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CLIMATE CHANGE, MARKETS, AND TECHNOLOGY

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The impacts of climate change in arid areas will be mostly driven by changes in water scarcity. While regional rainfall changes are uncertain, the increase in temperature is forecast with much more confidence; temperature change is a strong driving force behind forecast reductions in irrigation water supplies. Even with relatively unchanged average rainfall, changes in the timing of precipitation will cause supply shortages.

Climate Change and Agriculture

Take the case of California as an example of the likely effect of climate change on agriculture in an arid region with a postindustrial economy. California agriculture is heavily dependent on irrigation so it may offer lessons for adaptation to climate change that can be applied to irrigated agriculture in other arid regions. Climate change will have negative effects on California's irrigated agriculture in terms of increased water scarcity, more variation in water supply, and lower yields due to heat stress. Parallel changes in technology and markets will partially or totally offset the negative effects.

Technological advances such as fertilizers, disease resistant crops, and mechanical improvements have increased crop yields in California by an average of 1.4% per year (Brunke, Sumner, and Howitt, 2004). While increased yields will help dampen the negative effect of a warm-dry climate, continued growth of 1.4% per year is likely not sustainable and is expected to level off in the future (Alston and Pardey, 2009). Even so, technological change will offset climate related yield reductions for some California crops.

The market for select California crops is expected to grow significantly in response to growth in income, population, and domestic and foreign demands. Irrigated production of crops in temperate regions is dominated by “commodity crops” such as corn, alfalfa, cotton, and rice that have an elastic market demand, and a negligible or negative income elasticity of demand. In contrast, the revenue from irrigated agricultural production in California and other arid areas is dominated by “middle class crops” such as fruits, nuts, and vegetables which have inelastic price and income elasticities of demand that are positive and quite significant. These elasticity differences greatly alter projections of climate impacts. The strong income elasticities of California specialty crops combined with growth in incomes in the United States and many Pacific Rim economies translates into a growing demand for these crops. In addition, the inelastic price response provides a revenue buffer against any downside production effects.

Another adjustment mechanism is the role of water markets, including both inter-sector, between agriculture and urban users, and intra-sector transfers. Water markets allow regions with low agricultural scarcity value of water to trade water to regions with high agricultural water scarcity values, in essence allowing water to flow to its highest value use. Regional differences in climate change effects could be offset by developing water markets.

Visualizing California Agriculture under Climate Change

In order to develop insights into the future of agricultural production in California we use a combined hydrologic-economic model of agricultural production in California (Howitt, Ward, and Msangi, 2001). To estimate water deliveries, and regional water constraints, under climate change, we use a larger hydrologic-economic model of the entire California water system (Draper, et al. 2003). Changes in water and crop yields due to climate change are explicitly included in the models in addition to technological change; we include an increasing urban footprint that reduces agricultural land area, population growth, and changing market conditions. Among the IPCC panel climate scenarios we consider the warm-dry scenario which yields a statewide-average 4.5°C temperature rise and an 18% reduction in precipitation by the end of the century (Cyan, et al. 2008).

We consider two future cases for California's Central Valley agriculture in the year 2050, under the IPCC warm-dry climate change scenario and under a scenario where climate remains unchanged. We contrast both of these cases with each other and a base year of 2005 and compare changes in agricultural production, water use, and revenues. To focus ideas we consider agriculture in the Central Valley of California, the main production region in the state. Agricultural commodities in California are collapsed into 12 representative crop groups: alfalfa, citrus, corn, cotton, field crops, grains, grapes, orchards, pasture, sugar beet, tomato, and truck crops.

California Agriculture from 2005 to 2050: Future Scenarios

Statewide, in 2005 California used 82 million acre-feet (maf) of water, of which 8.9 maf went to urban uses, 32 maf went to agriculture, and 41.1 maf went to other uses including habitat. In California's Central Valley in 2005 there was 8.3 million acres of irrigated agriculture which used 25.8 maf of water. The Central Valley is divided up into two regions for our analysis, the Sacramento and San-Joaquin Valley. These represent two distinct regions separated, loosely, by the Sacramento-San Joaquin Delta.

The status of Central Valley agriculture in 2050 depends on technological changes, market conditions, water availability, and climate change. Changes in yield will result from better technology, changes in markets will result from increasing population and income, and changes in water availability will result from an increasing urban footprint in the San Joaquin valley and other parts of the state, and the need to consider environmental habitat. All of these factors will be influenced by climate change, which we discuss in turn below.

Changes in Yield

Yield improving technological innovations for California crops are likely to grow at the historic rate of 1.4% per year until the year 2020. In 2020, physical photosynthetic limits and other factors will cause the rate of growth to plateau. Taking into account the average historical rate of growth until 2020, and capping the rate of growth thereafter, suggests an average increase in yield of 29% across all California crop groups by 2050. These yield increases are independent of climate change and thus offer a significant buffer against the yield reducing effects of warm-dry climate change.

