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How Vulnerable is California Agriculture to Higher Energy Prices?

by

David Roland-Holst and David Zilberman

Energy price risk is important to California agriculture. The degree of vulnerability varies substantially across product categories and most of it is indirect, arising from energy costs embodied in farm inputs and product distribution services. These findings indicate that changing energy prices could induce significant structural adjustment across the state's farm sector. Ê

Rising energy prices pose a renewed challenge to U.S. economic security. A long legacy of lower domestic fuel costs has sustained patterns of economic structure and technology adoption that may not be appropriate to future market conditions. This is particularly true in agriculture, where inputs rely on subsidized energy resources and the sales of outputs are highly dependent on energy-intensive distribution services. In farming and elsewhere, significant and sustained increases in energy costs could induce far-reaching adjustments, yet the basis of evidence for understanding our energy-price vulnerability is relatively weak. Here we provide a snapshot of the energy-price dependence of California agriculture, using a new dataset to estimate how energy costs pass through to agricultural and food producer prices. Our results indicate that vulnerability of California farmers is high relative to other sectors, and there is wide variation in the level of energy dependence across the state's diverse portfolio of farm products. Both these findings imply that farm policy needs to better anticipate energy price impacts on agriculture.

Thanks to the energy shock three decades ago, most sectors of the U.S. economy know their direct energy needs relatively well, yet all are woven together in a web of indirect energy use via supply chains. The total amount of energy embodied in upstream inputs and downstream services may significantly exceed that used within an individual industry. The cost of such indirect energy use can still affect farm balance sheets, yet firms may have limited control over this. The goal of this article is to elucidate this network of energy interdependence, with California agriculture as an important, but by no means unique, case study. To the extent that this vulnerability to increased energy prices varies between agricultural activities, pressure will arise for structural adjustment in this sector. To the extent that the vulnerability arises from indirect sources, farms and agro-enterprises must alter their supply chain relationships. Finally, to the extent that own-energy costs are a source of vulnerability, energy security for agricultural producers must come from new commitments to process innovation and technology adoption.

Measuring Energy-Price Vulnerability

To better understand cost-price linkages across the California economy, we use the Social Accounting Matrix (SAM) framework, as applied in the price domain by Roland-Holst and Sancho (1995). The approach used here is a straightforward generalization of multiplier analysis,

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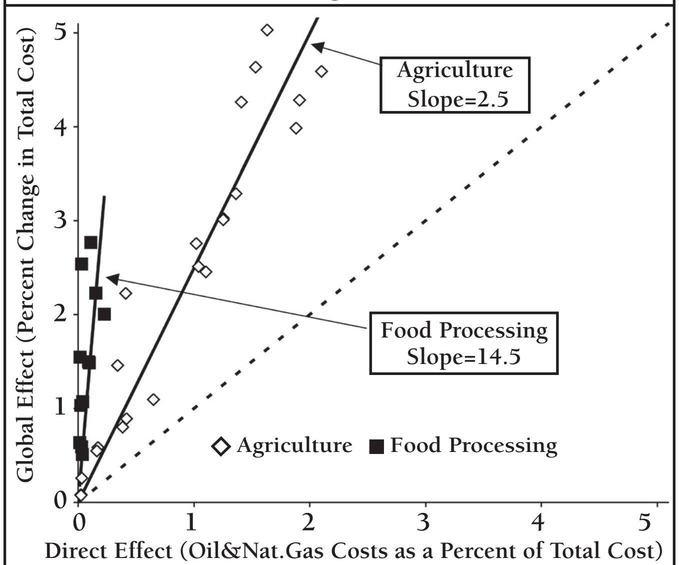
What Exactly Are They Paying For? Explaining the Price Premium for Organic Fresh Produce

by Yuko Onozaka, David Bunch, and Douglas Larson

Figure 1. Direct and Global Cost-Price Pass Through: Oil & Gas



assuming for convenience that costs pass through to prices in a linear fashion. Each production activity uses energy in the form of either oil/gas or electricity, with a coefficient that represents its share in total cost of production. Labor, as one factor of production, might represent 20 percent of the direct cost of producing a crop, and thus a 50 percent increase in the cost of labor would result in a 10 percent increase in the direct cost of producing this crop. The SAM approach emphasizes the distinction between the direct and indirect cost effects arising from price changes among factors (e.g. labor) and inputs (energy). The direct effect of energy price increases on the production of cotton arises from direct energy use in production, for example to power processing machinery. The indirect effect can be decomposed into upstream and downstream effects. The upstream effect includes energy-induced cost increases among inputs, such as fertilizers, pesticides, and water (which embodies conveyance costs). The downstream effect represents the indirect cost increase imposed on the sales of cotton by virtue of increased transportation and distribution costs. In assessing the impact of changes in major factors like energy on the economy, the SAM will divide the economy into several sectors, some of which are interdependent. Thus, prices to consumers are influenced at every stage of long supply and value chains, starting with the production of farm inputs, moving through farm production itself, and onward through to downstream transport, processing, marketing, and concluding with the distribution and retailing of finished goods.

