient.[4]

Water markets are increasingly used and promoted in the United States, Australia, Chile, and elsewhere. They are comparable to carbon markets and trading programs for sulfur dioxide in that they are cap-and-trade systems in which water rights are bought, sold, or leased independent of the land title.[5] [6] Economic theory has it that water trading brings about a more efficient water allocation. Those who can use water most productively *at the margin* are eager buyers of water, whereas *marginally* less-productive users are willing sellers. We investigate a common but untested prediction about the shift in production that water markets induce. With an explicit price of water and a cap on overall water use, water markets should move production from low- to high-value activities, which is short for saying away from activities that *on average* use less to ones that use more (non-water) factors of production per unit of water. To study this prediction, we focus on agricultural production in the Rio Grande water market, which is one of the U.S.' oldest markets.[7] In terms of our empirical proxies, our exercise amounts to checking whether water markets increase the share of crops that are on average most productive in terms of dollars in sales per units of water.[8]

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of the U.S. economy accounts for 35 to 50% of its water productivity gains since 1950. Debaere (2014) illustrates how water resources affect the international pattern of production and trade.

[3] Early references are Vaux and Howitt (1984) and Howe et al. (1986). Colby et al. (1987) and Easter et al. (1998) are influential publications covering many aspects of water markets with multiple case studies.

[4] Dinar et al. (2015) survey existing water-pricing policies worldwide. Olmstead (2010) emphasizes the role of price adjustments in quelling existing concerns of the limits-to-growth debate of the 1970s.

[5] For surveys and broad-based assessments of water markets, see Chong and Sunding (2006), Grafton et al. (2011), Grafton et al. (2012), and Debaere et al. (2014). Garrick et al. (2013) discusses the evolution of water markets. For a survey on cap and trade, see Schmalensee and Stavins (2017)

[6] This distinguishes water markets from groundwater ranching (buying land with associated groundwater resources) or internal water transfers within a district; see Chang and Griffin (1992).

[7] Ghimire and Griffin (2014) study the role of water districts on transfers between agriculture and cities.

[8] We prefer the common terminology of low- versus high-value activities, and its reference to more or less (non-water) production factors per unit of water, rather than referring to activities water intensity. 'Water intensity' is often defined in purely physical terms (water per kilo or water per hectare), almost devoid of economic value creation. Crops may use similar liters of water per kilo or hectare, but the high value crops are those that in addition use more capital, labor, etc.

Agriculture is the world's heaviest user of water. It is under ever-increasing pressure to feed the world's growing population and has to adapt to a changing climate.[9] It is clear that irrigation that has been expanding in recent decades has is important for how agriculture adapts.[10] It is here that water markets could play a key role. In the absence of an overall cap on water use and a realistic price of water, the trajectory of water use in agriculture is all too familiar. As has been observed in the Great Plains above the Ogallala aquifer, irrigation is often associated with agricultural expansion, a gradual shift toward more (not less) water-intensive crops, and depleting (ground) water resources.[11] The reason for this unfortunate trajectory is well understood. Water is the ultimate open-access resource that is often available for free, which invites overuse. Water markets, on the other hand, hinge on the private assignment of property rights, and they are an answer to the tragedy of the commons. To see whether water markets are effective, it is therefore critical to understand whether and how water markets alter the existing crop composition.[12] We study the Rio Grande market in Texas that came online in the early 1970s after a lengthy adjudication process and a lawsuit to prevent overuse. Between 1954 and 2012, we investigate with county-level data whether water markets change the composition of crops that are grown in water market counties compared to neighboring control counties. To our knowledge, ours is the first difference-in-difference analysis to investigate the actual impact of water markets on production. Moreover, a distinct advantage of our relatively long study period is that we have sufficient variation in weather conditions to assess the water market's operation.

Our difference-in-difference approach differs markedly from the existing literature. Linear programming methods and simulations are common to assess the potential gains from water trading.[13] While such analyses are insightful they, to some extent, assume the optimal outcome. They do not tell us whether the optimal crop allocation actually materializes once a water market is in place. Our approach also differs from studies with actual water market transactions, see Chang and Griffin, 1992, or on survey data of past transactions, as in Hearne and Easter (1999). We

[9] Hornbeck and Keskin (2014), Hornbeck (2012), Deschênes and Greenstone (2007), Conan (2011), Libecap (2011), Ostrom (2011).

[10] According to the FAO Aquastat, 13% of arable land was irrigated in 1961, and 23% in 2010.

[11] Hornbeck and Keskin (2014) and Sekhri (2011).

[12] Hardin (1968).

[13] See Easter et al. (1998), Howitt and Vaux (1984), Dinar and Letey (1991), Weinberg et al. (1993), and Rosen and Sexton (1993) for a few examples.

sidestep some of the challenges of such studies that depend relate to the (often poor) quality and availability of water price and quantity data, and the complexity of water-market transactions. Instead, we investigate the changing production patterns due to a water market.[14] Note that there is also a small experimental literature on water markets that seeks to understand their operation and impact with well-designed experiments in the lab.[15]

Any student of water markets quickly realizes that water-market transactions are complex, with many institutional and practical hurdles to their effectiveness.[16] There is a theoretical literature that studies, often with simulations, many potential complications. It has been investigated how the gains from water trading interact with search or intermediation costs, drainage, and environmental pollution; researchers have looked at how water markets are impacted by uncertainty and asymmetric information, different types of water rights or technologies, and orderings of crop plantings; it has been investigated how water markets are affected by interactions between ground and surface water, or by deviations from perfect competition.[17] The complexities of this literature open the door for an almost limitless set of possible circumstances and market outcomes. It is against the background of this literature that our paper is to be read.

In an effort to track the basic market forces at work, we want to consciously minimize the number of complicating factors, and choose the Rio Grande water market for our study. The Rio Grande market typically gets good reviews as a well-functioning market. [18] The water market is relatively thick and has low transaction costs. There are few concerns about externalities, and there are limited alternative water sources beyond the surface water that is traded. In this relatively favorable environment, we investigate how the crop composition changes with a water market. We include a whole battery of controls, taking into account county-, crop-, and year-specific factors and other time-varying factors that may differ between treatment and control counties. We also

[14] Data availability for water markets varies by water basin. It is often a struggle to identify the exact timing, exact geographic location, and specific characteristics of the buyer and the seller of water trades, as well as the particular nature of the water rights involved. For studies of water prices and transactions, see Brown (2006) and Brewer (2008).

[15] See, for example, Dinar et al. (1998), Murphy et al. (2000) and Cummings et al. (2004).

[16] Libecap (2011), Ostrom (2011), Hanemann (2006).

[17] See Lixia et al. (2010), Knapp et al. (2003), Dridi and Khana (2005), Dinar et al. (1991).

[18] See Leidner et al. (2011), Griffin (2011), and Section 1. Due to data constraints, comparisons across many water markets are only possible at a relatively aggregate level and in mostly in qualitative terms, see Grafton et al. (2011).

explicitly emphasize the implicit assumption behind the prediction of the impact of water markets, i.e., that water rights are initially misallocated in favor of lower-value crops.

Our difference-in-difference analysis reveals that markets increase the share of crops that are on average more productive in terms of dollar revenue generated per water used. Moreover, this effect is most pronounced during droughts. Within the confines of the available data, we use two data sets. One is relatively aggregate and compares the most productive crops, fruits and vegetables, with all other crops. Our estimates indicate that the ability to adjust the crop composition towards more productive crops is of significant economic consequence, accounting for roughly 30% of the revenue of the water market counties. We also use more disaggregate data that does not include the most productive crops. At the more disaggregate level, we show how specific crop characteristics such as drought resistance interact in interesting ways with a market. This enriches our understanding of agriculture's adaptation mechanisms also for non-irrigated crops.

The paper is structured as follows. First, we describe the Rio Grande Valley market. Next, we discuss the framework that rationalizes the shift in crop production due to a water market. This section shows how the initial distribution of water rights matters for the water reallocation and how water markets interact with water scarcity. We then discuss the empirical specification and our data. Finally, we discuss the estimation results and conclude.

1. The Water Market of the Rio Grande

One of the most established water markets in the United States operates along the lower and middle reaches of the Rio Grande. The Rio Grande river stretches from Colorado to the Gulf of Mexico (see Figure 1). The river constitutes the border with Mexico for 1,200 miles. The water market has been active since the early 1970s and encompasses 10 counties.[19] Both *The Water Rights Adjudication Act of 1967* and The *State of Texas vs. Hidalgo County Water Control and Improvement No 18* (1969) were critical for the establishment of the market. *Texas vs. Hidalgo County* was filed in 1956 by the Texas Attorney General. Its aim was to ensure sufficient water supply for domestic use and to prevent water districts, private corporations, and individuals from diverting water from the lower Rio Grande. While there is no explicit cap, the amount of water

[19] How the Rio Grande market functions and how it came into being is described in Leidner et al. (2011), Griffin (2011), Chang and Griffin (1991), Schoolmaster (1991), Levine (2007), and Kaiser (1987).

rights issued has been relatively stable. As is common, the establishment of a water market redefines water rights to facilitate trading. Our study of the effects of water markets is hence inextricably linked to the changing legal framework that made the water market possible.

A coherent apportionment of the valley's water resources was introduced to stem overuse. A procedure was put in place to resolve claims, acquire new water permits, and transfer permits. In addition, the *1967 Act* paved the way for the creation of the Rio Grande Watermaster's Office (RGWO) that oversees the market's operation. The priority *by seniority* which governs most of Texas and parts of the Western United States was abandoned, so farmers should be more flexible than their counterparts in the control counties. In case of a drought, for example, older water rights holders of control counties retain their privileged access even if they use water less productively. In market counties, on the other hand, water can be reallocated informed by who's willing to pay most. Also, inter-sectoral priority *by use* is introduced, which gives municipal and domestic users priority over industry, which in turn has priority over agriculture. For our purposes, inter-sectoral priority transfers out of agriculture should matter only to the extent that they reduce water for agriculture. We expect that such transfers out of agriculture in the post-market period affect the crop composition in the same way that, say, droughts do, moving water to more productive crops.[20] The Rio Grande water market has taken off since the early 1970. Only with permanent transfers does the ownership of the right change hands for good. Temporary, short-term contracts either run over a fixed term (like a year), or are a one-time sale. Permanent sales are mostly inter-sectoral from agriculture to cities. In spite of this, agriculture still holds 80% of the water rights (see Table 1). Moreover, water districts increasingly prefer temporary deals.[21] It is hence not surprising that the spot market for one-time, intra- agricultural transfers is especially active.[22]

Students of the Rio Grande water market give it high marks as a vehicle to reallocate water.[23] First and foremost, the region's scarcity makes water a valuable resource, creating an incentive to trade water rights. The level of precipitation is 65% of that of the contiguous 48 states, and the area's population almost quadrupled since 1950. Effective water markets also need sufficient

[20] Within irrigation rights there is also a differentiation between A and B rights. The 1969 suit defined the water rights in the lower Rio Grande. By 1984, water rights in the middle portion of the Rio Grande were defined in similar fashion, see Leidner et al., 2011.

[21] Chang and Griffin (2002).

[22] Yoskowitz (1999) reports 1274 transactions among irrigators between 1993-1998.

[23] See, Leidner et al. (2011), Schoolmaster (1991), Chang and Griffin (2002), and Levine (2007).

opportunities to reallocate water over time or across activities. The Rio Grande valley has expanding cities whose average water productivity is high compared to agriculture, and it has a wide variety of crops, see Table 2. The area's topography also supports the market's persistence. Much of the diverted water does not return to the Rio Grande, limiting potential (negative) externalities. Add to this the predominance of surface water whose rights are much better defined than groundwater.

Finally, there is the RGWO that, as Yoskowitz (1999) points out, effectively is a broker. RGWO brings together buyers and sellers. All (potential) market participants know RGWO keeps track of water balances for individual water-rights holders. It provides, either online or by phone, institutional information, data, and forms, reducing transaction costs. Paperwork and negotiation costs are fixed and low.[24] Spot-market transactions in agriculture can be processed within one day as they do not involve a change of water rights. Permanent and inter-sectoral sales, on the other hand, require public notification. The RGWO officers patrol the river and canals, making sure right holders comply with regulations and do not pump water illegally.

The upbeat assessment of the Rio Grande market makes it a good venue for our analysis. We want to document how water markets change the crop composition without disentangling too many complicating factors. Chang and Griffin (1992) and Leidner et al. (2011) report a shift toward higher-value crops which tend to be less water intensive/more productive. More analysis is needed, however. An increase in corn in the water-market counties cannot be readily attributed to water markets, given an overall rise in corn. Conversely, a reduction in vegetable output need not contradict the predicted crop composition shift induced by water markets if other counties show an even stronger reduction. We propose a difference-in-difference analysis that uses as treatment the counties that participate in the water market, and as control the neighboring counties that do not. We investigate the change in crop composition in the water-market counties relative to the others before and after the water market is introduced. The control counties not only share the same climate due to their proximity, as a group, they also have comparable agricultural potential. They have similar water access as The Nueces and its main tributaries, as well as the tributaries from the Rio Grande run through them, see Fig. 1b and see also the discussion of similarity of treatment and control counties in section 5.

[24] Watermaster website: http://www.tceq.state.tx.us/permitting/water_rights/wmaster/rgwr/riogrande.html.

Assessing the impact of water markets by studying the actual uses of water—in our case, the particular crops that are produced—has an additional benefit. Our analysis complements work with water-market transactions data, while sidestepping some of the challenges that are associated with studying water-transaction data directly.[25] As many have noted, the quality of the water-transaction data varies greatly. One often cannot retrieve the exact prices, distinguish actual transactions from gifts (with price zero), or identify the buyer or seller of the water rights by location and/or economic activity.[26] In addition, oftentimes only a subset of the water transactions is available. It is not uncommon that permanent sales are recorded, whereas temporary leases are not. This is a challenge if, for example, buyers of water rights lease back the acquired water.

2. Conceptual Framework

In this section, we focus on the basic prediction that water markets move water from (on average) lower- to higher-value activities. This is short for moving water from activities that use more (non-water) production factors per unit of water to ones that use less, or, in terms of our empirical work, from activities that generate on average less $ revenue per unit of water to ones with more $ generate per unit of water. To contrast high- versus low-value activities, one typically considers vegetables versus hay, or city output versus agricultural production. In a stylized but well-established two-sector, general-equilibrium framework, we specify under what conditions this basic prediction holds, and what is assumed about the initial distribution of water rights. Inspired by this setup and by the contrast it draws between a world with and without water markets, we present our empirical specification in Section 4.

We describe the impact of a severe drought shock in a specific-factors model with and without water markets. Specific-factors models are common in discussions of water markets.[27] Ours has two sector and two factors that are part of a small open economy with perfect competition in all markets. This model that operates in an international environment has a distinct record in international economics. Its short- and long-run impacts are well understood, and it is nice that

[25] See Chang and Griffin (1992), and Heade (1999).

