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Implications of Water Scarcity for Water Productivity and Farm Labor

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Abstract: Increasing water scarcity causes a variety of pressures on agricultural production given current and growing food demands. This paper seeks to add to our understanding of water scarcity adaptations by explicitly addressing linkages between water scarcity, water productivity, cropping choices, and farm labor. We challenge the widespread claim that tightening foreign (especially Mexican) labor supply will necessarily result in less labor-intensive crop choices. Instead, by linking water scarcity and farm labor through the lens of water productivity we illustrate scenarios under which climate and technological change result in greater future labor demand in agriculture, including temporary and seasonal workers, largely due to water productivity increases resulting from switching to more labor-intensive crops. We conclude that a focus on crop choices is central to understanding changes in water productivity, labor demand, and technological innovations in response to water scarcity.

Keywords: water scarcity; water productivity; farm labor; irrigation; agricultural production; climate change

1. Introduction

Increasing water scarcity causes a variety of pressures on agricultural production and related sustainability concerns given current and growing food demands. While there is a large amount of literature related to impacts of water scarcity on agricultural output, farm income, water resources impacts, irrigation technologies, and land use choices, little work has addressed possible outcomes related to farm labor inputs. This paper seeks to add to our understanding of water scarcity adaptations demonstrating that increasing water scarcity is likely to increase demand for farm labor. By explicitly addressing linkages between water scarcity, agricultural production, and farm labor we challenge expectations [1–3] that tightening foreign labor supply in the United States (U.S.) will result in fewer labor-intensive crop choices.

One approach to linking water scarcity and farm labor is through the lens of productivity. A metric increasingly used to consider irrigated agricultural production across time and space, water productivity is measured as physical or monetary output per unit of water input. We show that increases in water productivity are an outcome when opportunity costs of water use are borne by producers, but are not themselves a "solution" to water scarcity. When producers increase water productivity by switching to crops which more intensively use other inputs including labor, this will increase labor demand and hence labor productivity. More generally, we introduce a complementary framework identifying specific phases of water supply and agricultural development to anticipate levels of and evolving changes to labor demand and farm income. We conclude that in many contexts a useful understanding of agricultural adaptation to water and labor scarcity includes focusing on an evolving mix of crop choices in addition to technological innovations.

2. Background

2.1. Irrigated Agriculture, Water Scarcity, and Water Productivity

Central to food security has been the success of irrigated agriculture at increasing crop yields, leading to growing crop production while limiting needed increases on total agricultural land use. Greater exploitation of fresh water resources has enabled the growth of irrigation, to the point that across much of the world water scarcity has risen to critical levels. Expansion of water inputs is in many cases now no longer viable or desirable, and sustainable future increases in agricultural production are often tied to increases in "water productivity" and related measures [4]. More specifically, water productivity and related efficiency measures are now used as indicators for meeting sustainability goals [5]. For example, the United Nations' Sustainable Development Goals target 6.4 is to "substantially increase water-use efficiency across all sectors and ensure sustainable withdrawals ... " [6]. In practice, water-use efficiency has been defined as a broader measure than agriculture specific output per unit water input, and is defined, within a given economic sector, as the value added per unit water withdrawal.

However, water productivity is only one of many possible single input metrics characterizing the combined effect of multiple inputs on production. More commonly "land productivity", otherwise known as "yield" (physical output per unit land area, e.g., tons/acre or kg/ha) is a commonly reported and benchmarked agricultural productivity measure. Across all economic sectors labor is not only an ultimately limiting input, but is also directly related to potential living standards, with labor productivity (e.g., output/hour) is the common metric. Water productivity is then likely to be of greatest interest when the limiting fixed resource is water.

2.2. Farm Labor Inputs

Labor inputs to agriculture may be provided directly by owner-operators, or through hired labor. While the greatest focus in this paper is on hired or contracted labor, provision of unskilled, skilled, or management work can be performed both by owner-operators or as hired inputs. For example, likely responses to a decline in foreign contracted agricultural labor in the United States since 2009 include switching to less labor intensive crops or increased mechanization [7]. As we show in a case study in the U.S. state of California, labor intensity also varies greatly by crop type, with labor-intensive crops using predominately contracted labor. Additional possible outcomes and responses include wage growth in excess of U.S. average wage growth, and increased employment of guest workers through, for example, expansion of the H-2A Temporary Agricultural Program [3]. The latter is an increasingly utilized federally administered program providing temporary legal status for seasonal labor by foreign farm workers.

2.3. Farm Labor and Household Income

More broadly, irrigated agriculture is but one activity in the water-energy-food nexus related to sustainable development. Standard approaches focusing on water productivity and net farm income do not directly address farm labor inputs or the resulting household impacts. Farm labor leads to household income through two pathways. First, farm owner-operators enjoy the full net income of the farm operation. Owner-operator labor is often unpriced in most farm budgets, and is transferred to the household through farm income. Of greatest interest here, hired labor may include the primary income source for a household, or may be only one component [8].