To illustrate the approach, consider that producers and households are undertaking an economic activity. Producers pay for raw materials and factors which are combined to generate output; factors make use of household endowments to provide firms with labor and capital services. Households purchase output from producers for their own consumption. The government is an additional sector, to which each group may be liable to pay taxes and import duties. The system has to adjust to taxation in order to be realistic. The system of taxation has several elements. The government collects indirect production taxes from firms, taxes on the use of labor and capital from factors, and indirect consumption taxes and income taxes from households. Thus, each of these activities has an implicit cost or price index, which is linked to the rest of the price indices through the coefficients of the SAM.

To examine cost-price linkages in California agriculture, we use a new and detailed California SAM estimated for the year 2003. This framework can provide good estimates regarding the vulnerability of California agricultural producers to changes in energy prices. Figure 1 summarizes the relation between direct and global (includes direct and indirect) cost-price vulnerabilities in California. The horizontal axis of Figure 1 shows, for selected sectors, the share of total direct cost represented by Oil & Gas (LNG). On the vertical axis is the corresponding global multiplier, incorporating both the direct effect and all indirect cost-price linkages that extend over upstream and downstream supply chains. Because direct effects are included, all the points on these scatter diagrams are above the diagonal. Lastly, a trend line has been added in each case to indicate average ratios of global/direct effects. The slope of this line can be thought of as an average ratio of global to direct effects. We separate agricultural products and food processing, since the latter represent very different technologies and different stakeholders. Table 1 gives the exact product categories and also includes estimates for other sectors of the state economy for comparison.

To illustrate how the figure works, consider the cotton sector. Our estimates suggest that a 50 percent increase in the price of energy fuel will increase the direct cost of producing cotton by one percent because oil is two percent of the direct cost of cotton and, when all linkage effects are taken into account, cotton prices will rise by twice as much (two percent). A two to three percent increase in total cost of producing cotton because of a 50 percent increase in the price of energy

Table 1: Global and Relative Cost-Price Pass Through

Agriculture			Food Processing			Other Sectors		
Activities	Direct	Global	Activities	Direct	Global	Activities	Direct	Global
Cattle	1.6	5.0	Milk	0.1	2.8	AirTransport	5.7	9.7
OtherLivestock	1.5	4.6	Coffee/Tea	0.0	2.5	ChemFertilizer	3.9	7.6
OtherCrops	2.1	4.6	FoodMfg	0.2	2.2	TruckTransport	2.5	5.2
Hay	1.9	4.3	SnackFood	0.2	2.0	PublicTransport	2.8	5.0
AquaCulture	1.4	4.3	Meat	0.0	1.5	WaterTransport	1.4	3.8
Cotton	1.9	4.0	OtherProcFood	0.1	1.5	VehicleTransport	1.3	3.7
Citrus	1.4	3.3	FoodProcess	0.0	1.5	HouseHold	1.0	2.9
Grapes	1.3	3.0	OtherBeverage	0.0	1.1	OtherTransport	1.4	2.9
TreeNuts	1.3	3.0	Wine	0.0	1.0	Labor	0.0	2.8
OtherVegetable	1.0	2.8	PoultryProd	0.0	0.6	Capital	0.0	2.1
Berries	1.0	2.5	Baking	0.0	0.6	Chemical	0.7	2.1
Rice	1.1	2.5	SeaFood	0.0	0.5	WholsalRetlTrade	0.2	1.8
Poultry	0.4	2.2				OtherServices	0.1	1.4
Forest	0.3	1.5				ChemPesticides	0.4	1.1
Fishery	0.6	1.1				OtherMfg	0.1	1.1
OilseedGrain	0.4	0.9				Metal	0.1	0.8
OtherPrimary	0.4	0.8				Electron	0.0	0.7
Floral	0.2	0.6				Vehicle	0.1	0.6
Nursery	0.2	0.6				TextilesApparel	0.1	0.6
Mushroom	0.0	0.1				Machinery	0.1	0.5

Direct = Oil & Natural Gas Costs as a Percent in Total Costs *Global = Percent Change in Total Cost*

may not seem like a lot, but it must be recalled that this effect goes straight to the farmer's bottom line. Considering the relatively low profit margin in farming (e.g. five percent), the share of profit effect could be much higher (e.g. 20 percent), and this cost increase may tip the balance sheet of a farm from the black to the red.

Returning to the general results, at least three arresting features are immediately apparent in Figure1. First, the impact of energy prices on agriculture is far from uniform. The heterogeneity of cost-price vulnerability across agricultural activities (representing variations in both direct and indirect energy dependence) indicates that rising energy prices will affect different sectors in very different ways. Second, detailed results in Table 1 show that farm-product vulnerability is high relative to other state activities and generally higher (in some cases significantly) than the food sector.

In the rest of the economy, transport service sectors (Table 1) and agro-chemicals are more vulnerable than farming. This is to be expected given their energy intensity, but otherwise it is noteworthy that some farming activities are among the most energy dependent in the economy.