[26] Because of data limitation, Chang and Griffin (1992) and Heade (1999) rely on survey data of a subset of the transactions to evaluate the economic gains associated with representative transactions from agriculture to cities.

[27] See Colby,B. (1990), Easter et al. (1998), and Griffin (2006).

prices of the relatively homogenous commodities are pinned down by international markets.[28] What defines a specific-factors model is that some production factors are not mobile between sectors in the short run. In our agricultural region one sector produces high-value crops (vegetables), and the other low-value crops (hay). We seek to compare what happens in response to a drought when water can be transferred (i.e. there is a water market) with when it cannot.

Water, *W*, and capital, *K* are our two factors. Capital is a composite that includes both physical and human capital. Vegetables and hay need *K* and *W* and have a neoclassical constant-returns production function $Y_c = f_c(K_c, W_c)$, $c = h,v$. We assume low-value hay uses far less capital per unit of water compared to vegetables, i.e., $K_h/W_h < K_v/W_v$.[29] As is standard, capital and water cannot leave the region, and all resources are used, i.e., $K = K_c + K_v$, and $W = W_c + W_v$, where *K* and *W* amount to the region's capital and water. For ease of exposition, we assume no long-run frictions in the economy: Capital and water can freely move between the two crops in the long run. In the short run, however, this mobility is not guaranteed. Capital stays with its original crop in the short run. Water, on the other hand, can move between hay and vegetables only when there is a water market.

Now consider a drought or a drop in our region's available water, *W,* all else equal. We assume the drought has no impact on international prices and demand since our region is relatively small and takes international prices as given. The long-run outcome when both *K* and *W* can change sector is well known: The low-value crop takes the brunt of the shock, to such an extent even that its output may decrease so much that the high-value crop actually increases in output. This is the familiar Rybczynski (1955) effect. The short-term effect when only *W* can move is less extreme. Both crops decrease in output. Moreover, the larger the differences in K_c/W_c between hay and vegetables, and the more similar the substitutability between water and capital, the more likely it is that the output of the low-value crop (hay) will indeed shrink most.[30]

[28] See seminal papers by Mayer (1974), Mussa (1974), and Neary (1978). For a textbook version of the model, see Krugman et al. (2012), p.51-63, 91, and Feenstra (2004), p.64, 72–75.

[29] In the setup we consciously steer clear of "water intensity" which is often defined in physical terms of water per pound or water per hectare - almost devoid of economic value. For this reason, we consciously do not choose land as second factor next to water, and intentionally compare the two crops' capital/water ratio, rather than their water/capital ratio, or their water intensity. K stands for all (non-water) factors.

[30] See Neary (1978). Bhagwati et al. (1998), p. 157 (10.50), derives the exact condition to determine which sector decreases most in a specific factors model *in the short run,* i.e. when *K* cannot move between sectors, but *W* can. The sector with the lowest K/W

Figure 2 graphs the outcome. The downward-sloping line on the left is water demand by vegetable farmers for a given amount of capital, or water's-value marginal product. The upward-sloping line is the water demand for hay that mirrors a regular demand curve (the amount of water demanded is measured along the x-axis from the origin on the right). We assume for simplicity that point *A*, at which the demand curves intersect, is the long-run equilibrium. When the region's water shrinks, the base shrinks, and the right y-axis and demand curve shift to the left with the amount of the water reduction. With a water market water freely flows to the highest price. The new allocation coincides with point *B*, for which both crops' effective water use shrinks. In our particular example, vegetable water use shrinks less than that of hay.

To understand how water market operations are linked to how water rights are defined, let's study how the initial distribution of water rights constrains water use. Let everyone own just enough water rights to produce their initial output. Consistent with the legal doctrine in the Rio Grande before the water market, we assume there is seniority. First, let the hay farmer's rights be senior: The hay farmer has priority access to water if *W* decreases. With no water market, the drought may not affect the hay farmer's water use, $0^1{}_HC$, nor his output or the value-marginal productivity of the last unit of water he employs: $0^1{}_HC$ equals hay's initial water use, $0^0{}_H A$. Hay's value-marginal product stays at P_{W0}. The vegetable farmer with junior rights bears the full brunt of the drought as his water use shrinks from 0_VA to 0_VC. Without a water market, his output plummets. Water's value-marginal productivity for vegetables is higher than for hay ($P_{WC} > P_{W0}$), and vegetable farmers would be willing to pay more than P_{w0} to attract *CB* water. Note that the total welfare (consumer and producer surplus) of such water market transactions would be described by the triangle through (B, P_{W1}), (C, P_{WC}) and (C, P_{W0}). Now, consider the opposite initial water-rights distribution and its very different outcomes without a water market. With senior vegetable rights, the hay farmer is hit hard: His water use drops from $0_{0H}A$ to $0_{1H} A$, and hay's value-marginal product of water rises from P_{W0} to P_{WA}. The hay farmer wants to buy water, and the triangle (A, P_{WA}), (A, P_{W0}) and (B, P_{W1}) describes the welfare benefit of the transfer.

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always shrink most if there is an equal elasticity of substitution between water and capital for both crops (as with Cobb Douglas), or when the elasticity of substitution is highest in the low *K/W* sector. When the elasticity of substitution is highest in the high K/W sector, one needs a sufficient difference in the *K/W* ratios of the two sectors to ensure that output of the low K/W sector decreases most. It is a well-known result that the long-run equilibrium of a specific factors model corresponds to what is obtained in a standard Heckscher-Ohlin model.

Our analysis has two key implications. With increased water scarcity and a water market, we expect the high-value sector to increase in the short run relative to the low-value sector. Water should hence flow to where it has the highest (marginal) return. In the absence of friction, we end up in the long-run equilibrium point *B*.[31] It is critical that low-value crops have senior rights for water to flow to high-value crops. Only then do high-value crops have the highest value-marginal product. For water markets to increase the output of high-value crops relative to low-value crops under scarcity, and water rights to be sold from low- to the high-value crops, it is assumed the rights distribution is initially biased towards low-value crops. While this assumption is often not explicit (and hard to check), it may be justified by history. Farmers with enough water tend to continue to grow the low-value crops they grew before water became scarce. Similarly, when applied to cities and agriculture, lower-value agriculture has historically held most water rights. Given this initial distribution, in the absence of externalities, reallocating water towards high-value crops implies net societal benefits.

A second implication is directly relevant for our empirical strategy that compares counties with and without water market. With a water market the size of high-value crops increases relative to the low-value crops in case of a drought – We move from *A* to *B* in Figure 2. It is worth emphasizing that water rights are initially held more in low-value crops in counties without a water market will amplify the perceived shift towards high-value crops in water market counties. There will be a shift towards high-value crops in the water market counties (from *A* to *B*). In addition, in response to a drought, non-market counties may experience a shift exactly in the opposite direction as esp. high-value crops with junior rights suffer the adverse impact of the drought, and the size of high-value crops shrinks relative to low-value crops: We move from A to *C* in Figure 2.

3. Data

Our water market includes 10 counties at the lower and middle portions of the Rio Grande, see Figure 1a and 1b. Since the counties along the river constitute the U.S.-Mexican border, we choose its U.S. neighbor counties to the east as controls. Due to the geographic proximity, the climatic conditions of control and treated counties are quite similar. Moreover, as one can see from Figure 1b, the counties have similar access to water. While the treatment counties lie along the Rio

[31] In the absence of transportation costs, the final outcome is independent of the distribution of water rights, which is consistent with the Coase Theorem.

Grande, some of its tributaries as well as the Nueces, a major river in Texas, and its tributaries run through the control counties. The controls are also similar in terms of agricultural potential. For the set of crops that we study, we find no statistical difference between control and treated counties above the 95% confidence interval for both of the Agro-Ecological Suitability Values applied to, on the one hand, rainfed and, on the other hand, irrigated crops, see Table A5 of the appendix.[32] In section 5 we provide further evidence of the similarity of treatment and control counties. Note that we will also test the robustness of our results by expanding the control group with 12 additional neighboring counties.[33] In the final analysis, we exclude the counties Uvalde, Atascosa, and Medina from the baseline and expanded control group since they are part of the more recent water market above the Edwards Aquifer that was established in the 1990s. This leaves us with 9 counties in the baseline control group and 19 counties in the expanded control group.

The adjudication of water rights was completed in 1971 for all the four counties in the lower reaches downstream of the Falcon Reservoir: Cameron, Willacy, Hidalgo, and Starr. For the six counties in the middle reaches between the Amistad and Falcon Reservoirs—Zapata, Jim Hogg, Webb, Dimmit, Maverick, and Kinney—adjudication by the Texas Water Commission was completed in 1984 (Leidner et al, 2011). In one specification, 1971 marks the beginning of the post market period for all 10 counties, which could be justified in terms of rational expectations. In our preferred version, we use 1971 for the lower reaches and 1984 for the middle reaches.[34]

Our main data source is a county-level panel from the USDA *Census of Agriculture and Population*, which is collected approximately every five years between 1954 and 2012.[35] We

[32] The Agro-Ecological Suitability Values here are calculated at county-level average from the Global Agro-Ecological Zones database by the Food and Agriculture Organization of the United Nations and the International Institute of Applied Systems Analysis. See http://gaez.fao.org/Main.html#.

[33] The similar results with this expanded control group that includes also 12 additional neighbor counties are shown in Tables A1A, A1B, A3A, and A3B of the appendix.

[34] Allowing the water market to kick in at two points in time implies that we use for the years between 1971 and 1984 the middle-reach counties (which did not yet have a water market) as control counties for the lower reaches (which did have a water market). Tables A2A, A2B, A4A, and A4B in the appendix report the estimation results when we have the water market for the entire Rio Grande start at 1971. It turns out that these results will be similar to those that differentiate between 1971 and 1984.

[35]The exact dates of the published data are 1954, 1959, 1964, 1969, 1974, 1978, 1982, 1987, 1992, 1997, 2002, 2007, and 2012. We relied on “Historical, Demographic, Economic, and Social Data: The United States, 1790–2002 (ICPSR 2896)” by Michael R. Haines, Colgate University, via Inter-university Consortium for Political and Social Research at the University of Michigan. We supplemented the data with newer waves of the same census in 2007 and 2012 from USDA’s online publication. Specifically, the 1969 and 1974 Censuses only collected data on total irrigated areas for all crops as well as total harvest areas for a few crops

extract two datasets. One is relatively aggregate, and our best option for spanning more than 5 decades. It gives us for each of three categories (fruits, vegetables, and all other crops) consistent measures of the harvested and irrigated area as well as the overall (irrigated and non-irrigated) dollar value. The clear advantage of this dataset is that it captures all crops while singling out those that are most productive compared to the less productive "other crops." This dataset is ideal to investigate whether indeed the most-productive and thus higher-value crops become more prevalent compared to the less-productive water ones when there are water markets as opposed to when there are none.

We also consistently collect more disaggregate data for five crops from 1954 to 2012. These data, do not cover all the crops—they do not include the most productive crops. Studying these crops also reveals the challenge of using more disaggregate data. The issue arises how to handle specific characteristics of the crops such as their drought resistance that may interact with water markets. In particular, drought resistance may make it possible to grow crops without irrigation with expensive water. Corn, sorghum, wheat, hay, and cotton are in this group.

We construct a proxy measure for a crop's average (water) productivity as (real) sales over water use. We rely on a document from the *Food and Agriculture Organization*, Brouwer and Heibloem (1986), to provide an approximate measure of the quantity of water needed for each crop's harvest area.[36] We combine the measure with the harvest areas and the total market values for vegetables, fruits, and all other crops that we consistently extract from the USDA data from 1954 to 2012.[37] Formula (1) makes explicit our approximate real water-productivity measure for crops *c* in year *t*.[38]

$$Water\ Productivity_{ct}(\$/m^3) = \frac{Market\ Value_{ct}(2012\ \$)}{Harvest\ Area_{ct}(Acre) * Water\ Needed_c(m^3/Acre)} \qquad (1)$$

Keep in mind that this is a crude measure. Ideally, one would want a measure of the total value added for the crop, which is simply not available for agricultural data. In addition, for a study such

(corn and sorghum in 1974 and hay in both years) from larger farms with sales over $2,500 (or Class I-V farms). To make the data from these two years comparable, we scaled the variables by multiplying with (total cropland area/total cropland area in Class I-V farms. Moreover, the irrigated areas for fruits are not reported from 1978 to 1987.

36 The document is available at http://www.fao.org/docrep/s2022e/s2022e07.htm#chapter 3: crop water needs.

37 "Water Needed$_c$" for the three categories of crops is calculated by taking the average of water needed for major crops listed in Table 14 of Brouwer and Heibloem (1986), weighted by their pre-market harvested areas.

38 We deflate with the CPI that has 2012 as base year.

as ours that involves irrigation, it is worth pointing out that the quantity of water needed here is not the actual quantity of irrigation water used. Given the data limitations, this is the closest approximation possible and the values for our crops are shown in Columns (1)–(3) of Table 3. The productivity measure does not vary by county, and is clearly higher for fruit and especially vegetables than for the other crops. Note that in spite of the data limitations in the construction of our productivity measure, it is heartening to observe that its order of magnitude is reasonable, and actually in the same range of anecdotal evidence of reported water market prices.[39]

As for the second disaggregate set of five crops, the crops resort under the "all other crops" category of the aggregate data set. Their market value is not available in the *USDA Census* from 1954 to 1964, which is why we do not have a consistent measure for market values for the entire period. We, therefore, construct an estimate of the market value for crop *c* in year *t* using the output data in the *USDA Census* and the price data from USDA Feed Grains Data: Yearbook Tables (2015) as follows:

$$\widehat{Market\ Value}_{ct}(\$) = Market\ Price\ in\ Texas_{ct}(2012\ \$/ton) \times Output_{ct}(ton) \qquad (2)$$

Subsequently, we plug this estimated market value into formula (1) and obtain the water-productivity measures from Columns (4)–(8) of Table 3. To be explicit, given the different ways in which the productivity measures are constructed for the two sets of crops, the numbers in Columns (1)–(3) are not directly comparable with those in Columns (4)–(8). While we prefer the productivity measures for the more aggregate crops, the numbers for the more disaggregate crops do make sense. Consistently, for example, hay is the least (water) productive crop.