By directly addressing impacts of water scarcity and productivity on farm labor, this paper moves towards a more integrated water-energy-food nexus. In contrast to an application using a fully integrated systems dynamics-based model [9], this paper relies on the estimates of crop production and irrigation use resulting from income maximizing farms [10] to develop a perspective on tradeoffs between labor increasing and decreasing incentives resulting from increasing water scarcity. We provide foundational elements contributing to sustainable livelihood approaches requiring integrated assessments [11] by including theoretically consistent linkages between water use and allocation, food production, and farm labor. Unfortunately there is limited relevant work to link the modest and varied changes in labor demand predicted here to holistic impacts on households and livelihoods.

2.4. Farm Labor and Water Use: The Importance of Crop Types

Water use and farm labor are each directly related to cropping choices by producers. Figure 1 shows that the greatest use of farm labor is concentrated in a relatively small number of cropping types. Expressed as a function of cumulative consumptive water use, three crop categories include over half of farm labor use, but less than 20% of consumptive use. Further, 50% of consumptive use is used for crops which employ a full 95% of workers in direct farm production jobs.

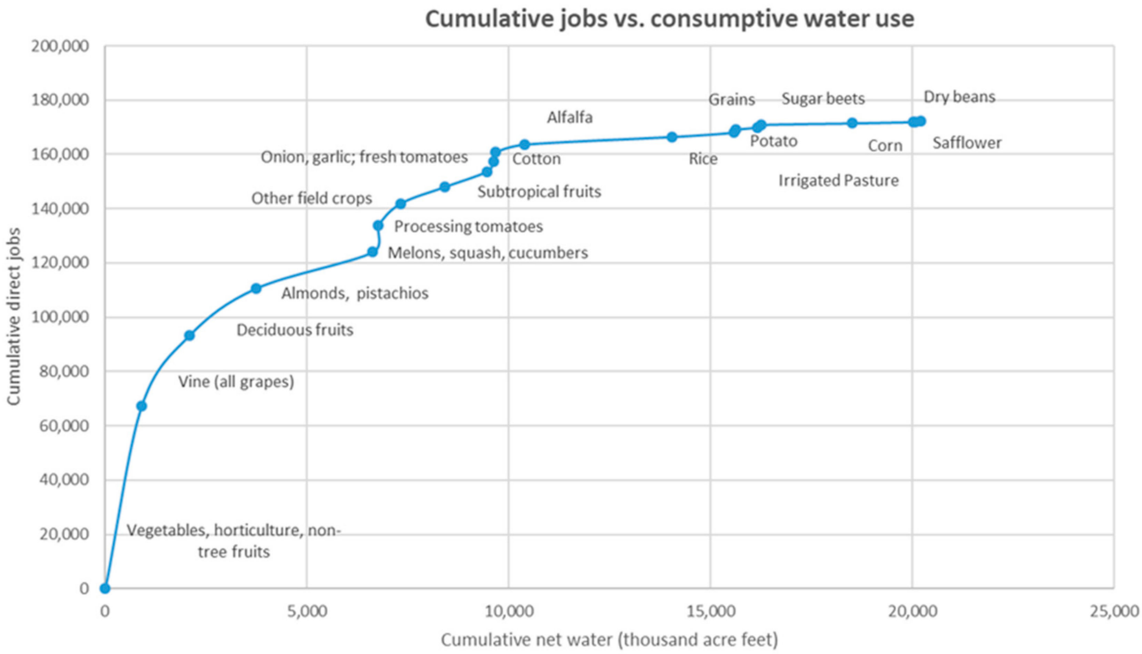


Figure 1. Use of water for irrigation and direct agricultural jobs in California. Crop categories are ordered by jobs per unit of net water use. Source: authors' calculations and [12].

3. Conceptual Frameworks

In considering linkages between water productivity and farm labor it is useful to consider both water supply conditions and agricultural development. While this is implicit in many discussions of water productivity, explicit recognition of development phases and their consequences is important. An integrating hypothesis of this paper is that differing starting states will result in different linkages between water productivity and farm labor outcomes.

3.1. Water Productivity

Water productivity holds appeal as a simple metric to compare irrigated agricultural performance across space and time. Defined in concept as simply the ratio of output to water inputs, widespread use of water productivity is driven by increasing water scarcity and long run projected imbalances between demand and supply of foodstuffs [13]. More succinctly, water productivity addresses the concern to grow more food by producing more "crop per drop".

However, water productivity suffers from a number of critical definitional, physical, and conceptual limitations as well. Many definitions for the numerator (output) appear in the literature, greatly complicating comparisons and leading to a variety of implied meanings in calls for increasing water productivity. A useful starting perspective [14] is that the numerator is a measure of net benefits. In physical terms some measure of agricultural output is used; for a measure of economic water productivity they specify that some measure of "value" be used in the numerator, but do not clearly distinguish between total and net revenue (or income). From an economic value added perspective (net) income would certainly be the preferred metric. Unfortunately production costs are often not available, while total revenue can readily be estimated from crop prices and production data. As a result, water productivity in practice is often measured as total revenue per unit of water input. The choice of water input is also problematic. As emphasized by [13], an appropriate definition for "water use" in the denominator of water productivity is essential. In many cases using irrigation water withdrawals, deliveries, or applications as the measure for water use can provide misleading perspectives, because return flows and percolation to aquifers is not accounted for. By neglecting water reuse, the system wide impacts of greatest interest cannot reasonably be evaluated. A solution to this is to focus on the (difficult to measure) consumptive use, or net water depletion in each particular irrigation use. That is, water that is not available for future beneficial use should be the preferred measure for water input, particularly for any question which extends beyond the field level. In cases where return flows are small, distinctions between alternative definitions of water use would not be expected to significantly affect water use or water productivity estimates.