The scientific consensus is that climate related crop yield changes are expected in California, and other regions, due to changes in precipitation and temperature. Changes in precipitation will lead to stress irrigation, where crops are irrigated at less than normal needs, with varying effects on yield depending on the specific crop. Similarly, temperature increases will change the timing of the growing season and have differential effects on yield across crops. Further complicating the story is that both changes in precipitation and temperature will vary significantly between regions under climate change. A handful of studies have been conducted which take these environmental conditions into account for California (Adams, Wu, and Houston, 2003; Bloom, 2006; Lee, De Gryze, and Six, 2009; Lobell, Cahill, and Field, 2007). Climate induced yield changes will vary across the two regions of the Central Valley. Table 1, below, summarizes the expected percent change in yield by 2050 under warm-dry climate change. The effect of climate change varies by both crop and region with crops like alfalfa expected to realize an increase in yields while vineyards are expected to realize a significant decrease.

Table 1

Expected Climate Related Yield Changes in California

Crop Group	Sacramento Region	San Joaquin Region
Alfalfa	4.90%	7.50%
Citrus	1.77%	-18.40%
Corn	-2.70%	-2.50%
Cotton	0.00%	-5.50%
Field	-1.90%	-3.70%
Grain	-4.80%	-1.40%
Orchards	-9.00%	-9.00%
Pasture	5.00%	5.00%
Grape	-6.00%	-6.00%
Rice	0.80%	-2.80%

Adapted from Howitt, Medellin-Azuara, & MacEwan, 2009

Changes in Market Forces

Market conditions for many "middle-class" California crops, including fruit, nuts, and vegetables, are characterized by inelastic demand and a positive income elasticity. In other words, consumers are not very responsive to changes in price and, additionally, are likely to buy more of these crops as incomes increase. Both of these effects are independent of climate change. Incomes in the U.S. and Pacific Rim economies are expected to grow significantly in the future, especially as China and other economies come online. At the same time, global population is expected to increase which will also lead to an increased demand for many California crops. Increasing population, income, and a muted response to increases in price suggests that California "middle-class" crops will be more profitable in the future. Additionally, this provides an incentive for growers of other crops, including rice, corn, and grains, to shift production into these more profitable specialty crops. The net effect is another revenue buffer against the effects of climate change.

In general, most crops prices are expected to increase by 2015 in real terms with a drop following afterwards. Thus rice, corn, and grain, "commodity crops," might experience price drops of 1.45%, 0.67% and 1.58%, respectively. This translates into demand shifts of -1.4% for rice, -17% for corn and -19.9% for grain, indicating that production shifts away from California. In contrast, for fruit, nuts, and vegetables, the so-called "middle-class" crops for which California has market power, population and income growth will increase demand. A U.S. population increase of 43% and income increasing by 2.5 times by 2050 translate into increases in U.S. demand for "middle-class" crops ranging from 3.44% for some field crops to 45% for vegetable truck crops (Howitt, Medellin-Azuara, and MacEwan, 2009).

Changes in Water Availability

Arguably the most important, and most popular in the media, effect of climate change is changes in water availability. In California's Central Valley, water is scarce and warm-dry climate change will put stress on water deliveries to agricultural locations as well as urban and habitat uses. For California under the climate scenario hypothesized in this paper, a reduction in precipitation of 27%, a reduction in inflows of 28%, and an increase of 15% in reservoir evaporation are expected (Medellin-Azauara, et al. 2008). In the Central Valley, groundwater inflows may be reduced by nearly 10% under this climate scenario. The expected reduction in water availability for urban and agricultural uses is summarized in table 2, below. In total, a 14% reduction in water is expected statewide, with a 21% reduction for agriculture and a much more modest 0.7% reduction for urban users.

Table 2

Expected Climate Related Reduction in Water Availability

Region	Agriculture	Urban	Total
California Statewide Total	21%	0.70%	14%

Adapted from Medellin-Azuara, Connell, Madani, Lund, & Howitt, 2008

California Agriculture under Climate Change

By 2050, climate change will have effects on water availability and on crop yields which vary significantly by region and crop. Under the same time frame, and unrelated to climate change, yields will increase due to technological innovations and the market for "middle-class" crops will grow significantly with growth in income and population. Changes in yield alter crop profitability, changes in water availability change the types of crops grown and the extent of the land area they use, and changes in market conditions impact the relative profitability of crops. Taking all of these considerations into account, what is the net effect on Central Valley agriculture and, by way of extension, agriculture in other arid regions? The net effect of climate change on agriculture can be summarized in terms of change in total irrigated crop land, water use, and agricultural revenues.