Closer inspection of Table 1 indicates that fully two-thirds of the agricultural products considered are above the median global value (2.2) for the economy as a whole. Third, the slope of estimated global-direct ratios suggest that indirect effects generally exceed direct effects, in both agriculture and food processing. Agriculture's direct cost-price vulnerability is relatively modest, but indirect cost-price effects make many farm activities much more vulnerable to energy prices. The average global/direct ratio for agriculture is 2.5, against 14.5 for food processing.

Components of Energy-Price Vulnerability

Ordering economic activities by energy-cost vulnerability is a simplistic beginning for policies and practices to address this challenge. To respond effectively, policymakers and enterprises need to identify the structural sources of energy-cost risks. In the present context, this can be done using the cost-price multiplier decomposition methods. This approach is relatively technical, yet the intuition is clear. To elucidate the paths of energy dependence, we decompose the agricultural supply chain and search for linkages that carry significant energy costs between economic factors. Rather than publishing elaborate network tables, for the present discussion we provide a few inductive examples.

Cattle is the agricultural activity with the highest overall oil and gas dependency coefficient (Table1), yet it has a modest direct effect coefficient (1.6). However, this sector is heavily dependent on hay and other crops (fodder) and on truck transportation. All these in turn have high global oil and gas coefficients. Hay is dependent on chemical fertilizers, which has a very high global oil and gas coefficient (7.6). Thus, for example, policies that will increase energy efficiency of transportation, or the introduction of nitrogen-fixation technologies to reduce dependency on natural gas in producing fertilizers, will make important indirect contributions to reducing energy-price vulnerability. The results in Figure 1 and Table 1 suggest that we can distinguish among three groups of crops in terms of vulnerability to increased energy prices. Livestock and field crops that produce low value per unit of volume are most vulnerable and have a global coefficient between 4.0 and 5.0. Fruits and vegetables, as well as poultry, produce more value per volume and have coefficients between 2.2 and 3.3, and high-value crops like nursery products and flowers are least vulnerable with global coefficients that are less than 1.0.

Our results do not imply, however, that the cattle and dairy industries will emigrate from California. It needs to be recognized that production technologies do not vary significantly between states in this sense. Thus, savings can be made by producing these products closer to the final market. For example, importation of some dairy products from New Mexico might become less profitable, increasing investment in dairy activities closer to California urban areas. On the other hand, some of the fruits and vegetables that are exported to the East Coast may be vulnerable to substitution by local producers. It is also noteworthy that the growing nursery sector does not seem to be very vulnerable to increases in energy prices.

As indicated in Figure 1, food processing activities have much higher rates of indirect energy-cost exposure. Although direct and total cost-price risk is lower than for most agriculture, indirect exposure represents 98 percent of the total for meat and 96 percent for wine. For meat, the primary source is energy services embodied in livestock inputs, while in wine it is a factor cost pass through from energy in the Consumer Price Index. Other important inputs, such as wine, fruits, distribution, and transport services, also play important roles.

Conclusions

Agriculture faces a variety of important challenges in the new energy era, and our results point to significant vulnerability if energy costs continue their ascent. Direct (own process) energy-price vulnerability will prompt a new search for technology and efficiency measures, while indirect (supply chain) vulnerability will induce substitution and complex market adjustments. These challenges need to be better anticipated by farmers and farm-technology companies, but also by agricultural policymakers. We cannot accurately predict the course of energy prices, but upside risks are ever more apparent and our results indicate California agriculture could face significant challenges.

In the absence of perfect foresight, policymakers can still improve this sector's ability to adapt effectively. In particular, incentives to develop technologies that reduce vulnerability to energy-price changes need to be introduced proactively, before energy shocks impose irreversible adjustment costs on producers. Just as importantly, the capacity of the marketplace to provide solutions should not be undermined by unnecessary barriers to technology introduction and, especially, adoption. California farmers have proven themselves again and again to be among the nation's most technologically savvy. Their capacity as a laboratory of innovation in process efficiency and product quality already sets global standards. With enabling policies in the present context, they can also serve a global agenda for improved food security and more sustainable energy use. We also expect insurance schemes against energy-price vulnerability to emerge for some sectors of agriculture. Without a coherent approach to public and private interest in this area, California agriculture could face disruptive structural adjustments with adverse spillovers to the state economy.

For additional information, the authors recommend:

Roland-Holst, D. and Sancho, F. (1995). "Modeling Prices in a SAM Structure," ***The Review of Economics and Statistics,*** **77: 361-371, 1995.**

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Determinants of California Farmland Values and Potential Impacts of Climate Change

by
Anthony C. Fisher

The value of California farmland is found to be influenced by climate-related variables such as degree days and available irrigation water, controlling for other influences such as soil quality and the proximity of urban areas. A measure of the impact of global warming on California agriculture is given by the change in farmland value estimated to result from changes in temperature, which affects degree days, and patterns of precipitation, which in turn affects water availability. Preliminary findings suggest the impact will be large and negative in a "business as usual" scenario, and modest but still negative in a scenario characterized by fairly stringent controls on greenhouse gas emissions.