Agricultural production relies of course on hundreds of inputs in addition to water. Just as labor productivity is a single factor measure which implicitly includes the contributions of other inputs, water productivity also implicitly includes contributions from numerous additional farm inputs. Economically efficient production required that opportunity costs of all inputs be considered; but in this case water productivity with technically efficient production depends not only on water scarcity (implying a marginal opportunity cost of water), but also on the prices of other inputs. Further, if economic water productivity is the measure of interest, gross revenue is linearly dependent on crop output price, and net income is typically critically impacted by changes in output prices.

Following [15], Figure 2 shows that technical efficiency at the farm level in use of water inputs is dependent on the relative price of water and other inputs. Points A and B are both technically efficient approaches to producing output Y, given respective water input prices P_A and P_B. The respective water productivities under conditions of relative water scarcity (point B) and abundance (point A) are Y/W_B and Y/W_A. This illustrates one expected behavior of water productivity: as water becomes more scarce, technical efficiency in production would result in greater (marginal) water productivity because $Y/W_B > Y/W_A$. More generally, the relative scarcity of inputs as represented by input prices would determine the efficient water productivity. Similar reasoning suggests that economically efficient water use depends also on the ratio of crop output prices to each other and to other goods.

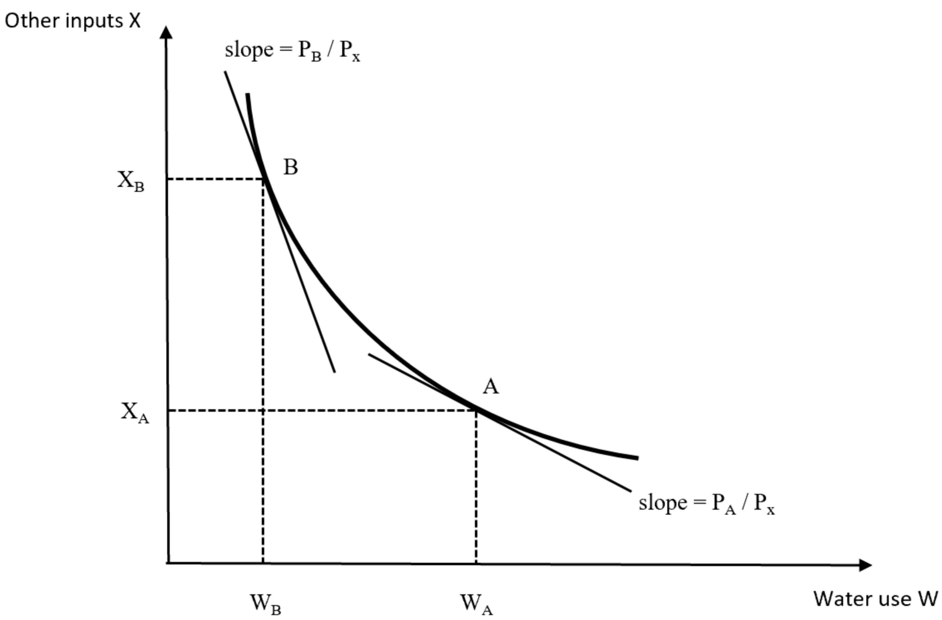


Figure 2. Technical efficiency in use of water and other inputs.

Three points are important here. First, because water scarcity varies, economic technical efficiency in the use of inputs (i.e., points A vs. B in Figure 2) results in varying water productivity. In considering differences in water productivity across time and space, some differences may reflect nothing more than widely different resource abundances, and may be indications of economically efficient adaptations to differing agricultural environments. Second, it should not be expected that market driven agriculture would necessarily result in economically efficient water productivities because water is typically an administratively priced (or unpriced) input. For a variety of reasons water prices rarely reflect full opportunity costs [16], and as a result are rarely a good representation of scarcity. Most frequently water is priced well below opportunity costs, and as a result water productivities resulting from market driven agriculture would be expected to be lower than economically efficient. Finally, stated another way, if water is priced below cost, overuse of water resources, and under use of other inputs such as labor is likely. If water scarcity drives the private cost of water closer to social opportunity costs this will tend to move production in Figure 2 from point A to point B, with corresponding upward pressure on other inputs including labor.