We also rely on annual precipitation and temperature data from the monthly, global-gridded, high-resolution point data (0.5-degree latitude × 0.5-degree longitude global grid) provided by the *Center for Climate Research* at the University of Delaware. The data are based on work by Willmott and Matsuura.[40] Since the revenue for some crops may depend on precipitation in the

[39] Yoskowitz (1999) reports an average water price for the Rio Grande water spot market for 1998. This price should proxy the marginal productivity. Expressed in similar units as the average productivity measures of Table 3, the average spot price amounts to 0.2 (2012) dollars per 10 cubic meters. Without wanting to press the price data and our crude proxies for productivity data too hard too hard, 0.2 approaches the average productivity of the less productive crops (other crops (column 3) and hays (column 7) – Since sellers will supply water from their least productive fields/crops, you'd expect the marginal productivity of the water sold to be lower than the average productivity.

[40] http://climate.geog.udel.edu/~climate. We use *Monthly Total Precipitation: Time Series (1900–2014).*

previous year, we report the average of two years (the survey year and the year before).[41] The temperature measure that we use as additional control variable comes from the daily temperature data collected by the *United States Historical Climatology Network* (USHCN) from 1,218 stations across the contiguous United States. To translate those station-level data into variables with the geographical circumscription of counties, we use the standard Inverse Distance Weighted (IDW) interpolation. The latter implicitly assumes that closer observations tend to be more alike. With this method, we generate raster data (with a numerical value estimated for every pixel on the map) for each year using GIS tools. Then, we calculate the average within each county boundary.

Figure 3 presents the average of the county-level precipitation at five-year intervals. The right-hand y-axis is the axis of reference for this measure. We also construct a measure of drought that equals 1 if the annual precipitation is smaller than the long-term (1954–2012) mean minus the long-term standard deviation for the entire period in the county, and 0 otherwise. The vertical bars (measured on the left axis) indicate the fraction of the counties that are in a drought. As one notices, the 1970s, 1980s, and 1990s are relatively wet, while the early 1950s and the most recent years represent a severe drought for virtually all the counties. A nice benefit of our long-run approach is that we have a period of drought before and after the water market was established.

4. Empirical Specification

We employ a difference-in-difference strategy to identify the impact that water markets have on the type of crops that are grown and whether there is a shift toward the more-productive crops in the counties with a water market compared to the control counties without.

Our primary fixed-effects regression of interest is expression (3).

$$\begin{aligned} Share_{cit} = {} & \alpha_i + \alpha_c \text{ x } \alpha_t + \beta_1 Watermarket_i \text{ x } Post_t \text{ x } Water\ Productivity_{ct} \\ & + \beta_2 Watermarket_i \text{ x } Post_t + \beta_3 Watermarket_i \text{ x } Water\ Productivity_{ct} \\ & + \beta_4 Post_t \text{ x } Water\ Productivity_{ct} + \beta_n \mathrm{X}_{\mathrm{nci}t} + e_{cit} \end{aligned} \quad (3),$$

where c refers to crop, t to year, and i to county.

On the left-hand side, we measure crop c's share in county i in two different ways in order to capture the change in composition over time:

- irrigated area of crop c in county i as a percent of the total cropland area in county i at time t.[42]

[41] This is potentially an issue for the earlier years of the census.

[42] Alternatively, we divide crop area by total farmland area, and our results will be qualitatively consistent.

- non-irrigated area of crop *c* in county *i* as a percent of county *i*'s total cropland area at time *t*.[43]

The first variable is directly relevant for water markets as they directly provide water for irrigation. The second variable matters for two reasons. On the one hand, we want to see whether what happens to non-irrigated crops is different between market and non-market counties. In addition, we may be able to extend some of Hornbeck and Keskin (2014)'s findings about farming's adaptation in light of water stress. Therefore, we study how crop characteristics such as drought resistance interact with water markets and droughts, and whether these interactions differ between irrigated and non-irrigated crops. Note that because irrigated and non-irrigated crop shares can be negatively correlated, we estimate the irrigated and non-irrigated outcome variables jointly using a generalized structural equation model. In this way the error terms can be correlated.[44] At the same time, we will cluster at the county level. Regression (3) includes county and time x crop fixed effects, and a set of interactions. In our formulation of regression (3) we include all the effects explicitly to make the interpretation of the many interactions easier. Note that with so many fixed effects and interaction terms, we prefer a linear to a nonlinear specification even though our outcome variables are bound between zero and one.[45]

The interactions combine the variables $Post_t$, $Watermarket_i$, and $Water\ Productivity_{ct}$. $Post_t$ is a dummy for the years since the water market was introduced, $Watermarket_i$ is a dummy that marks the counties that have a water market, and $Water\ Productivity_{ct}$ captures the real water productivity per crop as it varies over time. $Post_t$, $Watermarket_t$, and $Water\ Productivity_{ct}$ do not enter the regression separately as they are respectively subsumed under the year, county, and year x crop effects. The X_{ncit} variables bring in the time-varying characteristics of the counties and crops. We estimate the regressions weighted by the county-level average harvest area for each crop in pre-market years. e_{cit} is an idiosyncratic error term clustered at the county level.

The primary coefficient of interest is the coefficient β_1. It implies a triple interaction of dummies for counties with water markets, years after the introduction of the market, and crop real water productivity as measured in 2012 dollars in revenue per 10 cubic meters of water. The benefit

[43] The non-irrigated area is obtained by subtracting the irrigated area from the harvested area.

[44] It turns out, however, that the results of our joint estimation are fairly close to the ones obtained when estimating the regression separately for irrigated and non-irrigated crops.

[45] Nonlinear models have practical and methodological shortcomings when combined with fixed effects in relatively small samples, see Greene (2004).

from working in levels (and not logs) is that we can investigate for all crops the impact of, say, a 1 $ per 10 m^3 increase in average productivity, which is a meaningful measure from the perspective of the farmer deciding to allocate water optimally. We have calculated the relative water productivity for each crop by subtracting the productivity of the least-productive crop for each year. Because of this, β_2 gives the average baseline effect estimated at the annual lowest water productivity. Our basic hypothesis suggests that we should obtain a positive coefficient for β_1. The coefficient β_1 then shows the estimated average percent-point increase of the share of irrigated area in farmland due to an increase by one dollar per 10 cubic meters in average productivity from the baseline (least-productive) crop once the water market is established. To measure the full impact of introducing a water market, one needs to add together (β_1 × relative water productivity) and β_2.

In addition to precipitation and the degree-day counts, we also add a set of control variables that includes county-level logarithmic values of total farmland area, pasture area, and the per acre revenue from pasture. When estimating the same equation with a subset of all the crops (i.e., with the disaggregate data set), we, in addition, control for the logarithmic values of the sum for all crops excluded from the subset on harvest area, irrigated area, and total revenue. The reason for controlling for these variables is that we want to see if the results are robust conditional on alternative usage of the farmland. To alleviate the concerns of potentially differential pre-market trends of the outcome variables, another set of control variables is used. In particular, we insert the specific outcome variable for each regression as specified below in pre-market years (1954, 1959, 1964, and 1969) interacted with the dummies for each post-water-market year, following Hornbeck (2012).

Regression (4) is the most comprehensive and also the most complicated regression. It brings in the impact of droughts. $Drought_{it}$ equals 1 if annual precipitation in a county is less than the long-term mean minus the long-term standard deviation in that county, and equals 0 otherwise.

$$\begin{aligned} Share_{cit} = \; & \alpha_i + \alpha_c \text{ x } \alpha_t + \beta_1 Watermarket_i \text{ x } Post_t \text{ x } Water\ Productivity_{ct} \\ & + \beta_2 Watermarket_i \text{ x } Post_t + \beta_3 Watermarket_i \text{ x } Water\ Productivity_{ct} \\ & + \beta_4 Post_t \text{ x } Water\ Productivity_{ct} \\ & + \beta_5 Watermarket_i \text{ x } Post_t \text{ x } Drought_{it} \text{ x } Water\ Productivity_{ct} \\ & + \beta_6 Droughts_{it} + \beta_7 Watermarket_i \text{ x } Drought_{it} + \beta_8 Post_t \text{ x } Drought_{it} \\ & + \beta_9 Drought_{it} \text{ x } Water\ Productivity_{ct} + \beta_{10} Watermarket_i \text{ x } PostDrought_{it} \\ & + \beta_{11} Watermarket_i \text{ x } Drought_{it} \text{ x } Water\ Productivity_{ct} \end{aligned}$$

$$+ \beta_{12} Post_t \text{ x } Drought_{it} \text{ x } Water\ Productivity_{ct} +$$

$$+ \beta_n X_{ncit} + e_{cit} \qquad (4)$$

We are particularly interested in the coefficient β_5 of the quadruple interactions. A positive coefficient should tell us whether an increase in the water productivity of a crop affects the crop composition, and whether it is indeed the case that droughts make it more likely that water is given to the overall-more-productive crops.

To make sure our findings are not spurious, we include here also all the interactions of the components of the quadruple interaction. With those additional interactions, one has to be a bit careful to interpret the impacts correctly, and also to reinterpret some of the coefficients compared to previous specification (3).

Because of the new interactions with $Drought_{it}$, for example, the coefficient on $Watermarket_i$ x $Post_t$ now explicitly captures the impact of having a water market when there is *no* drought, and so does $Watermarket_i$ x $Post_t$ x $Water\ Productivity_{ct}$. To measure the full impact of introducing a water market, one needs to add together β_2, β_{10}, and $(\beta_1 + \beta_5) \times$ relative water productivity.

5. Results

A first set of estimates is found in in Table 4A and 4B for regressions of irrigated and non-irrigated shares of cropland area. Because irrigated and non-irrigated decisions may be related, we estimate the irrigated and non-irrigated shares regression jointly, allowing the error terms to be correlated. As such, each column of Table 4A is estimated jointly with the corresponding column of Table 4B. We use the same empirical specification for both outcome variables.[46] The Tables 4 use our relatively aggregate dataset that covers all crops, including the most (water) productive ones (vegetables and fruit) that are singled out from the 'other crops.' We first focus on Table 4A. The dependent variable is the irrigated area of a crop and is measured as a percentage of total cropland. There are three blocks of estimates, and within each block, moving from left to right, the specifications vary. We increasingly insert more control variables. We put most weight on the third column in each block. It includes a whole set of pre-water-market controls, including as in Hornbeck (2012) the outcome variables for the period before the treatment (the years 1954–1969)

[46] To be explicit, Column (1) of Table 4A estimated jointly with Column (1) of Table 4B, etc.

interacted with dummies for the post-market years. The latter controls should most clearly capture any pre-existing trends.

In the first block, we check whether water markets tend to affect the irrigation area. We rely on regression (3) with the *Post* × *Watermarket* interaction but without the water productivity-interaction terms. There is no significant way in which water markets affect the irrigation area per se across all crops. In the second block, we present the estimates of regression (3) with the critically important triple interaction of *Post* × *WaterMarket* × *Water Productivity*. The productivity interaction variable has a positive and significant coefficient across all the three specifications in the second block. The positive sign confirms the basic prediction associated with water markets. All else equal, water markets increase the share of more-productive crops. To be precise, relative to the least productive crops ("other crops"), a $1-per-10-cubic-meter increase in water productivity should give rise to an increase of nearly 0.8 percentage point in the irrigated area as a share of cropland.

In the third block, we present the most comprehensive estimates of regression (4) with the additional interaction for when there is a drought. Comparable to the first block, we find that the initial triple interaction with water productivity also has a positive and significant impact. The interpretation of the triple interaction in regression (4) is slightly different because of the added quadruple interaction with drought. The coefficient of around 0.54 in specification (9) implies that relative to the least-productive ("other") crops, a $1-per-10-cubic-meter increase in water productivity should give rise to an increase of about 0.5 percentage points that goes to more-productive crops *in non-drought or wet years*. As one can see, we estimate a positive and significant coefficient on the quadruple interaction of *Post* × *Watermarket* × *Drought* × *Water Productivity.* The coefficient indicates there is an additional 3.1 percentage points increase in the share of irrigated crops that is cultivated relative to the "other crops" when there is a drought. In other words, the shift toward higher-value or more (water) productive crops is even more pronounced in years of a drought at 3.6 percentage points in total, which is a sizable fraction of the within-county standard deviation (about 29% of it).

Note that there is an alternative way of interpreting the results. Instead of seeing them as reflecting the merits of market flexibility, one might read into them the relative inflexibility of a water rights system that is dominated by seniority in the neighboring counties and common throughout the Western United States. Those control counties have no market and more senior rights might withhold water from more-productive crops. If the least (water) productive crops hold most of the water rights, the more-productive crops will be hammered in the absence of water trading, see Libecap (2011) and Section 2. The interaction with drought thus puts on display the resilience of water markets and their ability to flexibly respond to external circumstances in a way that counties that cannot trade are not able to.

In Table 4B, we turn to the non-irrigated crops. We want to check whether some of the findings for irrigated crops, which should be the primary beneficiaries of the water from water markets, carry over to non-irrigated crops. Table 4B is set up in the same way as the previous Table 4A. There is on average a 7.7 percentage point increase in non-irrigated shares from Column (3), but no significant increase in the overall crop area of the more productive, non-irrigated crops in the post-water-market years, and nor do droughts matter more or less for the more productive, non-irrigated crops. Note that the Tables A1A – A2B in the appendix show our results are robust to doubling the number of control counties (including neighbors from neighbor counties), and to putting the start of the water market in 1971 for all counties, as opposed to 1971 and 1984 in our preferred specification.[47]

In a double-difference analysis that has a fixed effect for both the market and non-market counties, there can be systematic differences between the counties that we study. The validity of our analysis, however, is especially sensitive to any existing pre-market trends that could explain the differential impact between treatment and control counties. Of particular interest is to know how production of the more productive crops in both the treatment and control countries have evolved relative to the less productive crops.

Figure 4 focuses on the period *before* the water market was put in place and has four panels for the more aggregate data set. The left panel compares unconditionally the raw data for the pooled average of the crops' irrigated and non-irrigated shares in the pre-market years for both the treatment and control counties.[48] For our analysis to be credible, we do not want any pre-existing trend difference between treatment and control counties. On the right side, we compare the

[47] Moreover, the same set of results is still robust when we restrict to the subsample within the expanded control group that shares common support with water-market counties in FAO-IIASA Agro-Ecological Suitability Values specified in Table A5 of the appendix (results not shown).

[48] To draw the graph, we restrict the sample to a balanced panel. Due to a few missing observations for fruit, we focus on vegetables. Note that the estimates for a balanced panel are qualitatively similar.

residuals for the same variables for the two sets of counties while conditioning on our whole battery of controls.[49] Even though we were careful to choose similar treatment and control counties, one notices that there is a bit of a trend difference in the unconditional plots for treatment and control counties on the left. Once we introduce our controls in the panels on the right, however, we obtain approximately parallel trends for both groups on the right.

In Table 5, we also report for a long list of characteristics pooled across water-market and non-market-counties in all pre-market census years how similar treatment and control counties are. We run regressions on a dummy variable that is one for the water-market counties, and zero for the non-water-market counties. Water market counties have slightly less pasture, more irrigated vegetables, and more non-irrigated cotton than the control counties, but otherwise there is almost no statistically significant difference above the 95% level. To be explicit, since our difference-in-difference analysis includes county fixed effects, it is not the case that there cannot be any cross-county differences. It is critical that time trends are controlled for.