Many influences on the value of farmland can be hypothesized: soil quality, temperature, precipitation, encroaching urban development, and so on. Estimation of the potential impact of climate change on value needs to include variables such as temperature and precipitation. The estimation is, however, more complicated. First, measurement of the climate variables is not straightforward. Also, other possible influences on value, such as measures of soil characteristics and the proximity of urban areas with large and growing populations, need to be considered as well and held constant in order to identify the impact of the climate variables.

This article reports on work being undertaken to estimate the influence of these variables on California farmland values, and then make some inferences about the implications of changes in the climate variables under different policy scenarios—something like "business as usual," involving sustained heavy use of fossil fuels over the next several decades, versus a regime of fairly stringent control of greenhouse gas emissions, in particular the carbon dioxide that results from the combustion of fossil fuels. At this time only the first-stage estimation has been carried out, but it is possible to make a rough first cut at determining the potential impact on farmland values of the scenario-based climate changes. A detailed technical presentation is in Schlenker, Hanemann, and Fisher (forthcoming); see box for further information.

What are the consequences of the changes in temperature and patterns of precipitation for the value of California farmland?

Definition and Measurement of Climate Variables

Temperature/Degree Days. Plant growth responds to temperature in a nonlinear way. Plant growth is linear in temperature only within a certain range, between specific lower and upper bounds. This gives rise to the concept of degree days: the sum of degrees above a lower bound and below an upper bound during the growing season. Typically, these bounds are 8^0C and 32^0C. Thus, a day with a temperature below 8^0C contributes zero degree days; a day with a temperature between 8^0C and 32^0C contributes the number of degrees above 8^0C; and a day with a temperature above 32^0C contributes 24 degree days. Degree days are then summed over all days in the growing season.

In our study, which estimates the statistical relationship between farmland value (based on farm profits, in turn based on crop yield), and climate variables, we construct a degree-days variable from detailed temperature records. We find in accord with the agronomic results, that this variable outperforms raw temperature in explaining variation in farmland value.

Precipitation/Water Availability. It seems natural to hypothesize a relationship between precipitation and crop yields or profits, and indeed we have found a strong relationship in studies of the determinants of farmland values in areas of dryland, or rainfed, agriculture. More precisely, we find that increases in precipitation are beneficial up to a point, beyond which they can be harmful, in agricultural areas east of the 100th meridian in the U.S., the historical cutoff line for farming not primarily dependent on irrigation. This region comprises approximately 80 percent of U.S. counties and 72 percent of farmland value, so the impact of climate changes here clearly matters. It does not, however, include important agricultural areas in the arid West, most importantly California, where farming largely depends on irrigation.

Table 1. Hedonic Regression of California Farmland Value ($ per acre, 2000) Using Degree Days

Variable	Coefficient	t-Value
Constant	1365	(0.38)
Thousand degree days (8-32°C), April-September	5493	(2.48)
Thousand degree days (8-32°C), April-September squared	–1112	(2.78)
Precipitation, April-September (feet)	3591	(0.78)
Precipitation, April-September (feet) squared	–75.3	(0.02)
Percent clay (percentage points)	–70.2	(3.75)
K-factor of top layer	–29.7	(1.00)
Minimum permeability of all layers (inches/hour)	–130	(1.13)
Average water capacity (inches/inch)	–70.8	(1.01)
Percent high class soil (percentage points)	5.95	(1.27)
Population density	30.1	(2.32)
Depth to groundwater (feet)	–1.47	(0.37)
Federal + private water (acre-feet/acre)	656	(4.62)
Number of observations	2555	

Notes: The coefficient estimates are from a random-effects model, and t-values are in parentheses. The sample includes observations with farmland values below $15,000 per acre and water prices below $20 per acre-foot.

Source: Schlenker, Hanemann, and Fisher (forthcoming).

Other Influences on the Value of Farmland. To isolate the effect of climate-related variables on value, we need to control for other influences: soil characteristics, such as percent high-quality soil and percent clay; and a measure of population pressure, a weighted average of population in census tracts surrounding each farm. Although the latter does not contribute to agricultural productivity in the same way as soils and climate, it reflects the empirical finding that a substantial fraction of farmland value near urban areas is due to the option of converting the land to urban uses.

We might still include precipitation as an explanatory variable in our California study, supplemented by the inclusion of an appropriate irrigation variable. We would not, however, expect significant results, since precipitation is nearly nonexistent in the major farming areas in the state during the growing season of April-September. Further, this means that there is very little variation in precipitation across the farm-level observations, making it impossible to identify directly an effect of changing patterns of precipitation.