3.2. Water Economy and Irrigation Development Status

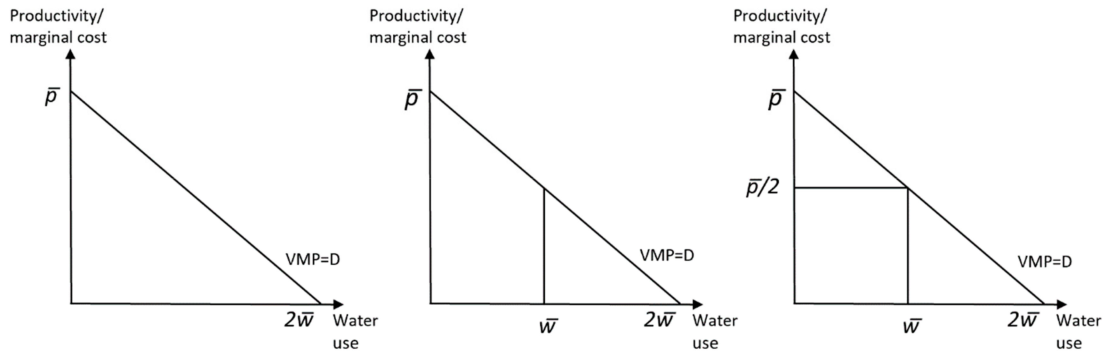
Water development costs and allocation policies, including pricing, are central to understanding tradeoffs between use of water and other inputs, including labor. The framework of expansionary versus mature water economies [17] is a useful starting point. Most simply, water expansion costs are low and elastic in the expansionary water economy. In contrast, mature water economies are characterized by very limited and costly water expansion opportunities; that is water supply has high costs at the margin and is inelastic. Figure 3 illustrates the framework, summarizing development conditions and opportunity costs.

Water economy phase	Characteristics	Agricultural development phase	Characteristics
Expansionary phase	Supply of delivered water is elastic; infrastructure new or in good conditions; minimal externalities; social cost of water is low	Traditional phase	Output largely for home and community consumption; reliance on nontraded family or community inputs; missing output markets; slow technological change; water use unmeasured
Mature phase	Supply of delivered water is inelastic; infrastructure aged, externalities including water logging, degraded water quality; competition with urban, industrial, and ecological users; expanded significance of pricing	Commercial phase	Output is marketed; reliance on hired labor; rapid technological change; market or regulatory response to water scarcity

Figure 3. Summary of the distinction between expansionary and mature water economies [15] and a simple dichotomy between traditional and commercial agriculture.

Water allocation is a conceptually different problem from water supply, and takes on increasing importance as the number of potential water uses generating returns lower than expansion costs grows. That is, as water economies transition from a predominately expansionary to predominately mature phase, water allocation will be increasingly central in determining agricultural outcomes, including those related to water productivity and the demand for farm labor. Most fundamentally, when the opportunity costs of water faced by irrigators are low, the value of water use at the margin will be similarly low. In contrast, when opportunity costs are high, then lower valued water uses will be squeezed out, and only higher valued uses will remain. Each has implications for farm labor demand. These conclusions hold regardless of agricultural development status, such as the classification of agricultural development in the context of water and poverty [18]. The simplified two phase scheme introduced in Figure 3 defines a traditional phase of agricultural development as one in which there are few traded inputs, and slow technological change. Commercial agricultural development defines conditions with endogenous technological change, and a trend towards greater economic water productivity is the norm.

Figure 4 formalizes water productivity implications o expansionary and mature water economies using a highly simplified framework which begins from the derived demand for water, where water a factor of production. In expansionary water economies water supply costs are zero. In a mature water economy, supply is perfectly inelastic at water use $\overline{w}$. Water demand is the value of the marginal product, or the marginal productivity of water. For illustration purposes demand is linear, with a reservation price for the highest valued $\overline{p}$. In this case, irrigators use water to the point where its marginal value product is zero—that is, to the point where water productivity at the margin is exactly zero. This corresponds to irrigating not only higher return crops, but also the marginally producing crop, or applying not only the most important irrigations, but also a final irrigation adding little to nothing to the value of farm yield (after accounting for harvesting costs). In panel (a), marginal productivity MP = 0, and average productivity, similar to commonly reported water productivity, is AP = $\overline{p}/2$.



(**a**) (**b**) (**c**)

Figure 4. Water productivity in expansionary (**a**) and mature (**b**,**c**) water economies. VMP stands for value of the marginal product, and D is water demand.

Panel (b) moves to the case of a mature water economy limited to water use $\overline{w}$. For discussion purposes, let this use $\overline{w}$ be exactly half the total desired water use. If water allocation is by strict quantity rationing, with no consideration of water value to differing irrigation uses, then only half of each specific use occurs. In particular, half of all zero productivity uses remain satisfied, as do half of the highest productivity uses. Thus MP = 0, and AP = $\overline{p}/2$. Reported water productivity in this case would not differ from that in the expansionary water economy with zero rationing.