Figure 5 is key for our results. We are in particular interested in the ratio of the (irrigated) acreage of vegetables, the most productive crop category, relative to the (irrigated) acreage of the less productive crop category, "all other crops." This ratio should indicate whether there is an increase in more productive crops relative to all others once a water market is in place, and how this compares to what happens in the control counties. We focus on the version conditional on all the control variables. For the pre-market period, parallel trends can be confirmed even measured for the ratio of the two crop categories. Although one can see some slight changes in the trends immediately after the Lower Rio Grande Water Market started, it is especially from the mid-1990s onwards when there is a significantly widening gap between treatment and control counties. In other words, as we get to the end of the period there is an even stronger shift towards more productive crops in the water market counties. What is striking is that no such shift occurs in the control counties where there is no water market. It is the case, however, that this shift is most pronounced in recent decades and can hardly be identified from the very moment the market starts operating. The most likely explanation for this delayed impact stems from the regression (4) results discussed above and from Figure 3. On the one hand, droughts amplify the shift towards high-productivity crops. On the other hand, droughts are more prevalent in the early and later years of

[49] To be explicit, the residuals for vegetables and "other crops" are obtained by running regression (3) without any of the interaction terms with *Post* and/or $Watermarket_i$. We weight the residual by the average pre-market shares.

the sample. In other words, it is not all that surprising that during "wet years" (the 1970s, 1980s, part of the 1990s) there is not a very pronounced difference between treatment and control counties. There is some anecdotal of significantly lower prices in the wet years to support this interpretation.[50] Also supportive of this reading of the result could be that in times of drought the most productive crops are the marginal crops that on net demand water from other crops, whereas in less dry periods they are not. In this case, water may be exchanged within the category of "other crops."

Based on our estimates, we find that the ability to redistribute water through a water market is economically significant. We first predict that the establishment of a water market gives rise to an increase of respectively 8-9 percent in the cropland area for vegetables and 0.4-0.6 percent for fruit in the water market counties.[51] We then combine this changed composition with the water productivity measures reported in Table 3 to calculate the additional revenue generated on an annual basis by the ability for water markets to redistribute their annual water use among crops. We find that an additional 326 million (2012) dollars of revenue is generated for all counties combined. This sum amounts to a 44 percent increase in total crop revenue, which is equivalent to a 31 percent increase in agricultural revenue for all water market counties.

In what follows, we now turn to our slightly more disaggregate analysis, which does not cover all the crops. We do not include the most-productive crops, such as vegetables and fruits. There is a marked difference in some of the relevant characteristics of the five crops that we study through time. In particular, sorghum and cotton are, according to the FAO, drought-resistant crops, whereas corn, wheat, and hay are not. Our analysis indicates that it is necessary to take such differences into account. This section clarifies the challenges of identifying the basic hypothesis that we are investigating when certain crop characteristics vary. At the same time, our findings are suggestive of how some crop characteristics, in particular drought resistance, may interact with the emergence of a water market and the occurrence of droughts, and how changing circumstances (i.e., a drought) may determine which crops are deserving of (expensive) additional water.

[50] Leidner et al (2011) reports that water prices were 3 to 4 times as high in the 2000s compared to the 1980s. Note, however, that the water prices reported are not for leases on the spot market, but rather for sales of (permanent) water rights. Libecap (2011) and Chang and Griffin (2002) report that in the 1970s and 1980s the Water Master considered there to be abundant water, allowing in some instances free pumping.

[51] We use the estimates from Table 4A, column 6.

The corresponding columns of Tables 6A and 6B are again estimated jointly as we analyze the irrigated and non-irrigated shares for five major crops within the relatively low-value category "other crops" – corn, sorghum, wheat, hay, and cotton. In Tables 6A, we have two blocks of results for regressions with irrigated land as a percentage of cropland on the left-hand side. As before, within each block, from left to right, we introduce more control variables. In the first block, we introduce an interaction *of Post × WaterMarket × Drought Resistance* to study how drought-resistant crops interact with the introduction of a water market. As one can see from the quadruple interaction, there is on average a significant decrease in the area share that irrigated drought-resistant crops occupy relative to the non- drought-resistant crops when a market is introduced. These findings are complemented by what we estimated in Table 6B, which focuses for the *non*-irrigated crops including the indicator for more drought-resistant crops.

In Table 6B we again have two blocks. We notice that drought-resistant, non-irrigated crops increase (not decrease as in Table 6A) when there is a drought in the water-market counties where water has a price and water use is capped. These findings are of interest in light of Hornbeck and Keskin (2014)'s observations that the areas that are not above the Ogallala Aquifer and as such do not have ready access to irrigated water, retained more drought-resistant practices. Our findings deepen these insights in the institutional context of a water market. We find that greater access to expensive water that can be more readily traded in a water market gives way to a *reduction* of drought-resistant crops that are irrigated. At the same time, however, we notice that the counties with a water market will tend to *increase* the fraction of drought-resistant crops that are *not* irrigated compared to counties that do not have a water market. Note that the Tables A3A – A4B in the appendix show our results when we double the number of control counties (including neighbors from neighbor counties), and also when we put the start of the water market in 1971 for all counties, as opposed to 1971 and 1984 in our preferred specification. We obtain the same signs, yet lose significance for non-irrigated drought-resistant crops.

Finally, Figure 6 complements Figure 4. Figure 6 documents the pooled average for our more disaggregate crops for treatment and control counties. Once we introduce a whole battery of controls, it is clear that there is no pre-market trends.[52]

[52] There is no easy complement to Figure 5 for our most pronounced result involving non-irrigated, drought resistant crops and how they behave differently between water market and control counties, and how droughts amplify the difference. Figure 5 takes the ratio of two types of crops. Unfortunately, in the case of drought resistant and non-drought resistant crops, for the residual

Conclusion

In many places, there is increased competition for scarce water resources. To ensure economic growth and attain rising standards of living poses a particular challenge in such an environment. It requires us to achieve more with less, or, as it is sometimes put, to decouple economic growth from water resource use. One way to achieve this objective is to, on the one hand, limit overall water use in a region and in doing so prevent further environmental degradation. At the same time, however, the cap on water use has to be complemented with continuously increasing productivity of the water that we use. In light of the mounting water challenges that we face, water markets that facilitate a transfer of water among different activities are receiving much attention. Along both critical dimensions that are necessary to decouple growth from water use, water markets potentially have a role to play. For one, they often come into existence with an explicit (or implicit) cap on overall water use in the water basin where they are established. In addition, water markets are a flexible way to react to unexpected events and to redistribute water. In particular, with a price on water, the expectation is that water markets will increase the productivity of water as they trigger a gradual shift in production from low- to high-value activities, which is short for activities that generate little value added per unit of water to ones that generate more.

There is an established literature that documents the potential efficiency gains water markets should bring about. The most common tools in this literature are simulations that, to a large extent, assume the favorable outcome. Our analysis is, to our knowledge, the first one to assess the actual impact of water markets on the ground within a difference-in-difference framework. We choose the Rio Grande water market in Texas for this exercise. It is one of the longest-functioning water markets in the United States. Moreover, we have the data to analyze its impact from a long-run perspective that includes both dry and wetter periods. We compare the change in the crop compositions between water market and control counties, before and after the water market was installed.

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version of the graph (with controls, not the raw data) we find residuals that change signs, which confuses the picture. During the drought years, residuals are more negative for non-irrigated drought resistant crops than for non-drought resistant ones in control counties. In water market counties, we see positive residuals for drought resistant crops and negative ones for non-drought resistant crops.

We find that water markets can indeed bring about a shift toward crops that are on average of higher value (more productive). This evidence confirms not only a basic and widespread hypothesis about water markets. The observation is also consistent with the prior that more water rights tend to be concentrated in lower-value crops than is justified on the basis of their productivity. We find that the shift toward higher-value crops is most strongly observed during droughts. Moreover, our estimates suggest that the ability that water markets provide to shift production to higher-value crops is of economic significance. In addition, we note that water markets have secondary effects. Water markets seem reduce growth of water-resistant crops in water market areas, and tend to increase their growth in non-water market areas.

Our findings of how water markets function give way to additional questions. One may wonder how scalable water markets are and whether the more extensive use of water markets (for example in Australia's Murray Darling Basin or in Chile) produces discernable shifts to more-productive activities on a more aggregate level. In addition, and this is especially important since so many cities lie in water-stressed water basins, it is worth investigating whether similar effects could be detected from water transfers between agriculture and the more-productive cities.

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Figure 1a: Counties in the Rio Grande River Valley Area

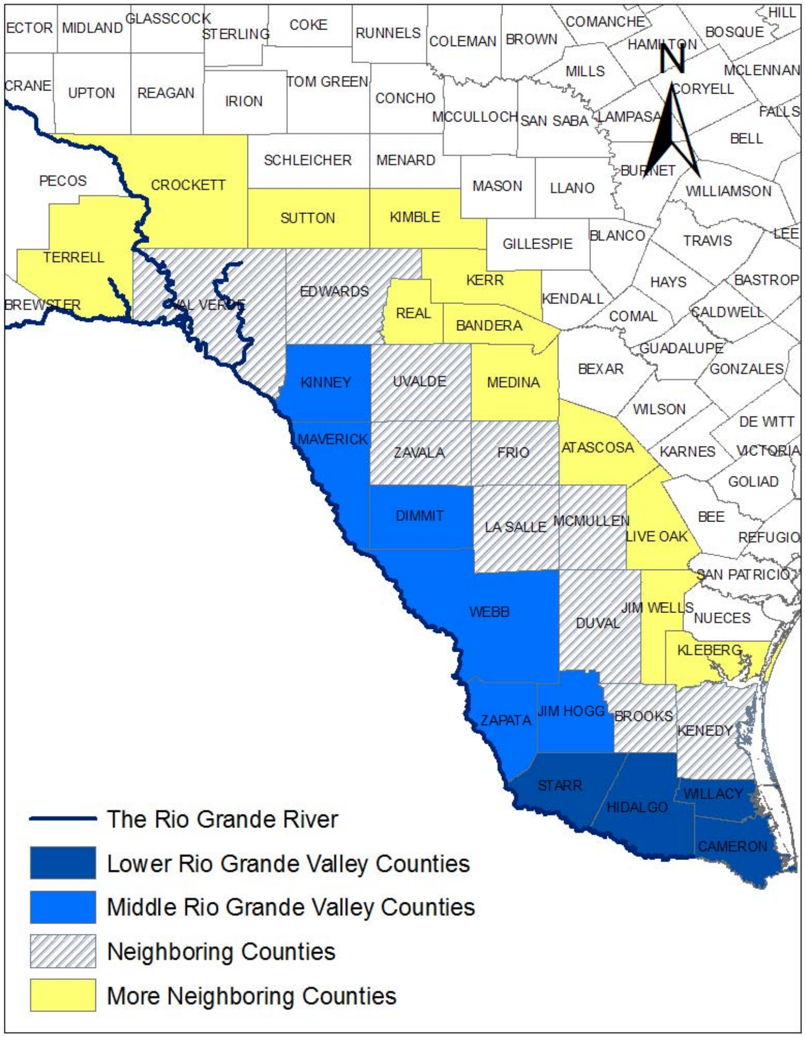
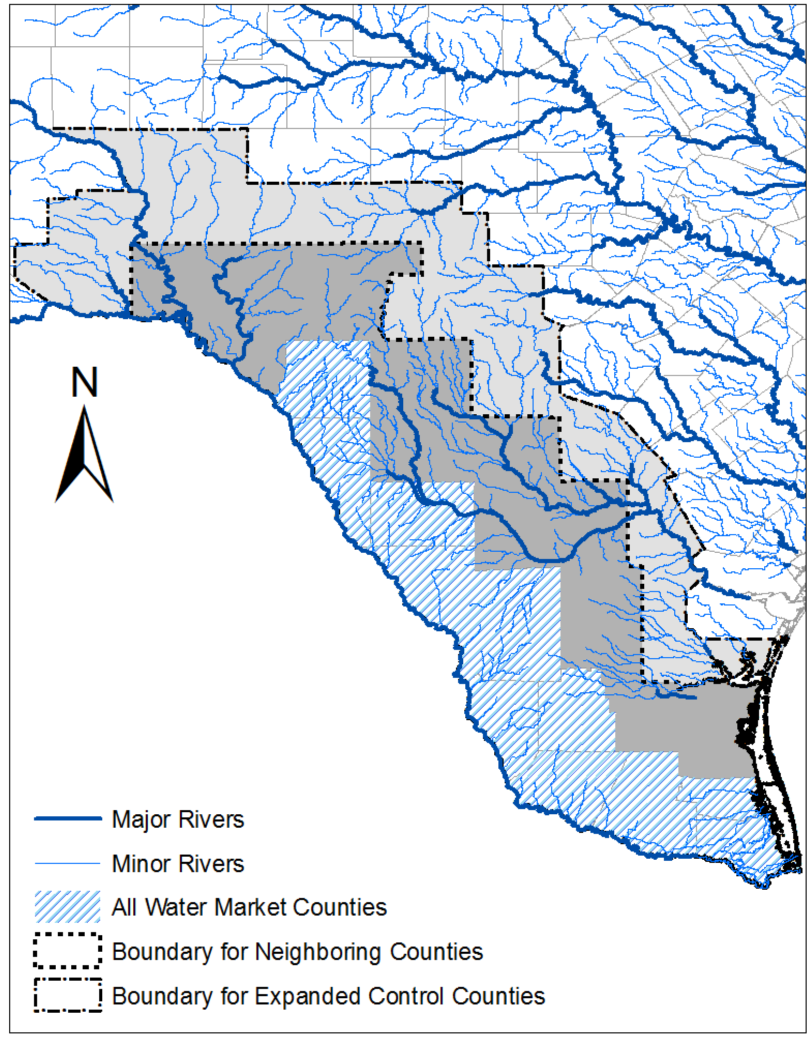
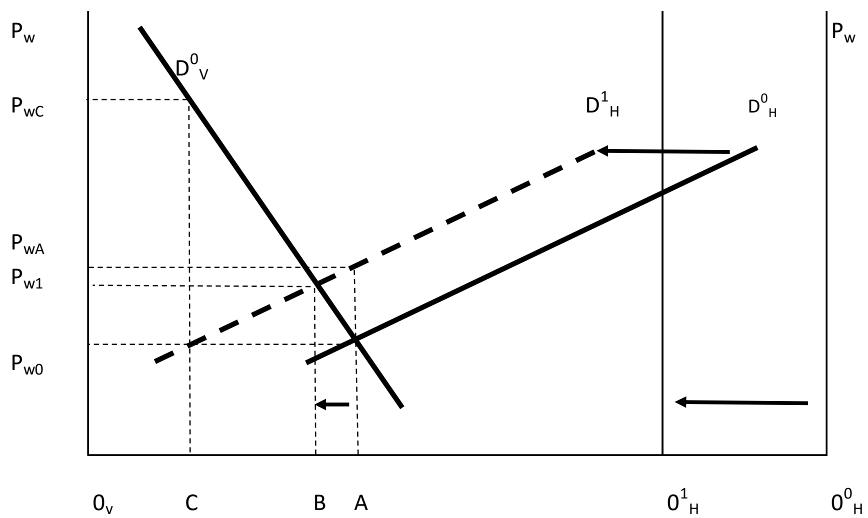