Our preferred measure of water availability is surface-water deliveries to farms in each of the state's irrigation districts. Water deliveries of course depend indirectly on precipitation, but not during the growing season, and not in the farming area, since surface-irrigation water comes largely from managed reservoirs that catch runoff from the Sierra snowpack. Thus there is a certain degree of intermediation by irrigation districts, which in turn provides the substantial variation needed to estimate a relationship between water availability, crop yields, and farmland values. We also look at access to groundwater, since farms may pump groundwater to supplement surface-water deliveries when and as needed. Groundwater is unregulated and we do not have data on groundwater use by farm, but calculate depth to groundwater at each farm as a weighted average of nearby well depths as a measure of access.

Results of Statistical Estimation

Results of the estimation of farmland value in California are given in Table 1. As a rough guide, an estimated coefficient is considered statistically significant if its t-value exceeds 2.0. The estimated coefficients on the climate-related variables are intuitively plausible. Taken together, the large positive coefficient on degree days and the smaller negative coefficient on degree days squared imply that increased degree days are beneficial up to a point but not beyond. The quadratic relationship peaks at around 2,400 degree days over a six-month growing season, or around 1,600 for the more typical four-month season for most crops, consistent with agronomic findings concerning degree-day requirements.

As expected, the coefficients on precipitation and precipitation squared are not statistically significant, though the signs and magnitudes are "correct": large and positive for the former, small and negative for the latter, implying a quadratic relationship in which a certain amount is beneficial but more is damaging. This does not mean, however, that water is not an important influence on farmland values in California. In fact, as shown by the coefficient on water availability, this is the most important influence, measured by statistical significance. Its importance is also suggested by the magnitude. The way to interpret the result is that long-run availability of an additional acre-foot of irrigation water per acre (restricting the sample to observations where the price is less than $20 per acre-foot) adds $656 to the value of an acre of farmland, or about 16 percent of the average value in our sample of $4,177 per acre. If a typical farm receives, say, two acre-feet per acre, then access to water would account for 32 percent of the value of an acre, and so on. The estimate is mildly sensitive to the cutoff price for irrigation water, but most of our observations fall well below $20, due to implicit subsidies.

Table 2. Predicted Impacts of Various Climate-Change Scenarios

Model	Scenario	Time Period	Change in Temperature	Impact on Value per Acre	t-Value
PCM	B1	2020-2049	1.2	–155	(1.67)
PCM	A1	2020-2049	1.4	–189	(1.76)
HadCM3	B1	2020-2049	2.2	–347	(2.09)
HadCM3	A1	2020-2049	3.1	–564	(2.43)
PCM	B1	2070-2099	2.15	–336	(2.07)
PCM	A1	2070-2099	4.1	–845	(2.72)
HadCM3	B1	2070-2099	4.6	–997	(2.83)
HadCM3	A1	2070-2099	8.3	–2166	(3.12)

PCM: Parallel Climate Model HadCM3: U.K. Met Office Hadley Centre Climate Model
Source: Schlenker, Hanemann, and Fisher (2006b).

As hypothesized on the basis of both theory and previous empirical findings, population pressure plays a role in determining farmland value. The estimated coefficient is positive and significant. Of the soil variables, only percent clay is strongly significant, and negative. Higher clay percentages are undesirable as they imply drainage problems, especially on the west side of the Central Valley. Percent high-class soil has the expected positive sign, but is not statistically significant. Interestingly, these results are reversed in our study of farmland values east of the 100th meridian; percent best-soil class is strongly significant and percent clay is not.

Potential Impact of Climate Change: Preliminary Estimates

Here we provide some preliminary calculations of the potential impacts of climate change on the average value of farmland in California. More definitive results require more complete and accurate data on water rights, prices and deliveries, and how these will be affected under different change scenarios. Initially, climate scientists speculated that the increase in annual precipitation under most major climate scenarios would moderate the pressure on water resources. However, recent studies for California suggest instead a modest decrease in annual precipitation. More importantly, the runoff during the main growing season between April and September is expected to decrease dramatically, even for a given amount of precipitation. Relatively more precipitation will fall as rain, rather than snow, and runoff from a melting snowpack will occur earlier in the spring. Both changes will result in reduced availability of water when needed most, in the late spring and early summer.

What are the consequences of the changes in temperature and patterns of precipitation for the value of California farmland? We look at two climate-change scenarios developed by the Special Report on Emissions Scenarios for the Intergovernmental Panel on Climate Change (IPCC): B1, representing a low-emissions future characterized by rapid switches to non-fossil energy sources and greater energy efficiency, and A1, representing a world of rapid fossil-fuel intensive growth, with the introduction of new and more efficient technologies toward the end of the century.