Assuming that all irrigation uses are reduced equally is an extreme assumption: for a single irrigator, there are likely crop and field switching opportunities, and perhaps irrigation timing decisions which can move water use from lower to higher productivity use. Thus the result of no change in water productivity is a lower bound. The upper bound occurs when irrigation rationing, whether by price or quantity, fully excludes all irrigation use for all of the lowest valued half of water uses, as shown in panel (c). Thus only uses above the shadow price determined by the intersection of the water demand curve and the vertical supply constraint are served. In this case water productivity at the margin is the shadow price MP = $\overline{p}/2$, and average water productivity is AP = $3\overline{p}/4$. Marginal productivity is necessarily increased by a large proportion as opportunity costs rise from a very low level, while average productivity increases are proportionally and absolutely more modest.

Water productivity can now be considered with agricultural development to address potential changes to farm labor demand. Figure 5 summarizes our conclusions. We begin with an expansionary water economy with low cost opportunities for greater provision of irrigation water coupled with traditional agriculture. In this case new low opportunity cost irrigation supplies may supplement rainfed crop production, resulting in increased drought resistance and yields. Both higher returns to labor, and higher total farm income would be expected. With increased water use and traditional technology it is likely that water productivity would either remain constant or possibly decline slightly if irrigation water is overused. Additionally, some new irrigation dependent land may be brought into production. To the extent that yields are higher than for rainfed crops, income and productivity changes may be similar to those seen with supplementary irrigation. However, if irrigation supplies are weather dependent and yields do not exceed rainfed yields, then farm labor and farm income per unit area may not increase, and water productivity will decline. An example illustrating the two cases would include irrigation supplementation of recession agriculture and irrigated expansion to neighboring uplands, both in the presence of capital constraints [19].

Water economy	Agricultural development	
	Traditional phase	Commercial phase
Expansionary phase	WP low Labor income: low Farm income: low; rising *Quadrant 1*	WP variable Labor income: variable Farm income: variable and rising *Quadrant 2*
Mature phase	WP low and falling Labor income: low and falling Farm income: low and falling *Quadrant 3*	WP high; rising and/or falling Labor income: variable; rising and/or falling Farm income: high; rising and/or falling *Quadrant 4*

Figure 5. Conceptual framework the relationship between irrigation development status and for level and changes in water productivity, farm wages, and farm income. WP = water productivity.

If traditional agriculture faces a mature water economy (similar to the condition of basin closure [20]), then water productivity starting at low levels is likely to decline further as externalities such as water logging and land and water salinization become increasingly important. With no access to low cost infrastructure improvements or new freshwater supplies, crop yields over time are likely to fall. With no basis for improvements to farm income or labor productivity, agricultural incomes will generally face downward pressure.

Commercial agricultural activity shaped by continual technological change may occur in either expansionary or mature phases of a water economy. In the expansionary phase new irrigation supplies may again supplement rain fed agriculture, or may open new land to agricultural production. Without substantial competition for existing water supplies, both low and high average water productivity is likely to be present simultaneously; scarcity (price) of non-water factors will determine production technologies including crop selection. Irrigation technologies will be chosen [1] for reasons unrelated to water savings, such as associated labor costs and yield impacts.

Farm wages and farm income are likely to be highly variable, reflecting a wide variety of skilled and unskilled labor categories, and a variety of farm types and scales. Regions with increasing water scarcity may see reallocations from irrigated agriculture to non-agricultural uses, and may be faced with future irrigation reductions when groundwater use is not managed sustainably. For example, Ogallala aquifer users in the central U.S. are essentially mining the aquifer. In contrast, Central Valley, California groundwater use is potentially sustainable, but in recent decades there has been substantial and increasing net overdrafting when averaged across decadal time periods ([21], p. 11).

As water economies become mature and competition for limited water supplies intensifies, irrigation practices supporting low net value practices will give way to higher valued agricultural and other uses. In addition, as water and land quality is stressed, competitive pressures may drive changes in crop choice and production practices. Generally high water productivities will in some cases be driven higher through improved yields, while in other cases improvements in technology and increased capital use may be insufficient to overcome water and land quality degradation. Less productive agricultural operations may be replaced by the most productive, leading to farm production dominated by large and technologically advanced farming businesses. Farm income (per unit area) may continue to grow, and crop switching and new production techniques may either increase or decrease labor demand. A range of skilled and unskilled labor demands is likely to persist.

4. Case Study: Farm Labor and California Agriculture

The U.S. state of California provides an illustrative case study. Irrigated agriculture in California shows characteristics present to some extent in all four quadrants of Figure 5, though it is most stereotypically a mature water economy with dynamic agricultural development. First, statewide estimates suggest ongoing declines in total water use for irrigation (withdrawal and consumptive use) [21], and little remaining opportunity for low cost development of new water supplies. This does not mean that possible new supplies are fully lacking: ground water overdraft can in the short run be viewed as a supply enhancement, and is widely practiced by growers, particularly in the Central Valley. Additional groundwater replenishment may also be possible at relatively modest cost [22]. For example, experiments [23] using existing infrastructure to deliver unused winter flows to flood actively farmed parcels (e.g., irrigated alfalfa stands) suggest some limited potential for expansion. To the extent that growers do not, or do bear the costs of increasing water quantity or reliability, such irrigated farming could be placed in quadrants 1 and 2, respectively.