Figure 1b: Rivers in the Rio Grande River Valley Area



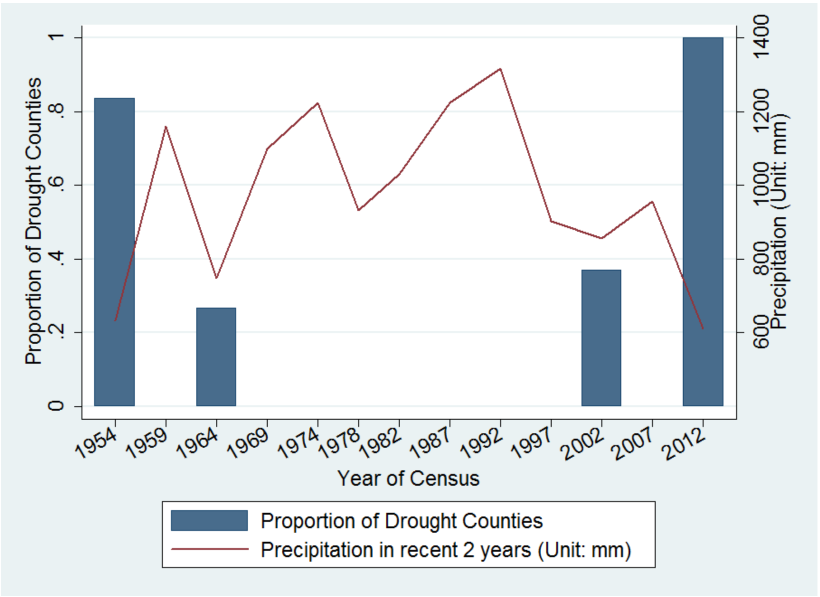
NOTE: The county boundary shapefile data come from the University of Minnesota Population Center. *National Historical Geographic Information System: Version 2.0*. 2011. http://www.nhgis.org. The river shapefile data come from National Weather Service GIS—AWIPS Shapefile Database.

Figure 2: Reallocating Water with a Water Market in a Specific-Factors Model



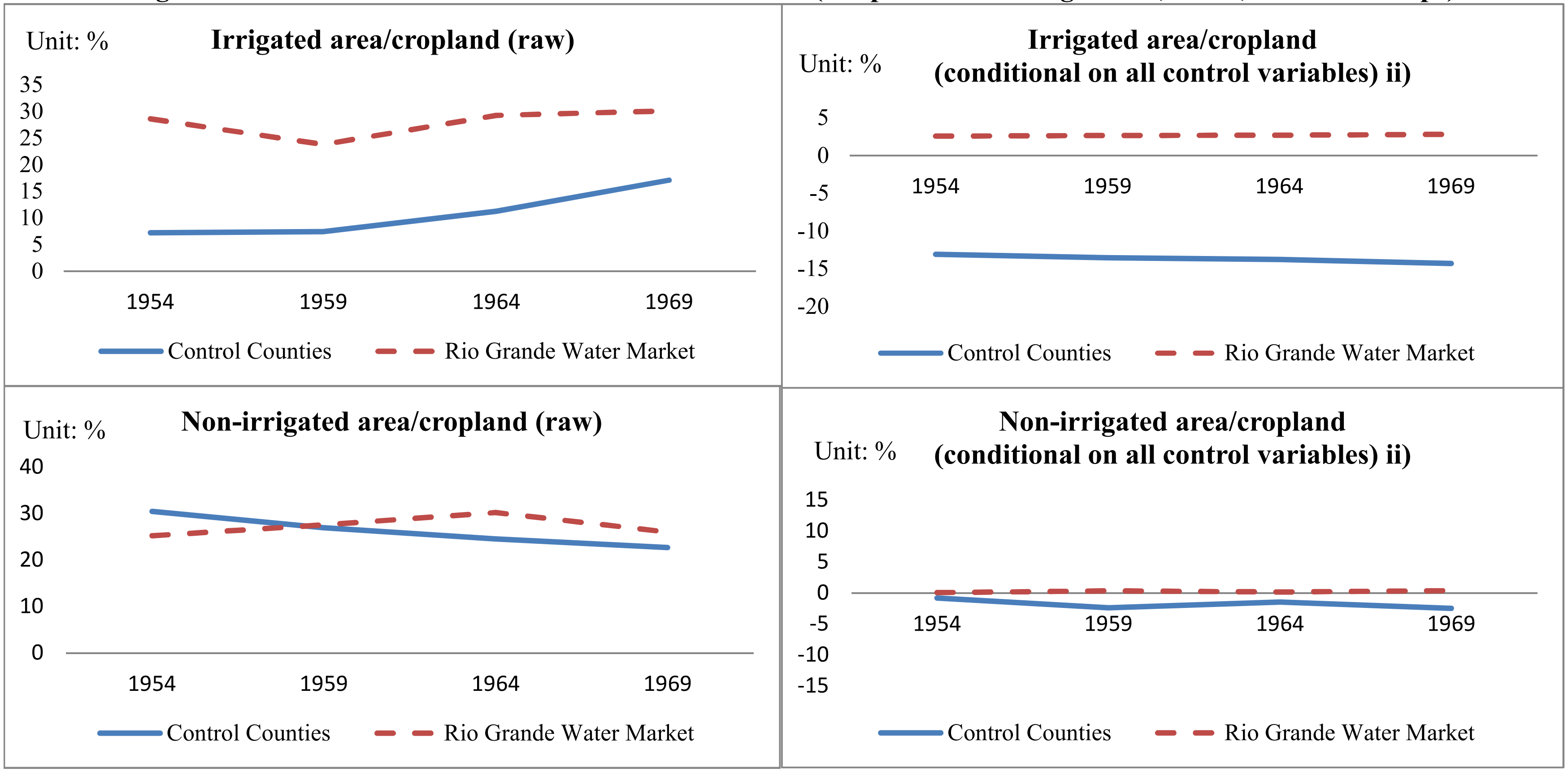
NOTE: D^0_v and D^0_H are the initial demand for water (marginal-value product of water) for vegetables and hay—$D^0_{H's}$ has 0^0_H as origin. D^1_H is the demand for water when the region's available water shrinks from $0_v0^0_H$ to $0_v0^1_H$ (i.e., D^1_H's left shifts equals inward shift of outer-right y-axis). With a market, water's price rises from P_{w0} to P_{w1}, and vegetable water use shrinks with less (A-B) than hay's (B-C). C shows the water allocation after water reduction when hay has senior rights—the entire water reduction goes to vegetables, and their marginal-value product (P_{Wc}) is higher than for hay (P_{w0}). With senior rights for vegetables, A marks the water distribution for less water: hay's value-marginal product is higher (P_{wA}) than vegetables' (P_{w0}).

Figure 3: Drought/Precipitation in Rio Grande



NOTE: The average two-year, county-level precipitation (census and previous year) is reported for census years 1954 - 2012 in millimeters and measured along right y-axis. Our drought measure equals 1 if annual precipitation < long-term (1954–2012) mean minus long-term standard deviation in the county, otherwise it equals 0. The vertical bars (measured along left axis) give fraction of the counties that experience a drought. The 1970s, 1980s, and 1990s are less dry.

Figure 4: Pre-treatment Trends for Outcome Variables (Crops included: Vegetables, fruits, and other crops)

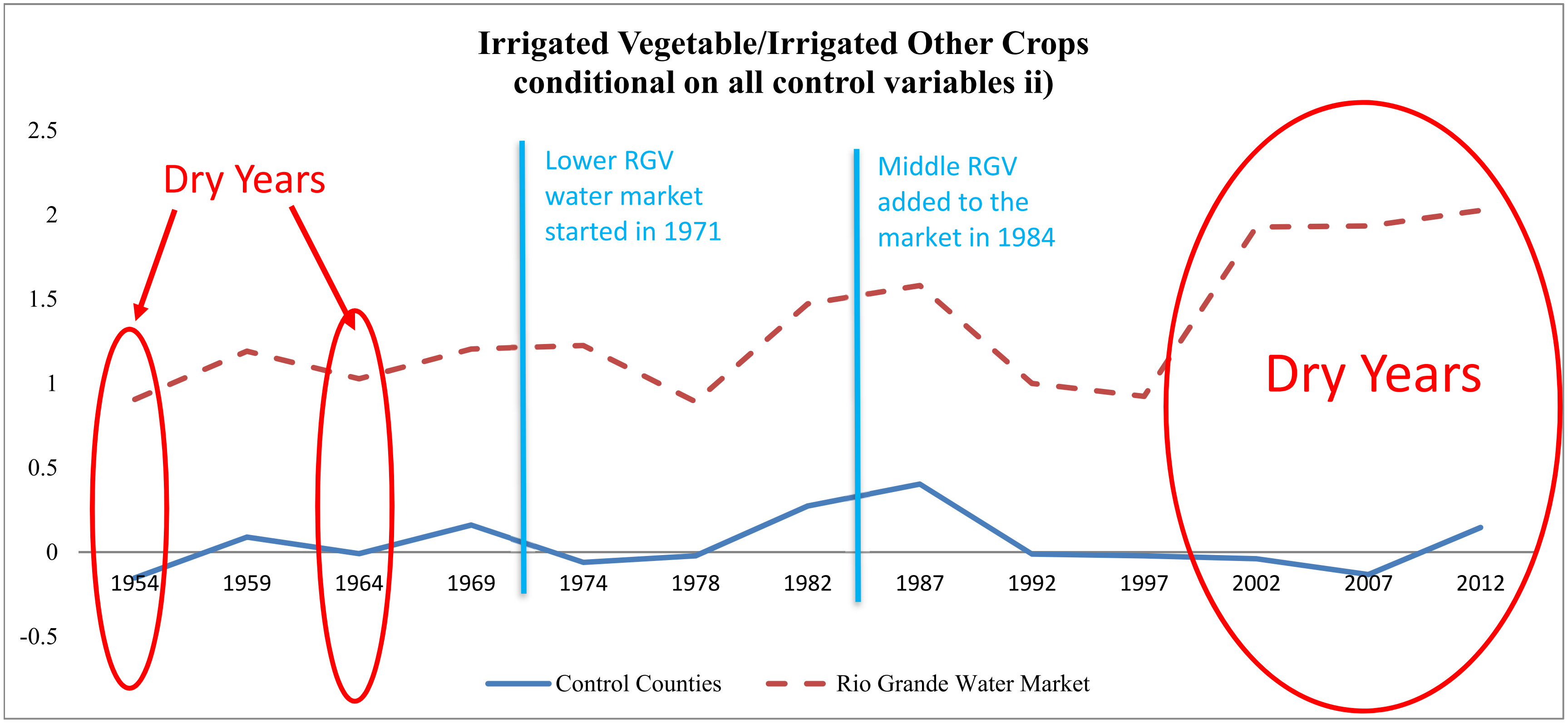


Note: i) Raw data from USDA Census of Agriculture and Population; precipitation data from the Center for Climate Research at the University of Delaware. by Willmott and Matsuura; temperature data collected by the United States Historical Climatology Network (USHCN).

ii) "Conditional on all control variables" means that residuals are reported after controlling the full set of control variables including precipitation, the degree-day counts, county-level logarithmic values of total farmland area, pasture area, and the per acre revenue from pasture, the values of the outcome variables in pre-market years interacted with year dummies, as well as county fixed-effect and crop x year dummies. These residuals are esitimated by linear regressions weighted by the county-level average harvest area for each crop in pre-market years.

iii) The two figures on the left show that the raw averages of outcome variables do not exhibit perfectly paralell pre-market trends for the treatment and control conties, but the residuals conditional on our full set of control variables exhibit paralell pre-market trends as in the two figures on the right.

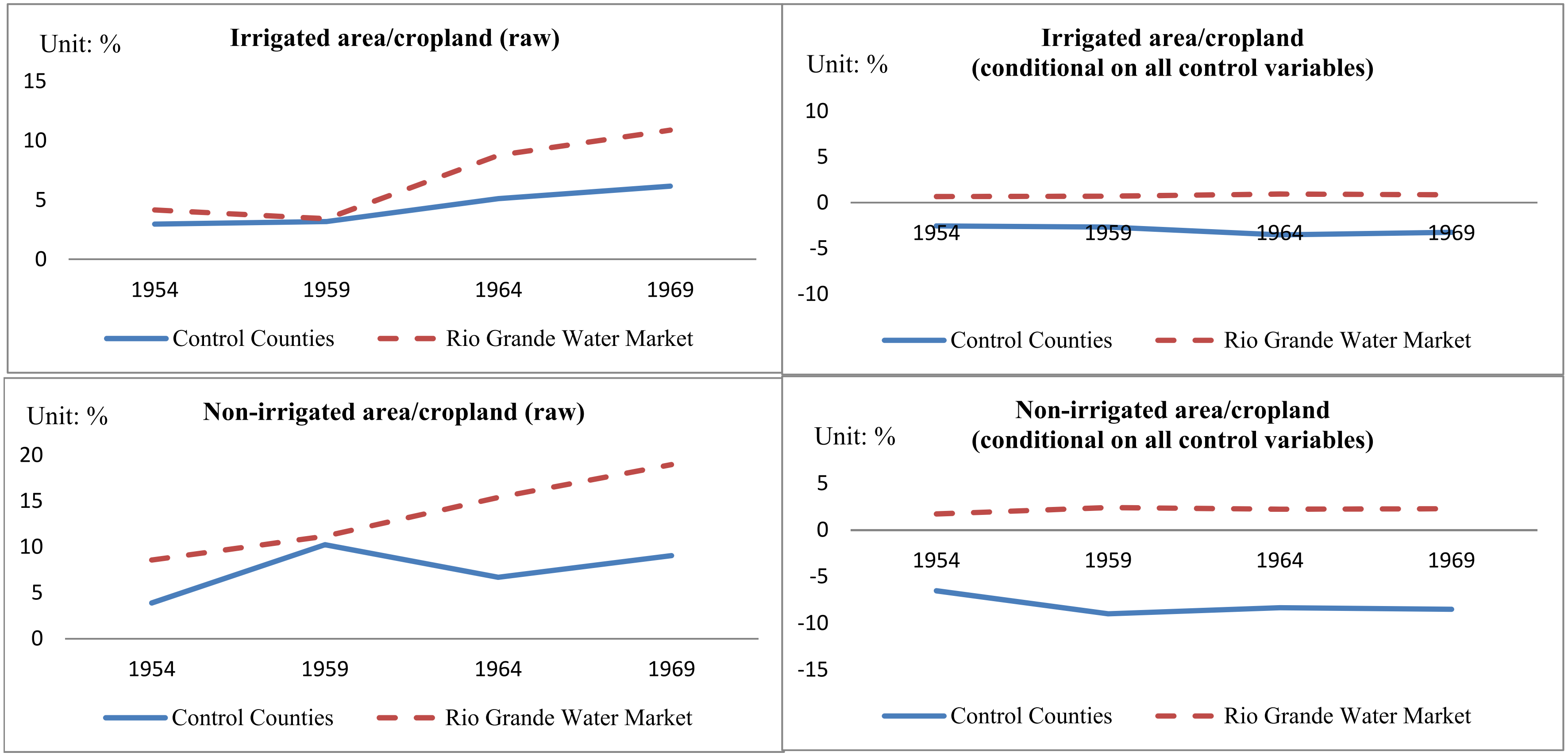
Figure 5: Ratios from Higher- to Lower-Value Irrigated Crops Conditional on All Control Variables ii)



Note: i) Raw data from USDA Census of Agriculture and Population; precipitation data from the Center for Climate Research at the University of Delaware. by Willmott and Matsuura; temperature data collected by the United States Historical Climatology Network (USHCN).

ii) "Conditional on all control variables" means that residuals are reported after controlling the full set of control variables including precipitation, the degree-day counts, county-level logarithmic values of total farmland area, pasture area, and the per acre revenue from pasture, the values of the outcome variables in pre-market years interacted with year dummies, as well as county fixed-effect and crop x year dummies. These residuals are esitimated by linear regressions weighted by the county-level average harvest area for each crop in pre-market years.