Results for the two scenarios, using two different global climate models, are given in Table 2. The PCM, or Parallel Climate Model, is a low-sensitivity model developed in the United States by the National Center for Atmospheric Research and the U. S. Department of Energy. HadCM3, the U.K. Met Office Hadley Centre Climate Model, is a relatively high-sensitivity model, where sensitivity refers to the effect on global mean temperature resulting from a given change in the atmospheric concentration of greenhouse gases. The column "change in temperature" shows a projected impact on average annual temperature in California of one to three degrees Celsius toward the middle of the century, and two to eight degrees Celsius toward the end of the century. We translate these numbers to a projected change in degree days, which is then used with our regression equation (Table 1) to determine the impacts on farmland value per acre. This is shown in the column "impact on value per acre" in Table 2. Since the average per acre value of all observations in our sample is $4,177, the impact toward the end of the century in the "business as usual" A1 scenario, $2,166, represents a loss of more than half the value, with correspondingly lower but still substantial losses in the near term and even under the low-sensitivity and low-emissions scenarios.

We also calculate the impact on farmland value of projected changes in surface-water deliveries. Here we need to be very tentative, since we do not (yet) have information on how deliveries will be affected at a disaggregated level, that is, at the level of the individual farm or irrigation district. We do, however, have a very recent estimate of the impact on the ability of the major California water projects, the Central Valley Project and the State Water Project, to deliver water to agricultural users in the major growing area, the Central Valley south of the Delta. Due to the changes in the volume and timing of runoff, toward the end of the century deliveries fall by 15 to 30 percent in the lower temperature scenarios and by 40 to 50 percent in the medium and higher temperature scenarios.

Assuming these numbers apply across districts and farms, and an average pre-warming level of water use of approximately two acre-feet per acre, and given our estimate in Table 1 of a capitalized value of the long-run availability of an acre-foot per acre of $656, we can calculate the impacts toward the end of the century on the value of an acre of farmland under each of the scenarios and each of the models. Thus we associate a reduction in deliveries of 15 percent with PCM/B1, 30 percent with PCM/A1, 40 percent with HadCM3/B1, and 50 percent with HadCM3/A1.

These reductions in turn imply losses in value per acre of $197, $394, $525, and $656, respectively. The losses are to be added to those due to the changes in temperature and degree days. For example, under the A1 scenario in the HadCM3 model, the impact on value due to the changes in both degree days and water availability would be $2166 + $656, or $2,822 per acre, which represents a loss of just over two-thirds of the current value. This is of course a "worst case" outcome. On the other end of the range of outcomes is the impact associated with the B1 scenario and the PCM model: $336 due to the change in temperature/degree days, and $197 due to reduced water deliveries, for a total of $533 per acre, or about 13 percent of the current value.

It should be emphasized that none of these impacts are predictions of what California or the world will look like in, say 2085, the mid-point of the 2070-2099 period. Rather, they can be understood as estimates of impacts given a set of assumptions, such as, in the case of the A1 scenario, continued heavy use of fossil fuels and rapid growth over the next several decades. It may well be that the results of studies such as this one will have some influence on policymakers in the direction of greater reliance on alternative energy sources and improved energy efficiency, that is, in the direction of the B1 scenario.

For additional information, the author suggests the following sources:

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After Methyl Bromide: The Economics of Strawberry Production with Alternative Fumigants

by

Rachael E. Goodhue, Steven A. Fennimore, Karen Klonsky, and Husein Ajwa

Results from a two-year study suggest that drip-applied chloropicrin, and 1,3-D may potentially be economically feasible alternatives to methyl bromide in commercial California strawberry production. Using virtually impermeable film instead of high-density polyethelyne when fumigating may improve economic feasibility, depending on the location and fumigant.

Methyl bromide, combined with chloropicrin, is commonly used as a pre-plant soil fumigant for many crops in California, including strawberries, grapes and almonds. Because methyl bromide is an ozone-depleting compound, the United States and other developed country signatories to the Montreal Protocol banned the use of methyl bromide, beginning in 2005, except for certain "critical uses" that receive annual exemptions to apply a specified amount when no alternative is technically or economically feasible. Commercial strawberry production in California received an exemption for 2005 and for 2006. The application process is underway for 2007.

One of the requirements for obtaining a critical use exemption is that there must be ongoing research efforts to find technically and economically feasible alternatives. In order to be economically feasible, alternatives must be feasible under the pesticide registration and use regulations facing producers. For California strawberry growers, two alternative fumigants that meet regulatory requirements are chloropicrin and 1,3-D (1,3-dichloropropene). While other compounds, most notably iodomethane, also demonstrate technical promise as alternatives, only chloropicrin and 1,3-D are currently registered for use in California. Metam sodium, while registered, is primarily used for weed control, as this product alone is not adequate to suppress pathogens. Therefore, metam sodium is most often used following an application of 1,3-D and/or chloropicrin. While organic strawberry production is growing, organic acreage is only four percent of total acreage: (1,300 of 30,000 acres in 2003). Because of the need for crop rotation in organic production, limited land availability, and high cost of land, it is unlikely that organic acreage will expand significantly as a share of total acreage in the medium term.