Apart from these modest opportunities to increase quantity or reliability, California agriculture is more typically faced with high costs for development of new water supplies, intense competition with urban and environmental purposes, adverse climate related timing changes and quantity reductions, and regionally deteriorating water quality, all illustrative of a mature water economy [17]. In addition, in many if not most cases California farmers are now exposed to something approaching full opportunity costs for their water use. Examples include monetarily significant transfers from the Imperial Irrigation District to San Diego municipal water users, groundwater pumping costs, and local farmer to farmer surface water markets. To the extent that farm production decisions include the full social cost of water, and there is little opportunity to reasonably increase supplies, irrigated farming would be placed in quadrant 4. High and growing water productivity would be expected, reflecting growing incentives to increase revenue or net income per unit of water use.

4.1. Water Productivity and Farm Labor

It is useful to examine the large differences in relative input expenditure shares for typical crop types through budgets illustrating typical costs and returns for irrigated crops. Table 1 summarizes production costs for six representative crops in a portion of California's Central Valley (San Joaquin south region) [24]. Caution is needed in interpreting the budgets: for example, (producer) water prices vary substantially just within a single region based on a grower's access to surface water and ground water of varying depths. Reflecting this, the illustrated budgets assume different prices. Using the budgets as reported, Table 1 shows that irrigation costs range from 3% to 30% of total crop operating and non-operating production costs. That is, for all crops combined non-water inputs represent the more significant input from an expenditure share perspective, and in some cases total irrigation costs are only a minor component of total production costs. As expected, resulting water productivities vary dramatically as well.

Table 1. Crop production costs, selected California Central Valley (San Joaquin south region) crops [24] and expenditure shares. 2016 U.S. dollars.

	Crop with Specific Production Technologies					
Irrigation Technology	Almonds	Alfalfa	Black Eyed Beans	Grapes (Flame)	Peaches (Processing)	Tomatoes (Processing)
	Drip	Sprinkler for Establishment, then Flood	Furrow; Double Cropped	Drip	Micro-Sprinkler	Sub-Surface Drip
	Costs ($/acre)					
Total operating costs	4027	1346	813	17,867	5550	3345
Total labor cost	345	74	70	10,641	251	396
Irrigation labor cost (operating)	124	42	20	124	41	85
Total cost of irrigation water	1144	693	432	432	210	625
Total irrigation cost (total)	1602	717	213	700	405	859
Total operating and overhead costs	6241	2409	1244	21,668	8825	4461
Irrigation cost proportion (total)	26%	30%	17%	3%	5%	19%
Labor cost proportion (operating)	3%	3%	2%	1%	1%	3%

More broadly, it is possible to look directly at water productivity and labor requirements across all crops produced in California. Following findings in [10], for the twenty crop classes defined by the California Department of Water Resources there is a clear relationship between labor and water as shown in Figure 6, showing a tendency for higher farm labor requirements for higher productivity crops. However, there is also considerable variation: an economically mature water economy with a technologically flexible farm sector is expected to face both labor increasing and labor decreasing forces. In the case of grapes and most vegetables, for example, the labor increasing forces dominate, while in the case of tree nuts and subtropical fruits automation has resulted in relatively modest labor requirements.

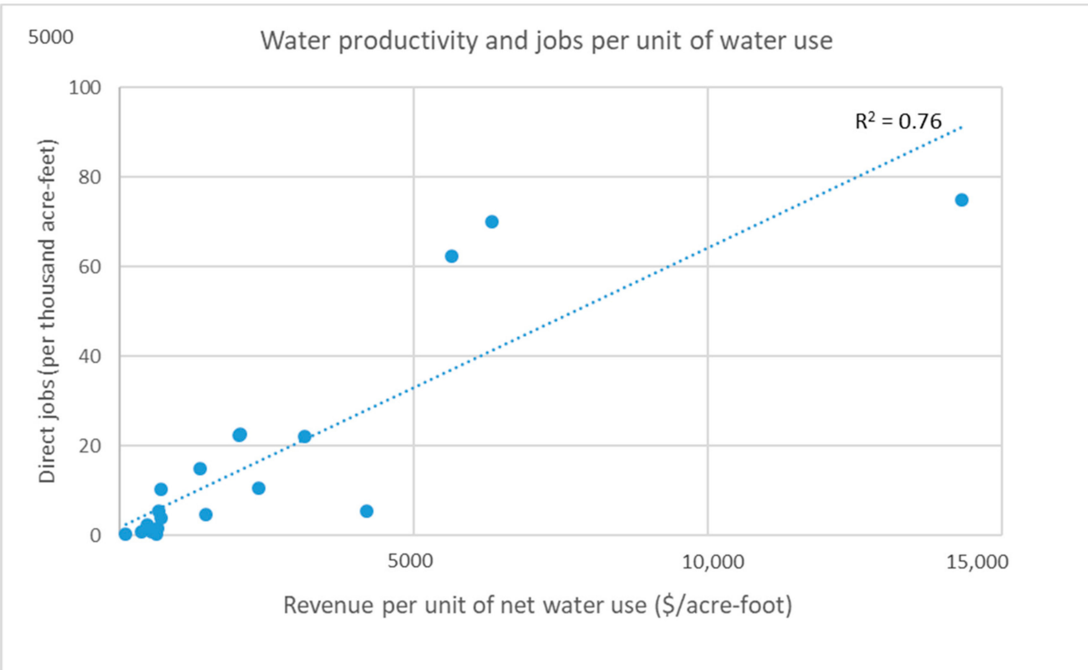


Figure 6. Direct farm labor jobs per unit net water use, state of California. Authors' calculations and [10]. Contract labor is 96% of total direct labor jobs. 2005 U.S. dollars.