Figure 6: Pre-treatment Trends for Outcome Variables (Crops included: Corn, sorghum, and hay) [iv)]



Note: i) Raw data from USDA Census of Agriculture and Population; precipitation data from the Center for Climate Research at the University of Delaware. by Willmott and Matsuura; temperature data collected by the United States Historical Climatology Network (USHCN).

ii) "Conditional on all control variables" means that residuals are reported after controlling the full set of control variables including annual precipitation, the annual total degree-day counts above 32°C, county-level logarithmic values of total farmland area, pasture area, the per acre revenue from pasture, harvest area of other crops, and revenue from other crops, the values of the outcome variables in pre-market years interacted with year dummies, as well as county fixed-effect and crop x year dummies. These residuals are esitimated by linear regressions weighted by the county-level average harvest area for each crop in pre-market years.

iii) The two figures on the left show that the raw averages of outcome variables do not exhibit perfectly paralell pre-market trends for the treatment and control conties, but the residuals conditional on our full set of control variables exhibit paralell pre-market trends as in the two figures on the right.

iv) Cotton is excluded due to a data issue in 1969. Similarly, wheat is excluded because data are missing in the 1950s.

Table 1: Water Rights in Rio Grande

water use	1,000 m^3	share (%)
domestic/municipal	459307	16
industry	61596	2
agriculture	2268327	80
mining	29028	1
Total	2818258	100

NOTE: Rio Grande Watermaster, http://www.tceq.state.tx.us/permitting/water_rights/wr-permitting/wr_databases.html.

Table 2: Total Acreage of Counties in the Region

(Number of Counties: 19)

Variables		Total acreage in 1964	Total acreage in 2012
Farmland area		14,706,300	13,337,032
Total cropland area		1,600,181	1,543,247
Irrigated land area		740,878	449,108
Corn	Non-irrigated area	3,723	38,997
	Irrigated area	6,393	38,783
Sorghum	Non-irrigated area	187,802	345,142
	Irrigated area	129,250	92,989
Wheat	Non-irrigated area	1,879	17,870
	Irrigated area	687	12,561
Vegetable	Non-irrigated area	20,074	16,605
	Irrigated area	147,199	43,407
Fruit	Non-irrigated area	4,602	5,402
	Irrigated area	60,919	21,496
Cotton	Non-irrigated area	173,794	67,674
	Irrigated area	214,141	69,334
Hay	Non-irrigated area	86,177	61,856
	Irrigated area	64,207	31,863

NOTE: *Census of Agriculture and Population*, 1964 & 2012.

Table 3: Real Water Productivity by years and crops (2012 baseline, $/10 m^3)

	Categorical Measures			Measures for individual crops calculated from prices				
	Vegetables	Fruits	Other Crops	Corn	Sorghum	Wheat	Hays	Cotton
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
1954	5.0477	1.3589	1.3787	0.8793	1.7355	0.6615	0.5679	2.5202
1959	4.7314	1.7707	1.5412	0.9602	1.7415	1.0792	0.5405	2.5579
1964	6.4251	2.1025	1.0400	1.1788	2.0127	1.0455	0.8479	2.0299
1969	9.5975	0.8685	0.7409	1.2904	2.1722	0.8075	0.6340	1.0663
1974	19.3664	2.1118	1.1506	2.0286	4.2010	2.0536	0.9183	1.6961
1978	10.9928	1.4180	2.6502	1.7956	2.2561	0.9850	0.8149	2.1748
1982	10.8391	2.4065	1.4478	1.8491	2.0851	0.8828	0.6678	1.6500
1987	10.2998	1.2306	1.5089	1.1470	1.3507	0.6140	0.5711	1.8557
1992	8.6846	2.1305	1.4036	1.0891	1.3829	0.6891	0.4505	1.0407
1997	13.0934	1.4775	1.1078	1.3696	1.4937	0.7558	0.5205	1.1183
2002	17.2564	1.5056	1.0016	0.8336	1.0903	0.4715	0.4932	0.9454
2007	16.4071	2.8842	1.3131	1.7740	1.8526	0.7254	0.8725	1.5619
2012	14.9963	2.9065	1.6618	2.5017	2.8037	1.1261	0.5929	1.6393

NOTE: Data constructed from USDA Census of Agriculture and Population (1954-2012), Brouwer and Heibloem (1986), and USDA Feed Grains Data: Yearbook Tables (2015). Market values of crops in Columns (1)-(3) are directly taken from the USDA Census, while those in Columns (4)-(8) are calculated from the price data in USDA Feed Grains Data (2015). Therefore, the numbers in Columns (1)-(3) are not comparable to the numbers in Columns (4) - (8).

Table 4A: The Effect of Water Market on Irrigated Area/Total Cropland Area for Three Categories of Crops (Unit: %) [i)]
(Crop categories included in regressions: Vegetables, fruits, and other crops)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Post x WaterMarket	-5.624	-4.841	0.534	-5.796	-5.073	0.263	-4.510	-3.810	1.567
	(3.478)	(3.382)	(1.549)	(3.984)	(3.876)	(1.718)	(3.638)	(3.613)	(1.638)
Post x WaterMarket				1.050***	1.049***	0.800***	0.755***	0.726***	0.542**
x Water Productivity [ii)]				(0.271)	(0.280)	(0.254)	(0.225)	(0.245)	(0.230)
Post x WaterMarket x Drought [ii)]							-9.088	-8.954	-1.572
							(6.959)	(6.490)	(3.296)
Post x WaterMarket x Drought							3.152**	3.272***	3.067***
x Water Productivity							(1.245)	(1.209)	(1.165)
Other triple and double interactions [iv)]	-	-	-	Yes	Yes	Yes	Yes	Yes	Yes
County-fixed Effect	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Item x Year Dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Other Control Variables [v)]	-	Yes	Yes	-	Yes	Yes	-	Yes	Yes
Pre-water-market Controls [vi)]	-	-	Yes	-	-	Yes	-	-	Yes
Observations	580	574	567	580	574	567	580	574	567

NOTE: i) Each column is estimated jointly with corrsponding specification in Table 4B, so standard errors are correlated and clustered at the county-level.

ii) Water productivity is in real term in 2012 \$/10 m^3 and is relative to the lowest category each year.

iii) "Drought" equals to one if the precipitation in recent two years is less than long-term mean minus long-term standard deviation, and equals to zero otherwise.

iv) For Columns (4)-(6), "Other triple and double interactions" includes Low RGV Counties x Water Productivity, Middle RGV Counties x Water Productivity, and Post x Water Productivity. For Columns (7)-(9), "Other triple and double interactions" includes Post x Drought, Drought x Water Productivity, Low RGV Counties x Drought, Middle RGV Counties x Drought, Low RGV Counties x Water Productivity and x Drought, Middle RGV Counties x Water Productivity and x Drought, Post x Water Productivity and x Drought. Other interaction terms are absorbed by fixed effects controlled.

v) Other control variables include the logarithmic values of farmland area, pasture area, and per acre revenue from pasture.

vi) Pre-water-market Controls is the outcome variables in 1954 - 69 before the water market implemented interacted with dummies for the post-market years.

vii) Weighted by average county-level harvest areas in pre-market years by crops. *** $p<0.01$, ** $p<0.05$, * $p<0.1$

Table 4B: The Effect of Water Market on Non-irrigated Area/Total Cropland Area for Three Categories of Crops (Unit: %) i)
(Crop categories included in regressions: Vegetables, fruits, and other crops)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Post x WaterMarket	8.859*	6.869	7.670**	11.10**	9.058*	9.739***	10.54**	8.024*	8.356**
	(4.708)	(4.523)	(3.339)	(5.114)	(4.959)	(3.656)	(4.812)	(4.843)	(3.612)
Post x WaterMarket				-0.493	-0.482	-0.359	-0.469	-0.356	-0.241
x Water Productivity ii)				(0.645)	(0.656)	(0.517)	(0.550)	(0.568)	(0.450)
Post x WaterMarket x Drought ii)							16.62***	16.34**	12.40**
							(5.820)	(6.690)	(5.346)
Post x WaterMarket x Drought							-1.212	-1.621	-1.441
x Water Productivity							(1.697)	(1.642)	(1.846)
Other triple and double interactions iv)	-	-	-	Yes	Yes	Yes	Yes	Yes	Yes
County-fixed Effect	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Item x Year Dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Other Control Variables v)	-	Yes	Yes	-	Yes	Yes	-	Yes	Yes
Pre-water-market Controls vi)	-	-	Yes	-	-	Yes	-	-	Yes
Observations	580	574	567	580	574	567	580	574	567

NOTE: i) Each column is estimated jointly with corrsponding specification in Table 4A, so standard errors are correlated and clustered at the county-level.

ii) Water productivity is in real term in 2012 $/10 m^3 and is relative to the lowest category each year.

iii) "Drought" equals to one if the precipitation in recent two years is less than long-term mean minus long-term standard deviation, and equals to zero otherwise

iv) For Columns (4)-(6), "Other triple and double interactions" includes Low RGV Counties x Water Productivity, Middle RGV Counties x Water Productivity, and Post x Water Productivity. For Columns (7)-(9), "Other triple and double interactions" includes Post x Drought, Drought x Water Productivity, Low RGV Counties x Drought, Middle RGV Counties x Drought, Low RGV Counties x Water Productivity and x Drought, Middle RGV Counties x Water Productivity and x Drought, Post x Water Productivity and x Drought. Other interaction terms are absorbed by fixed effects controlled.

v) Other control variables include the logarithmic values of farmland area, pasture area, and per acre revenue from pasture.

vi) Pre-water-market Controls is the outcome variables in 1954 - 69 before the water market implemented interacted with dummies for the post-market years.

vii) Weighted by average county-level harvest areas in pre-market years by crops. *** p<0.01, ** p<0.05, * p<0.1

Table 5: Counties Characteristics in Pre-market Years (1954-69): Water Market Versus Neighboring Control Counties

Variables		Pooled Mean and Std. Dev. i)	Differences ii)	Variables		Pooled Mean and Std. Dev. i)	Differences ii)
		(1)	(2)			(3)	(4)
Log(farmland area)		13.697	-0.345	Wheat (in %)	Irrigated area/cropland	0.602	0.902*
		(0.490)	(0.219)			(1.418)	(0.470)
Log(pasture area)		13.592	-0.647**		Non-irrigated area/cropland	0.161	-0.0509
		(0.687)	(0.284)			(0.314)	(0.108)
Log(per acre revenue from pasture)		1.408	0.356	Vegetable (in %)	Irrigated area/cropland	6.256	5.299**
		(0.760)	(0.340)			(5.984)	(2.206)
Log(harvest area of excluded crops) iii)		7.618	0.826		Non-irrigated area/cropland	2.086	0.0304
		(1.615)	(0.711)			(4.149)	(1.309)
Log(irrigated area of excluded crops) iii)		5.060	1.960	Fruit (in %)	Irrigated area/cropland	1.085	1.993
		(3.182)	(1.362)			(2.577)	(1.168)
Log(revenue from excluded crops) iii)		11.406	0.901		Non-irrigated area/cropland	0.466	-0.250
		(3.357)	(1.235)			(0.975)	(0.494)
Corn for Grain (in %)	Irrigated area/cropland	0.437	0.0272	Cotton (in %)	Irrigated area/cropland	5.445	8.012*
		(0.692)	(0.336)			(8.502)	(3.936)
	Non-irrigated area/cropland	0.928	-0.674		Non-irrigated area/cropland	5.876	8.493**
		(1.982)	(0.499)			(9.605)	(3.733)
Sorghum for Grain (in %)	Irrigated area/cropland	3.326	2.615	All Hays (in %)	Irrigated area/cropland	7.056	-2.471
		(5.231)	(1.941)			(11.645)	(5.938)
	Non-irrigated area/cropland	6.595	3.927		Non-irrigated area/cropland	8.699	-8.774*
		(8.980)	(3.970)			(17.191)	(4.160)

Note: i) For the first 6 variables in logarithmic terms on the left panel, the mean and the standard deviation is weighted by each county's average farmland area in pre-market years; for the other variables by crops, each county's average harvest area for each crop in pre-market years is used as the weight.

ii) The differences reported are the coefficients for the water market dummy from cross-county linear regressions controlling rainfall, temperature, and year fixed effects, pooling all pre-market years. For the first 6 variables in logarithmic terms on the left panel, the regressions are weighted by each county's average farmland area in pre-market years; for the other variables by crops, the regressions are weighted by each county's average harvest area for each crop in pre-market years.

iii) Excluded crops are those other than corn, sorghum, wheat, vegetables, fruits, cotton, and hay, and are only relevant for when we run regressions on disaggregate crops for Tables 7 & 8.

iv) Standard errors clustered at the county-level. *** p<0.01, ** p<0.05, * p<0.1