Fumigants are volatile organic compounds. Once applied, they volatilize, and enter the air. One way their rate of loss from soil can be reduced is by covering the ground with plastic at the time of application. Reducing the rate of loss keeps the fumigant in the ground longer, which increases, at least potentially, its ability to control pathogens, weeds, and other pests. This physical characteristic suggests that the technical efficacy of alternative fumigants may be improved when less permeable plastic is used, which may alter their economic feasibility. Impermeable films work well to retain fumigants applied through the drip system, which results in improved weed control with chloropicrin and 1,3-D. Due to differences in application techniques, under broadcast fumigation impermeable films do not regain fumigants better than standard films.

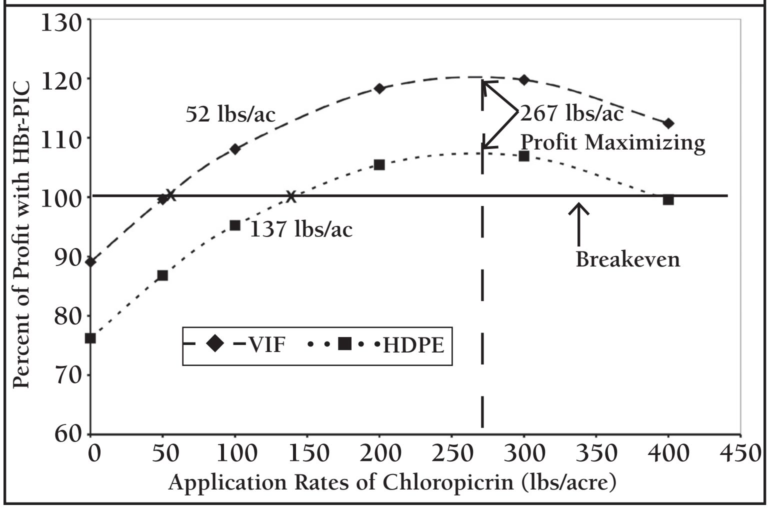
Using data from a USDA-funded project undertaken in cooperation with other UC and USDA researchers, we evaluate the profit-maximizing application rates for chloropicrin and 1,3-D drip-applied to strawberry beds prior to planting. We then compare these profits to profits from methyl bromide-chloropicrin fumigated fields. We also examine how profits are affected by using virtually impermeable film (VIF) to cover the beds, rather than the more permeable high-density polyethylene (HDPE) which is the most commonly used material.

Data and Research Methods

In 2002-03 and 2003-04, field trials were conducted in the Oxnard and Watsonville areas. Each year, in each location, weeding times and yields were measured for twelve treatments under two tarps, VIF and HDPE: The twelve treatments included Chloropicrin EC (PIC) and Inline (1,3-D and chloropicrin), each drip-applied at rates of 50, 100, 200, 300, and 400 lbs/acre; methyl bromide-chloropicrin (MBr-PIC) 67:33 shank-applied at a rate of 350 lbs/acre; and an untreated control. All application rates are reported as pounds per fumigated acre. Only the beds are fumigated, so the application rate per total acre is lower: about 30 percent lower for Watsonville, and about 25 percent lower for Oxnard.

Weeding time and yield information were combined with information regarding weeding costs per hour and other production costs from the UC cost and return

Figure 1. Estimated Profits as Percentage of MBr-PIC Profits: Chloropicrin with HDPE and VIF, Watsonville, 2003-04



studies for strawberries in each region; 2004 cost per pound or gallon information on alternatives collected from suppliers, growers, and other stakeholders; and fresh strawberry price information from the USDA. Profits per acre were calculated for each individual plot, and the resulting values were used to conduct a statistical analysis examining the effects of tarp choice and fumigant application rate on profits.

Estimated Per Acre Profits

Results suggest that at commercially popular application rates of 200–300 pounds per acre, PIC had higher expected profits per acre than methyl bromide in both locations and both years. Results for 1,3-D were not consistent across years and locations. Differences in chemical prices, application costs, yields, and weeding time affect the relative profitability of treatments. Using 2004 prices, MBr-PIC costs 17 percent more per pound than PIC, and 28 percent more per pound than 1,3-D. The cost of a broadcast application of MBr-PIC using HDPE is roughly $200 per acre more than using VIF and drip fumigation, and roughly $400 more per acre than using HDPE and drip fumigation.

Figure 1 illustrates our analysis. It graphs the profits by application rate estimated using the data for PIC in Watsonville in 2003-04. The profits for each application rate of PIC are reported as a percentage of the profits from applying MBr-PIC 67:33 at 350 pounds per acre. The dashed line reports profits when VIF is used. The dotted line reports profits when HDPE is used.

Notice that at each application rate, profits from using VIF are higher than profits from using HDPE. In the results reported here, we estimate a profit difference from using VIF that is required to be constant across application rates. Allowing the application rate to vary does not substantively affect our results in any way. At the profit-maximizing application rate of 267 pounds per acre, PIC is about 20 percent more profitable than MBr-PIC under VIF, and about eight percent more profitable under HDPE. For purposes of comparison, profits for the untreated control plot were 65 percent lower than profits from MBr-PIC.