4.2. Crop Switching and Farm Labor

California agriculture illustrates the broad mix of higher and lower water productivity crops present in a water economy with variable and changing regional water allocation and scarcity conditions. In water mature and commercially developed agriculture (Figure 5, quadrant 4), irrigators respond through complex changes in crop mixes in addition to changes in crop-specific farm technologies and capital inputs, including irrigation methods. The responses to increases in farm labor scarcity can be similarly complex: while increases in water scarcity and resulting water productivity will increase farm labor demand and apparently labor use (Figure 6), mechanization could potentially limit absolute increases in labor use.

Looking at past changes to irrigation practices and crop mixes, the major changes in California irrigation practices from 1991 to 2010 [25] result primarily from a move from field crops to specialty crops. In projecting future crop changes, the likelihood is a further movement towards specialty crops [10]. Though projecting a decrease in total water withdrawals for agriculture in the face of competing water demands and climate limited supply, acreage increases across several labor-intensive crops are nonetheless predicted [10]. The identified changes are consistent with those expected in commercial agriculture constrained by a mature water economy. The move towards higher valued crops is analogous to land use responses to rising land values. With land, urbanization is the expected response, with greater population density enabled by greater density of, and taller structures. The direct equivalent of higher population density would be higher physical production per unit area, or simply crop yields. However, crop yield is biologically quite limited, so the economic response is to shift to higher value crops as measured by net farm income per unit of water (and frequently also revenue per unit of water). This upward pressure on production of traditionally labor intensive crops in response to water scarcity may, however, be countered by likely increases in labor scarcity.

In such cases direct estimates of future cropping choices under specific assumptions of water scarcity and labor market conditions allow calculation of direct impacts on farm labor jobs given changed crop acreage projections. One projection of future California irrigated crop acreage [10] assumes modest reductions in available land due to population growth, and in applied water as a result of climate warming (each about 9%.). Increases in real prices of non-forage crops are assumed, and technological change is represented by increased crop-dependent yield increases of 30%–40% [8]. Combining crop acreage proportions identified by [25] allows calculation of changes in potential farm labor employment over time by crop category, as shown in Table 2. Aggregating across crops shows that contract labor jobs may have decreased since 1991 due to changes in crop mix. The change is driven by a fall in production of deciduous tree fruits, but offset by modest increases in contract labor jobs in other labor-intensive crop categories. However, despite a projection of total irrigated crop acreage and water application reductions projected for 2050, crop switching is expected to very modestly increase total demand for contract labor. Not included in the 2050 projections is any impact on climate change for production of deciduous tree fruits. Other work [26–28] suggests declines in this category, as substantial parts of California become unsuitable for production of crops such as peaches, apples, and cherries. Further sensitivity analysis could be considered using alternative scenarios presented by [29].

Table 2. Estimates of direct, contract, and total full time equivalent (FTE) jobs attributable to irrigated agriculture in California, 1991, 2015, and 2050. Source: Authors' calculations using data from [10,12,25].

Irrigated Crop	2015 FTE Jobs Direct Jobs	Contract Labor	Total Jobs	2050 FTE Jobs Direct Jobs	Contract Labor	Total Jobs	1991 FTE Jobs Direct Jobs	Contract Labor	Total Jobs
Corn	454	92	546	368	75	442	172	35	207
Cotton	2875	2891	5766	2606	2620	5226	11,133	11,195	22,328
Dry beans	119	24	143	107	22	129	-	-	-
Grains	928	189	1117	723	147	871	1049	214	1263
Safflower	126	25	151	120	24	144	-	-	-
Sugar beets	895	103	999	895	103	999	6910	795	7713
Other field crops	6114	5557	11,671	5003	4547	9550	3961	3600	7562
Alfalfa	2801	2546	5347	2,620	2381	5001	3056	2777	5833
Irrigated Pasture	588	534	1122	206	187	392	307	279	586
Cucurbits	9675	9136	18,811	10,291	9718	20,009	-	-	-
Onion, garlic	3647	3444	7092	3886	3670	7557	-	-	-
Potato	1011	954	1965	1073	1012	2085	-	-	-
Fresh tomatoes	3427	3236	6664	3647	3444	7092	-	-	-
Processing tomatoes	8214	7756	15,970	8652	8169	16,821	15,442	14,581	30,022
Vegetables, horticulture, non-tree fruits	67,227	63,484	130,711	71,563	67579	139,142	62,004	58,552	120,556
Almonds, pistachios	13,383	7006	20,389	13,498	7066	20,564	-	-	-
Deciduous fruits	17,383	20,315	37,699	17,538	20496	38,035	43,965	51,380	95,348
Subtropical fruits	5686	6645	12,331	5442	6360	11,802	8128	9499	17,628
Vine (all grapes)	26,008	30,395	56,404	26,965	31514	58,480	26,271	30,702	56,974
Rice	1573	320	1893	1566	319	1885	1499	305	1,803
Total	172,134	164,652	336,791	176,769	169,452	346,226	183,897	183,915	367,823