Table 6A: The Effect of Water Market on Irrigated Area/Total Cropland Area for 5 Crops (Unit: %) [i)]
(Crops included in regressions: Corn, sorghum, wheat, hay, and cotton)

	(1)	(2)	(3)	(4)	(5)	(6)
Post x WaterMarket	-2.628	-2.679	1.644	-4.146	-4.241*	-0.130
	(2.389)	(2.084)	(1.909)	(2.647)	(2.245)	(2.113)
Post x WaterMarket	3.940	4.171	2.409	5.710	6.277*	4.400
x Drought Resistant Crops [ii)]	(3.028)	(3.007)	(2.447)	(3.555)	(3.462)	(3.004)
Post x WaterMarket x Drought [iii)]				6.440*	7.315**	9.052***
				(3.425)	(3.298)	(3.016)
Post x WaterMarket x Drought				-7.693*	-8.432**	-7.985**
x Drought Resistant Crops				(4.003)	(3.320)	(3.138)
Other triple and double interactions [iv)]	Yes	Yes	Yes	Yes	Yes	Yes
County-fixed Effect	Yes	Yes	Yes	Yes	Yes	Yes
Item x Year Dummies	Yes	Yes	Yes	Yes	Yes	Yes
Other Control Variables [v)]	-	Yes	Yes	-	Yes	Yes
Pre-water-market Controls [vi)]	-	-	Yes	-	-	Yes
Observations	1,058	1,051	1,033	1,058	1,051	1,033

NOTE: i) Each column is estimated jointly with corrsponding specification in Table 6B, so standard errors are correlated and clustered at the county-level.

ii) "Drought Resistant Crops" refers to sorghum and cotton, which are categorized as low drought sensitvity crops by FAO.

iii) "Drought" equals to one if the precipitation in recent two years is less than long-term mean minus long-term standard deviation, and zero otherwise.

iv) For Columns (1)-(3), "Other triple and double interactions" include Low RGV Counties x Drought Resistant Crops and Middle RGV Counties x Drought Resistant Crops. Post x Drought Resistant Crops is absorbed by Item x Year Dummies. For Columns (4)-(6), "Other triple and double interactions" include Post x Drought, Drought x Drought Resistant Crops, Low RGV Counties x Drought, Middle RGV Counties x Drought, Low RGV Counties x Drought Resistant Crops and x Drought, Middle RGV Counties x Drought Resistant Crops and x Drought, and Post x Drought Resistant Crops x Drought. Other interaction terms are absorbed by fixed effects controlled.

v) Other control variables include the logarithmic values of farmland area, pasture area, per acre revenue from pasture, harvest area of other crops, and revenue from other crops.

vi) Pre-water-market Controls is the outcome variables in 1954 - 69 before the water market implemented interacted with dummies for the post-market years.

vii) Weighted by average county-level harvest areas in pre-market years by crops. *** $p<0.01$, ** $p<0.05$, * $p<0.1$

Table 6B: The Effect of Water Market on Non-irrigated Area/Total Cropland Area for 5 Crops (Unit: %) [i)]

(Crops included in regressions: Corn, sorghum, wheat, hay, and cotton)

	(1)	(2)	(3)	(4)	(5)	(6)
Post x WaterMarket	1.227	0.805	-0.444	0.425	0.197	-1.069
	(1.187)	(1.491)	(1.654)	(1.440)	(1.568)	(1.453)
Post x WaterMarket	3.309	3.075	4.534**	2.644	2.241	3.526*
x Drought Resistant Crops [ii)]	(2.625)	(2.764)	(2.248)	(2.649)	(2.764)	(2.098)
Post x WaterMarket x Drought [iii)]				5.057	4.950	5.672*
				(3.425)	(3.333)	(3.011)
Post x WaterMarket x Drought				13.50***	13.53***	14.05***
x Drought Resistant Crops				(5.184)	(5.176)	(5.185)
Other triple and double interactions [iv)]	Yes	Yes	Yes	Yes	Yes	Yes
County-fixed Effect	Yes	Yes	Yes	Yes	Yes	Yes
Item x Year Dummies	Yes	Yes	Yes	Yes	Yes	Yes
Other Control Variables [v)]	-	Yes	Yes	-	Yes	Yes
Pre-water-market Controls [vi)]	-	-	Yes	-	-	Yes
Observations	1,058	1,051	1,033	1,058	1,051	1,033

NOTE: i) Each column is estimated jointly with corrsponding specification in Table 6A, so standard errors are correlated and clustered at the county-level.

ii) "Drought Resistant Crops" refers to sorghum and cotton, which are categorized as low drought sensitvity crops by FAO.

iii) "Drought" equals to one if the precipitation in recent two years is less than long-term mean minus long-term standard deviation, and zero otherwise.

iv) For Columns (1)-(3), "Other triple and double interactions" include Low RGV Counties x Drought Resistant Crops and Middle RGV Counties x Drought Resistant Crops. Post x Drought Resistant Crops is absorbed by Item x Year Dummies. For Columns (4)-(6), "Other triple and double interactions" include Post x Drought, Drought x Drought Resistant Crops, Low RGV Counties x Drought, Middle RGV Counties x Drought, Low RGV Counties x Drought Resistant Crops and x Drought, Middle RGV Counties x Drought Resistant Crops and x Drought, and Post x Drought Resistant Crops x Drought. Other interaction terms are absorbed by fixed effects controlled.

v) Other control variables include the logarithmic values of farmland area, pasture area, per acre revenue from pasture, harvest area of other crops, and revenue from other crops.

vi) Pre-water-market Controls is the outcome variables in 1954 - 69 before the water market implemented interacted with dummies for the post-market years.

vii) Weighted by average county-level harvest areas in pre-market years by crops. *** p<0.01, ** p<0.05, * p<0.1

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Appendix Tables for "The Effects of Water Markets" by Peter Debaere and Tianshu Li

Table A1A: The Effect of Water Market on Irrigated Area/Total Cropland Area for 3 Categories of Crops (Unit: %) i)

(Using the expanded control group as in Figure 1a; Crop categories included in regressions: Vegetables, fruits, and other crops)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Post x WaterMarket	-4.953**	-4.575*	-0.569	-4.954*	-4.615	-0.825	-4.098	-3.849	0.0693
	(2.485)	(2.512)	(1.472)	(2.768)	(2.813)	(1.572)	(2.823)	(2.971)	(1.693)
Post x WaterMarket				1.057***	1.094***	0.846***	0.780***	0.790***	0.604***
x Water Productivity ii)				(0.251)	(0.254)	(0.271)	(0.205)	(0.217)	(0.225)
Post x WaterMarket x Drought ii)							-6.667*	-6.223*	-1.319
							(3.641)	(3.475)	(2.268)
Post x WaterMarket x Drought							2.423**	2.478**	2.888***
x Water Productivity							(0.992)	(1.036)	(0.935)
Other triple and double interactions iv)	-	-	-	Yes	Yes	Yes	Yes	Yes	Yes
County-fixed Effect	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Item x Year Dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Other Control Variables v)	-	Yes	Yes	-	Yes	Yes	-	Yes	Yes
Pre-water-market Controls vi)	-	-	Yes	-	-	Yes	-	-	Yes
Observations	876	853	846	876	853	846	876	853	846

NOTE: i) Each column is estimated jointly with corrsponding specification in Table A1B, so standard errors are correlated and clustered at the county-level.

ii) Water productivity is in real term in 2012 \$/10 m^3 and is relative to the lowest category each year.

iii) "Drought" equals to one if the precipitation in recent two years is less than long-term mean minus long-term standard deviation, and equals to zero otherwise

iv) For Columns (4)-(6), "Other triple and double interactions" includes Low RGV Counties x Water Productivity, Middle RGV Counties x Water Productivity, and Post x Water Productivity. For Columns (7)-(9), "Other triple and double interactions" includes Post x Drought, Drought x Water Productivity, Low RGV Counties x Drought, Middle RGV Counties x Drought, Low RGV Counties x Water Productivity and x Drought, Middle RGV Counties x Water Productivity and x Drought, Post x Water Productivity and x Drought. Other interaction terms are absorbed by fixed effects controlled.

v) Other control variables include the logarithmic values of farmland area, pasture area, and per acre revenue from pasture.

vi) Pre-water-market Controls is the outcome variables in 1954 - 69 before the water market implemented interacted with dummies for the post-market years.

vii) Weighted by average county-level harvest areas in pre-market years by crops. *** p<0.01, ** p<0.05, * p<0.1

Table A1B: The Effect of Water Market on Non-irrigated Area/Total Cropland Area for 3 Categories of Crops (Unit: %) i)
(Using the Expanded Control Group as in Figure 1a; Crop categories included in regressions: Vegetables, fruits, and other crops)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Post x WaterMarket	12.01***	11.08***	8.647***	13.67***	12.81***	10.36***	12.89***	11.88***	8.876***
	(4.042)	(4.143)	(2.638)	(4.301)	(4.413)	(2.755)	(3.992)	(4.062)	(2.764)
Post x WaterMarket				-1.037*	-1.138*	-0.816	-0.921*	-0.965*	-0.610
x Water Productivity ii)				(0.568)	(0.589)	(0.523)	(0.504)	(0.526)	(0.469)
Post x WaterMarket x Drought ii)							15.52***	14.94***	13.19***
							(3.984)	(4.039)	(2.821)
Post x WaterMarket x Drought							-2.871*	-3.045**	-2.726*
x Water Productivity							(1.470)	(1.462)	(1.521)
Other triple and double interactions iv)	-	-	-	Yes	Yes	Yes	Yes	Yes	Yes
County-fixed Effect	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Item x Year Dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Other Control Variables v)	-	Yes	Yes	-	Yes	Yes	-	Yes	Yes
Pre-water-market Controls vi)	-	-	Yes	-	-	Yes	-	-	Yes
Observations	876	853	846	876	853	846	876	853	846

NOTE: i) Each column is estimated jointly with corrsponding specification in Table A1A, so standard errors are correlated and clustered at the county-level.

ii) Water productivity is in real term in 2012 \$/10 m^3 and is relative to the lowest category each year.

iii) "Drought" equals to one if the precipitation in recent two years is less than long-term mean minus long-term standard deviation, and equals to zero otherwise

iv) For Columns (4)-(6), "Other triple and double interactions" includes Low RGV Counties x Water Productivity, Middle RGV Counties x Water Productivity, and Post x Water Productivity. For Columns (7)-(9), "Other triple and double interactions" includes Post x Drought, Drought x Water Productivity, Low RGV Counties x Drought, Middle RGV Counties x Drought, Low RGV Counties x Water Productivity and x Drought, Middle RGV Counties x Water Productivity and x Drought, Post x Water Productivity and x Drought. Other interaction terms are absorbed by fixed effects controlled.

v) Other control variables include the logarithmic values of farmland area, pasture area, and per acre revenue from pasture.

vi) Pre-water-market Controls is the outcome variables in 1954 - 69 before the water market implemented interacted with dummies for the post-market years.

vii) Weighted by average county-level harvest areas in pre-market years by crops. *** p<0.01, ** p<0.05, * p<0.1

Table A2A: The Effect of Water Market on Irrigated Area/Total Cropland Area for Three Categories of Crops (Unit: %) [i)]
(Post period since 1971 for all 10 counties; Crop categories included in regressions: Vegetables, fruits, and other crops)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Post x WaterMarket	-5.979	-5.136	1.216	-6.122	-5.237	1.153	-4.324	-2.456	3.125*
	(3.854)	(3.831)	(1.864)	(4.182)	(4.147)	(1.990)	(3.552)	(3.937)	(1.736)
Post x WaterMarket				1.266***	1.221***	1.147**	0.461	0.433	0.541
x Water Productivity [ii)]				(0.484)	(0.468)	(0.535)	(0.402)	(0.390)	(0.463)
Post x WaterMarket x Drought [ii)]							-8.558	-9.482	-2.265
							(6.190)	(5.874)	(2.841)
Post x WaterMarket x Drought							3.569***	3.681***	3.135***
x Water Productivity							(1.327)	(1.322)	(1.091)
Other triple and double interactions [iv)]	-	-	-	Yes	Yes	Yes	Yes	Yes	Yes
County-fixed Effect	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Item x Year Dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Other Control Variables [v)]	-	Yes	Yes	-	Yes	Yes	-	Yes	Yes
Pre-water-market Controls [vi)]	-	-	Yes	-	-	Yes	-	-	Yes
Observations	580	574	567	580	574	567	580	574	567

NOTE: i) Each column is estimated jointly with corrsponding specification in Table A2B, so standard errors are correlated and clustered at the county-level.

ii) Water productivity is in real term in 2012 $/10 m^3 and is relative to the lowest category each year.

iii) "Drought" equals to one if the precipitation in recent two years is less than long-term mean minus long-term standard deviation, and equals to zero otherwise

iv) For Columns (4)-(6), "Other triple and double interactions" includes Low RGV Counties x Water Productivity, Middle RGV Counties x Water Productivity, and Post x Water Productivity. For Columns (7)-(9), "Other triple and double interactions" includes Post x Drought, Drought x Water Productivity, Low RGV Counties x Drought, Middle RGV Counties x Drought, Low RGV Counties x Water Productivity and x Drought, Middle RGV Counties x Water Productivity and x Drought, Post x Water Productivity and x Drought. Other interaction terms are absorbed by fixed effects controlled.

v) Other control variables include the logarithmic values of farmland area, pasture area, and per acre revenue from pasture.

vi) Pre-water-market Controls is the outcome variables in 1954 - 69 before the water market implemented interacted with dummies for the post-market years.

vii) Weighted by average county-level harvest areas in pre-market years by crops. *** p<0.01, ** p<0.05, * p<0.1

Table A2B: The Effect of Water Market on Non-irrigated Area/Total Cropland Area for 3 Categories of Crops (Unit: %) [i)]
(Post period since 1971 for all 10 counties; Crop categories included in regressions: Vegetables, fruits, and other crops)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Post x WaterMarket	10.77*	9.271	9.950**	12.51**	10.94*	11.53**	11.48*	9.463	8.810*
	(5.935)	(5.665)	(4.129)	(6.346)	(6.102)	(4.480)	(6.214)	(6.013)	(4.562)
Post x WaterMarket				-1.004	-0.921	-0.881	-1.199	-0.971	-0.933
x Water Productivity [ii)]				(1.089)	(1.105)	(0.994)	(0.867)	(0.897)	(0.790)
Post x WaterMarket x Drought [ii)]							15.54***	14.64**	11.67**
							(4.875)	(5.738)	(5.288)
Post x WaterMarket x Drought							-0.234	-0.760	-0.527
x Water Productivity							(1.490)	(1.374)	(1.615)
Other triple and double interactions [iv)]	-	-	-	Yes	Yes	Yes	Yes	Yes	Yes
County-fixed Effect	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Item x Year Dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Other Control Variables [v)]	-	Yes	Yes	-	Yes	Yes	-	Yes	Yes
Pre-water-market Controls [vi)]	-	-	Yes	-	-	Yes	-	-	Yes
Observations	580	574	567	580	574	567	580	574	567