The "breakeven" rates at which PIC profits equal MBr-PIC profits are marked on the graph. Although these rates are much lower than the profit-maximizing rates, it is important to interpret them with caution. As the application rate increases, the gain from each incremental pound of PIC applied falls, so that the low breakeven rates do not necessarily imply a huge difference in profitability between PIC and MBr-PIC. For example, profits for PIC applied under HDPE equal those for MBr-PIC at an application rate of 137 pounds per acre. Almost doubling the rate to 267 pounds per acre increases profits by eight percent, rather than almost doubling them.

Profit-Maximizing Application Rates

Our statistical approach allows us to estimate the application rate that results in the highest per-acre profit (the profit-maximizing application rate). For Oxnard, the profit-maximizing application rate for PIC is roughly 300 pounds per acre (Table 1). The data are much less informative regarding the profit-maximizing application rate for 1,3-D, and there is much less consistency across datasets. The 2003-04 data generate an estimated profit-maximizing application rate that is larger than the largest experimental rate and is 137 lbs/acre greater than the 2002–03 estimate. For Watsonville, the profit-maximizing application rate for PIC is roughly 260 pounds per acre (Table 2). The profit-maximizing application rate for 1,3-D is approximately 370 pounds.

Effect on Estimated Profit Per Acre of Using VIF

Overall, the results suggest that using VIF increases profits in the Oxnard area (Table 3). Estimates from the 2003-04 dataset have high levels of statistical significance, which means that there is a very low chance that using VIF will not increase profit. The analysis for Watsonville is much less conclusive. The 2002-03 data suggest that using VIF reduces profits, and that this reduction is statistically significant for1,3-D. In contrast, due to differences in yields and weeding times, the 2003-04 data suggest that using VIF increases profits, and that this increase is statistically significant for 1,3-D.

Caveats

Even for questions where our research found a clear answer, it is important to keep in mind that a number of caveats apply to our results. First, we do not consider the cost of purchasing drip irrigation equipment that is robust enough to withstand fumigation, although this may be offset in part by the reduced cost of using a single plastic tarp for fumigation and production, instead of the two plastic tarps used for broadcast fumigation and production. Second, prices and costs change over time. Because we used information from 2004 for the fumigants, changes in relative costs may affect the relative profitability of different treatments. Third, field trial conditions may not fully replicate commercial production conditions, and individual growers' costs may vary from those used here. Fourth, variability in soils and topography may alter the efficacy of the treatments we evaluated, relative to the efficacies demonstrated here. For example, it is much more difficult to achieve uniform drip application of fumigants on hilly fields. Fifth, very little is known about the implications for pathogen control of using alternatives for many years in a row. Sixth, this experiment used clear VIF. Because PIC photodegrades quickly when exposed to sunlight, it may have persisted longer and its performance may have been better, if colored VIF had been used to protect chloropicrin from photodegradation. Finally, another caveat may be the fragile nature of VIF itself. It is a three or five layer material, including one or two impermeable layers. Stretching can break the impermeable layer. Greater care must be used in the installation of VIF which increases labor and machine costs.

Implications and Unanswered Questions

Although subject to a number of significant caveats, our analysis suggests that PIC and 1,3-D are potentially economically viable alternatives to methyl bromide. Two important questions that will affect economic viability, and are as of yet unanswered, regard the effect on the price of strawberries if all growers move to alternatives, and the effect on pathogens of repeatedly using an alternative on the same field. Because yield profiles over time for the alternatives are different than the yield profile for methyl bromide, average prices received by growers may change, which will alter revenues. If alternatives are slightly less effective at controlling a given pathogen, there is the potential for this reduction in efficacy to have larger effects after repeated use.

The motivation for research on VIF and other emissions reduction methodologies is to reduce human exposure to fumigants, and improve fumigant performance on soil pests. VIF is just one possible method of accomplishing these goals. Increasing regulatory constraints means that a method to reduce fumigant emission must be found; otherwise, fumigant use will be drastically curtailed. At the same time fumigant emission reduction technology must not be so costly that growers can not afford to use it. California growers have not yet perceived sufficient benefit, either economically or in terms of relaxed fumigant application regulations, to use VIF on a wide scale. The data presented here suggest that there are economic benefits to the use of VIF. However, determination as to whether there are environmental benefits to the use of VIF need to be more thoroughly evaluated.

Table 1. Estimated Profit-Maximizing Application Rates (lbs/acre): Oxnard

	2002-03	2003-04
PIC	276	317
1,3-D	282	419*

** Profit-maximizing point outside of data range*

Table 2. Estimated Profit-Maximizing Application Rates (lbs/acre): Watsonville

	2002-03	2003-04
PIC	259	267
1,3-D	353	381

Table 3. Estimated Gain from Using VIF Instead of HDPE (Dollars per Acre)

Year	2002-03		2003-04	
	Oxnard	Watsonville	Oxnard	Watsonville
PIC	$448	-$260	$1,136*	$1,170
1,3-D	$651	-$1,459**	$1,654**	$1,350**

** Significant at the 10% level   ** Significant at the 5% level*

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