5. Discussion

Crop switching as a response to water scarcity may have significant direct impacts on labor demand. In contrast, related or unrelated changes in irrigation technologies will have only small effects on labor demand. Water productivity is a tantalizingly simple approach to aggregating effects of water use across agricultural production, but as a single indicator it predictably loses substantial information on specific dynamics and adaptations. For example, identifying low water productivity in agricultural production gives little insight into either underlying causes or appropriate responses. Similarly, high water productivity may indicate the presence of labor-intensive specialty crops, or alternatively could be related to technologically advanced and capital-intensive commodity crops. From an economic development perspective each might be desirable, but no inference related to irrigation water management can be made.

Any discussion of the consequences of water conservation on agriculture and farm owners should acknowledge the significant feedback that any changes will likely have on the wages and living conditions of both contract and directly hired workers in the industry. Of particular concern is the impact of crop switching on seasonal and temporary workers, who make up a large share of all farm workers and are the most vulnerable. Due to increasing demand for agricultural workers coupled with a dwindling supply of those willing to engage in farm labor, both domestic and from other countries, wages in agriculture are on the rise. In addition, the U.S. Department of Labor has the responsibility of administering the H-2A program, which allows farmers to hire non-immigrant foreign workers when employers can document that domestic workers are not available. As part of the H-2A regulations, it is stipulated that these non-immigrant foreign workers must be paid special rates of pay, termed the adverse effect wage rate, or AEWR. This is meant to ensure that wages for domestic workers are not negatively impacted by competition from foreign labor.

The question is whether this improvement will continue in the future. An important takeaway of the current research is that crop switching will be more important to labor demand, and by extension wages, than improvements in the water efficiency of irrigation and other new technologies. On the surface, if we are correct in focusing attention on crop switching, this might bode well for the continued rise in the wages of agricultural workers. However, there is the possibility of less obvious negative consequences from crop shifting, particularly for seasonal workers who often move from farm to farm and crop to crop during the year. Different crops are harvested at different times during the growing season, and it is easy to imagine that for many workers there will be costs associated with trying to coordinate changing work schedules. For seasonal or migrant farm workers, it might mean lost opportunities to work, but it also might mean significant disruptions in family life. Whatever routine has been established in the past may not be viable in the future.

Although crop switching as it is used in this research is more meant to imply an existing farm making the decision to change the crops they plant, in a broader sense crop switching might mean specific crops that were grown in one region are now grown in a completely different geographic location. Rather than trying to discover and pay for new technology, and rather than staying put and simply changing the plants that are grown, there is the very real possibility that certain crops and the farmers that grow them will simply move to places where growing conditions are more ideal. This is already happening, but little has been written about the impact on agricultural workers when farms move. In economics we too often assume that workers who lose a job can easily and with little or no cost find work in an emerging sector of the economy. For agricultural workers, who may have little education and skills that are specific and narrow in scope, this is not realistic.

Another, more positive possibility, is that rather than switching from one monoculture crop to another, farms diversify and turn to organic farming. Organic produce has been the fastest growing segment of the retail food industry, and it is both land efficient and labor intensive. This latter fact could exert even more pressure on worker demand, which in turn affects wages. At the same time, the health hazards faced by farm workers has long been documented, and the prospect of dealing with crops that are grown organically should be a significant improvement in working conditions. In short, water conservation is likely to lead to crop switching, and in the aggregate, this should not greatly affect the demand for farm workers or recent trends in their wages. However, for individual workers and their families, there could be significant hardships imposed by crop switching.

6. Conclusions

It may be appropriate in considering the interplay between water scarcity, agricultural production, and farm labor to start from a framework of water development and agricultural development status, with a focus on specific consequential adaptations. As shown in this paper, crop switching by commercial agricultural producers in a mature water economy may be highly consequential in understanding how the largest water using sector uses irrigation water today, and how it might adapt to future conditions. In particular, water scarcity is tending to increase the demand for hired farm labor.

This perspective provides insight into rising real and relative wages for hired farm labor observed over the past two decades [3]. Not only is farm labor demand increasing, but farm labor abundance resulting from Mexican seasonal immigration has ended, and is being replaced by a period of shrinking supplies of immigrant farm labor. If the argument [2] of aggregate inelastic farm labor supply is overstated, it may be premature to conclude that the "decline in foreign labor supply to farms in the United States ultimately will need to be accompanied by switching to less labor intensive crops".

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