NOTE: i) Each column is estimated jointly with corrsponding specification in Table A2A, so standard errors are correlated and clustered at the county-level.

ii) Water productivity is in real term in 2012 $/10 m^3 and is relative to the lowest category each year.

iii) "Drought" equals to one if the precipitation in recent two years is less than long-term mean minus long-term standard deviation, and equals to zero otherwise

iv) For Columns (4)-(6), "Other triple and double interactions" includes Low RGV Counties x Water Productivity, Middle RGV Counties x Water Productivity, and Post x Water Productivity. For Columns (7)-(9), "Other triple and double interactions" includes Post x Drought, Drought x Water Productivity, Low RGV Counties x Drought, Middle RGV Counties x Drought, Low RGV Counties x Water Productivity and x Drought, Middle RGV Counties x Water Productivity and x Drought, Post x Water Productivity and x Drought. Other interaction terms are absorbed by fixed effects controlled.

v) Other control variables include the logarithmic values of farmland area, pasture area, and per acre revenue from pasture.

vi) Pre-water-market Controls is the outcome variables in 1954 - 69 before the water market implemented interacted with dummies for the post-market years.

vii) Weighted by average county-level harvest areas in pre-market years by crops. *** p<0.01, ** p<0.05, * p<0.1

Table A3A: The Effect of Water Market on Irrigated Area/Total Cropland Area for 5 Crops (Unit: %) [i)]
(Using the Expanded Control Group as in Figure 1a; Crops included in regressions: Corn, sorghum, wheat, hay, and cotton)

	(1)	(2)	(3)	(4)	(5)	(6)
Post x WaterMarket	-2.462	-2.417	1.740	-3.707	-3.736	0.301
	(2.012)	(2.098)	(1.692)	(2.356)	(2.381)	(1.922)
Post x WaterMarket	1.442	2.103	0.358	2.999	3.800	1.977
x Drought Resistant Crops [ii)]	(2.513)	(2.613)	(1.962)	(2.975)	(3.027)	(2.388)
Post x WaterMarket x Drought [iii)]				4.847**	4.937**	6.956***
				(2.210)	(2.101)	(1.740)
Post x WaterMarket x Drought				-6.590**	-6.907***	-6.137***
x Drought Resistant Crops				(2.718)	(2.233)	(1.840)
Other triple and double interactions [iv)]	Yes	Yes	Yes	Yes	Yes	Yes
County-fixed Effect	Yes	Yes	Yes	Yes	Yes	Yes
Item x Year Dummies	Yes	Yes	Yes	Yes	Yes	Yes
Other Control Variables [v)]	-	Yes	Yes	-	Yes	Yes
Pre-water-market Controls [vi)]	-	-	Yes	-	-	Yes
Observations	1,612	1,572	1,554	1,612	1,572	1,554

NOTE: i) Each column is estimated jointly with corrsponding specification in Table A3B, so standard errors are correlated and clustered at the county-level.

ii) "Drought Resistant Crops" refers to sorghum and cotton, which are categorized as low drought sensitvity crops by FAO.

iii) "Drought" equals to one if the precipitation in recent two years is less than long-term mean minus long-term standard deviation, and zero otherwise.

iv) For Columns (1)-(3), "Other triple and double interactions" include Low RGV Counties x Drought Resistant Crops and Middle RGV Counties x Drought Resistant Crops. Post x Drought Resistant Crops is absorbed by Item x Year Dummies. For Columns (4)-(6), "Other triple and double interactions" include Post x Drought, Drought x Drought Resistant Crops, Low RGV Counties x Drought, Middle RGV Counties x Drought, Low RGV Counties x Drought Resistant Crops and x Drought, Middle RGV Counties x Drought Resistant Crops and x Drought, and Post x Drought Resistant Crops x Drought. Other interaction terms are absorbed by fixed effects controlled.

v) Other control variables include the logarithmic values of farmland area, pasture area, per acre revenue from pasture, harvest area of other crops, and revenue from other crops.

vi) Pre-water-market Controls is the outcome variables in 1954 - 69 before the water market implemented interacted with dummies for the post-market years.

vii) Weighted by average county-level harvest areas in pre-market years by crops. *** $p<0.01$, ** $p<0.05$, * $p<0.1$

Table A3B: The Effect of Water Market on Non-irrigated Area/Total Cropland Area for 5 Crops (Unit: %) [i)]

(Using the Expanded Control Group as in Figure 1a; Crops included in regressions: Corn, sorghum, wheat, hay, and cotton)

	(1)	(2)	(3)	(4)	(5)	(6)
Post x WaterMarket	2.405	2.011	1.176	0.952	0.371	-0.837
	(1.969)	(2.129)	(1.835)	(1.691)	(1.696)	(1.402)
Post x WaterMarket	1.672	2.348	6.220	3.203	3.884	7.264**
x Drought Resistant Crops [ii)]	(4.204)	(4.194)	(3.867)	(3.162)	(3.038)	(2.896)
Post x WaterMarket x Drought [iii)]				6.518	7.893*	9.064**
				(4.404)	(4.334)	(4.192)
Post x WaterMarket x Drought				1.106	-0.704	2.660
x Drought Resistant Crops				(8.166)	(8.682)	(8.574)
Other triple and double interactions [iv)]	Yes	Yes	Yes	Yes	Yes	Yes
County-fixed Effect	Yes	Yes	Yes	Yes	Yes	Yes
Item x Year Dummies	Yes	Yes	Yes	Yes	Yes	Yes
Other Control Variables [v)]	-	Yes	Yes	-	Yes	Yes
Pre-water-market Controls [vi)]	-	-	Yes	-	-	Yes
Observations	1,612	1,572	1,554	1,612	1,572	1,554

NOTE: i) Each column is estimated jointly with corrsponding specification in Table A3A, so standard errors are correlated and clustered at the county-level.

ii) "Drought Resistant Crops" refers to sorghum and cotton, which are categorized as low drought sensitvity crops by FAO.

iii) "Drought" equals to one if the precipitation in recent two years is less than long-term mean minus long-term standard deviation, and zero otherwise.

iv) For Columns (1)-(3), "Other triple and double interactions" include Low RGV Counties x Drought Resistant Crops and Middle RGV Counties x Drought Resistant Crops. Post x Drought Resistant Crops is absorbed by Item x Year Dummies. For Columns (4)-(6), "Other triple and double interactions" include Post x Drought, Drought x Drought Resistant Crops, Low RGV Counties x Drought, Middle RGV Counties x Drought, Low RGV Counties x Drought Resistant Crops and x Drought, Middle RGV Counties x Drought Resistant Crops and x Drought, and Post x Drought Resistant Crops x Drought. Other interaction terms are absorbed by fixed effects controlled.

v) Other control variables include the logarithmic values of farmland area, pasture area, per acre revenue from pasture, harvest area of other crops, and revenue from other crops.

vi) Pre-water-market Controls is the outcome variables in 1954 - 69 before the water market implemented interacted with dummies for the post-market years.

vii) Weighted by average county-level harvest areas in pre-market years by crops. *** $p<0.01$, ** $p<0.05$, * $p<0.1$

Table A4A: The Effect of Water Market on Irrigated Area/Total Cropland Area for 5 Crops (Unit: %) i)
(Post period since 1971 for all 10 counties; Crops included in regressions: Corn, sorghum, wheat, hay, and cotton)

	(1)	(2)	(3)	(4)	(5)	(6)
Post x WaterMarket	-6.202	-6.259*	-2.053	-7.864*	-7.959**	-4.165
	(3.831)	(3.468)	(3.393)	(4.022)	(3.555)	(3.628)
Post x WaterMarket	9.725*	10.01*	8.748	12.19*	12.73**	11.46*
x Drought Resistant Crops ii)	(5.643)	(5.588)	(5.450)	(6.253)	(6.104)	(5.977)
Post x WaterMarket x Drought iii)				10.45**	11.39***	12.94***
				(4.648)	(4.358)	(4.201)
Post x WaterMarket x Drought				-14.74**	-15.44***	-15.44***
x Drought Resistant Crops				(6.750)	(5.986)	(5.708)
Other triple and double interactions iv)	Yes	Yes	Yes	Yes	Yes	Yes
County-fixed Effect	Yes	Yes	Yes	Yes	Yes	Yes
Item x Year Dummies	Yes	Yes	Yes	Yes	Yes	Yes
Other Control Variables v)	-	Yes	Yes	-	Yes	Yes
Pre-water-market Controls vi)	-	-	Yes	-	-	Yes
Observations	1,058	1,051	1,033	1,058	1,051	1,033

NOTE: i) Each column is estimated jointly with corrsponding specification in Table A4B, so standard errors are correlated and clustered at the county-level.
ii) "Drought Resistant Crops" refers to sorghum and cotton, which are categorized as low drought sensitvity crops by FAO.
iii) "Drought" equals to one if the precipitation in recent two years is less than long-term mean minus long-term standard deviation, and zero otherwise.
iv) For Columns (1)-(3), "Other triple and double interactions" include Low RGV Counties x Drought Resistant Crops and Middle RGV Counties x Drought Resistant Crops. Post x Drought Resistant Crops is absorbed by Item x Year Dummies. For Columns (4)-(6), "Other triple and double interactions" include Post x Drought, Drought x Drought Resistant Crops, Low RGV Counties x Drought, Middle RGV Counties x Drought, Low RGV Counties x Drought Resistant Crops and x Drought, Middle RGV Counties x Drought Resistant Crops and x Drought, and Post x Drought Resistant Crops x Drought. Other interaction terms are absorbed by fixed effects controlled.
v) Other control variables include the logarithmic values of farmland area, pasture area, per acre revenue from pasture, harvest area of other crops, and revenue from other crops.
vi) Pre-water-market Controls is the outcome variables in 1954 - 69 before the water market implemented interacted with dummies for the post-market years.
vii) Weighted by average county-level harvest areas in pre-market years by crops. *** $p<0.01$, ** $p<0.05$, * $p<0.1$

Table A4B: The Effect of Water Market on Non-irrigated Area/Total Cropland Area for 5 Crops (Unit: %) [i)]
(Post period since 1971 for all 10 counties; Crops included in regressions: Corn, sorghum, wheat, hay, and cotton)

	(1)	(2)	(3)	(4)	(5)	(6)
Post x WaterMarket	-1.486	-1.922	-2.926**	-2.674*	-3.031*	-4.089***
	(1.245)	(1.496)	(1.170)	(1.619)	(1.766)	(1.111)
Post x WaterMarket	7.743***	7.568***	9.074***	7.859***	7.612***	8.931***
x Drought Resistant Crops [ii)]	(1.962)	(2.087)	(1.719)	(2.047)	(2.211)	(1.747)
Post x WaterMarket x Drought [iii)]				8.472**	8.510**	9.514**
				(3.955)	(4.047)	(3.810)
Post x WaterMarket x Drought				7.746	7.694	8.441
x Drought Resistant Crops				(5.265)	(5.399)	(5.416)
Other triple and double interactions [iv)]	Yes	Yes	Yes	Yes	Yes	Yes
County-fixed Effect	Yes	Yes	Yes	Yes	Yes	Yes
Item x Year Dummies	Yes	Yes	Yes	Yes	Yes	Yes
Other Control Variables [v)]	-	Yes	Yes	-	Yes	Yes
Pre-water-market Controls [vi)]	-	-	Yes	-	-	Yes
Observations	1,058	1,051	1,033	1,058	1,051	1,033

NOTE: i) Each column is estimated jointly with corrsponding specification in Table A4A, so standard errors are correlated and clustered at the county-level.

ii) "Drought Resistant Crops" refers to sorghum and cotton, which are categorized as low drought sensitvity crops by FAO.

iii) "Drought" equals to one if the precipitation in recent two years is less than long-term mean minus long-term standard deviation, and zero otherwise.

iv) For Columns (1)-(3), "Other triple and double interactions" include Low RGV Counties x Drought Resistant Crops and Middle RGV Counties x Drought Resistant Crops. Post x Drought Resistant Crops is absorbed by Item x Year Dummies. For Columns (4)-(6), "Other triple and double interactions" include Post x Drought, Drought x Drought Resistant Crops, Low RGV Counties x Drought, Middle RGV Counties x Drought, Low RGV Counties x Drought Resistant Crops and x Drought, Middle RGV Counties x Drought Resistant Crops and x Drought, and Post x Drought Resistant Crops x Drought. Other interaction terms are absorbed by fixed effects controlled.

v) Other control variables include the logarithmic values of farmland area, pasture area, per acre revenue from pasture, harvest area of other crops, and revenue from other crops.

vi) Pre-water-market Controls is the outcome variables in 1954 - 69 before the water market implemented interacted with dummies for the post-market years.

vii) Weighted by average county-level harvest areas in pre-market years by crops. *** $p<0.01$, ** $p<0.05$, * $p<0.1$

Table A5: FAO-IIASA Agro-Ecological Suitability Values for Treated and Control Counties

		Rio Grande Water Market Counties (10 counties)		Neighboring Counties (9 counties)		Difference from Market Counties
	Crops	Mean	Std. Dev.	Mean	Std. Dev.	
Rainfed	Maize	2,532.20	785.43	2,252.43	994.35	279.77
	Sorghum	3,891.65	1,932.02	3,428.44	1,641.03	463.21
	Wheat	2,443.09	607.73	2,245.23	726.57	197.86
	Cabbage	2,441.48	607.14	2,228.85	697.22	212.63
	Citrus	3.75	14.90	26.88	70.58	-23.13
	Alfalfa	5.05	20.07	35.74	77.22	-30.69
	Cotton	3,585.81	1,493.37	3,065.76	1,557.57	520.05
Irrigated	Maize	4,482.94	2,216.01	3,292.81	2,940.25	1,190.12
	Sorghum	4,735.61	2,485.11	3,299.41	2,936.92	1,436.20
	Wheat	3,552.11	1,643.89	2,521.13	2,006.88	1,030.98
	Cabbage	3,248.53	1,403.99	2,494.72	2,032.62	753.82
	Citrus	1,826.50	2,495.16	1,849.57	2,740.43	-23.07
	Alfalfa	4,118.41	2,573.28	3,081.36	2,944.61	1,037.05
	Cotton	4,616.54	2,354.01	3,292.81	2,940.25	1,323.72

NOTE: Weighted by farmland area in pre-market years. * $p<0.1$

Source: Global Agro-Ecological Zones database by the Food and Agriculture Organization of the United Nations and the International Institute of Applied Systems Analysis. See http://gaez.fao.org/Main.html#.