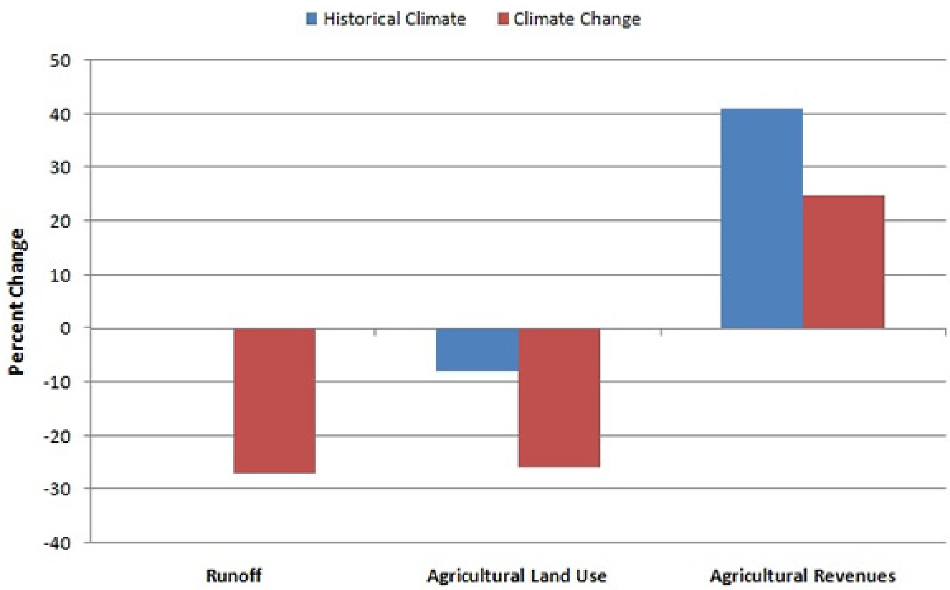
Without climate change, agricultural land use is expected to decrease by 7.3% in California's Central Valley by 2050. This is mostly driven by an increasing urban footprint as urban areas continue to expand into agricultural land. Under climate change, agricultural land use would be reduced by another 18.7%, for a total combined reduction of 26%. The additional decrease in land use is largely due to a reduction in water availability. Reduced water availability pushes marginal agricultural land out of production. So, in the future, California will have a smaller agricultural sector, in terms of total land use, both due to expanding urban footprint and reduced water availability.

Without climate change, total agricultural water use, applied water, will decrease by about 7% by 2050 to 23.9 maf by 2050. This is the result of a contraction in total irrigated land area and a shifting mix of crops in response to evolving markets. Under climate change however, total agricultural water use is expected to fall by an additional 19.3%, for a total reduction of 26.3% by 2050. The additional decrease in water use under climate change is due to several factors in response to a decrease in water availability. Adaptation of agricultural production to climate drives cropping patterns to more profitable and less water intensive crops making total water use reduce more than total land use in agriculture.

The combined effect of a change in total land use, water use, and shifting cropping pattern translates into changes in total agricultural revenues. Without climate change, agricultural revenues in the Central Valley are expected to increase from $20 billion in 2005 to $28.4 billion in 2050, an increase of 42%. Under climate change, agricultural revenues in the Central Valley are expected to increase from $20 billion in 2005 to $25.2 billion in 2050, a lesser increase of 26%. In short, climate change by year 2050 is likely to reduce agricultural revenues relative to a case of no climate change, such as the historical climate pattern. However, revenues will increase from the base year of 2005, as adjustments are made, including the more profitable and less water intensive crops that make up the 2050 future crop mix.

Figure 1 summarizes the percent change in water availability, agricultural land use, and agricultural revenues between 2005 and 2050 under the case of climate change and the case of no climate change, the historical climate.

Figure 1: Water Use, Land Use, and Agricultural Revenues under Historical Climate and Climate Change Adapted from Medellin-Azuara, Howitt, MacEwan, and Lund, 2010 In Review.



In isolation, the effects of climate change will have detrimental effects on agricultural production and revenues. However, the revenue losses are partially compensated by higher crop prices, technology, and adaptation to less water intensive crops. Figure 1 succinctly summarizes the future of agriculture in California's Central Valley under climate change. Water deliveries will be significantly decreased since water shortages for crops are expected to be a major outcome of climate change. Land use decreases mirror changes in water availability, and reflect the need to accommodate the 2050 urban footprint as well as a shifting of cropping patterns into higher valued crops on less land. This unused cropland with minimal water supplies will pose a challenge for conversion to environmental habitat.

Concluding Observations

The take-home message is that a contracting total area in agricultural production and decreases in water availability and yields due to climate change are offset by increased yields due to technological change, and increasing prices of select crops. The shift in agricultural production still results in an increase of agricultural revenues relative to 2005, although relatively less than the increase in revenues under a no climate change scenario. California's Central Valley becomes a smaller, but still more profitable, agricultural production region by 2050.

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