Chapter 2: Underlying drivers of nitrogen flows in California

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What is this chapter about?

To understand the stocks and flows of nitrogen in California, we first identify important underlying drivers—the economic, political, and technological processes that influence human decision-making in such a way as to affect nitrogen's presence in and passage through California ecosystems. These drivers encompass a range of temporal and spatial scales and, in turn, influence direct drivers of nitrogen use and, ultimately, the statewide mass balance of nitrogen. This chapter examines four key underlying drivers affecting nitrogen use decisions in California: 1) human population and economic growth; 2) market opportunities for California commodities; 3) agricultural production costs and technological change; and 4) policies targeting nitrogen in California.

Main messages

Forces affecting levels of agricultural production and fossil fuel combustion have been the dominant drivers of the nitrogen (N) cycle in California.

California's agriculture ships a large share of its products to other states and regions of the world - for 2009, almost 50% of production went to Europe and Canada, and another 27% to Mexico, China, and Japan. Long–term reduction of transportation costs and reduction of international trade barriers have increased access to international markets for California producers. Thus California carries a lot of the nitrogen burden for many non-Californians.

Over the last fifty years, world population doubled and global income quadrupled. The resulting increase in global demand for food has been a fundamental driver of expansion of agricultural production in California.

Demand for many of California's main agricultural exports (pistachios, almonds, rice, walnuts, and oranges) is driven by rising per capita incomes and perceptions of quality. Accordingly, population growth of high-income countries and increases in household incomes in regions such as East Asia have been the dominant underlying drivers of demand for food and other agricultural commodities produced in California.

Long-term decline in nitrogen fertilizer prices resulted in a large increase in fertilizer use in California from the 1950s through the 1970s. Thereafter, fertilizer prices were relatively stable relative to the prices of crops until 2000. Fertilizer price increases between 2001 and 2011 have exceeded increases in crop prices.

California's population doubled over the last fifty years while income more than doubled over the same period. The growth of California's economy has resulted in a growth in non-agricultural activities that generate nitrogen emissions, including fossil fuel combustion and wastewater creation. In addition, population and economic growth in California has increased non-agricultural use of resources such as land and water.

Value of development for housing and other urban land uses drove land use change in California for most of the 20th century. Historically, financial returns to agriculture have been much less than these land development alternatives; hence levels of farm revenues have had little or no influence on conversion of land to non-farm uses. These relationships have attenuated since the mid-2000s. The contraction in home construction brought by the Great Recession lowered demand for conversion of agricultural land to housing and other forms of development. Over the same period, increases in tree nut and other export commodity prices have driven significant increases in California agricultural land prices; it remains to be seen what effect the drought (still ongoing in 2015) will have on farm land values.

In comparison to the effects of economic growth on fossil fuel combustion or the increase in fertilizer use, policies targeting nitrogen pollution have had small effects on nitrogen flows in California to date.

The bottom line: **short of catastrophe, demand side fundamentals driven by growth in population and income in the rest of the world suggest that nitrogen flows in California agriculture are unlikely to decrease and indeed are likely to continue to grow.** In short, California agriculture is unlikely to disappear; in fact, on balance, it seems more likely to continue growing. Moreover, while there is considerable uncertainty about future climate, water supply, energy prices, and labor costs, the history of innovation in California agriculture gives some tentative (but unproven) reasons to believe that technological change and other forms of adaptation will enable California agriculture to continue to grow in value and employment. Since these underlying drivers on balance portend continued growth in agriculture and attendant nitrogen flows for the foreseeable future, we proceed to assess the direct drivers, relative magnitudes of N flows, and their consequences for the state's ecosystems and the wellbeing of California's inhabitants in Chapters 3, 4, and 5, respectively. As long as the direct benefits of the system are so big, it is not likely that the attendant external costs (environmentally or socially) will be mitigated on their own. The main sources of uncertainty regarding the future balance of costs and benefits of nitrogen flows in California agriculture concern policy choices regarding trade and exchange rates determined in national and international policy arenas and regarding environmental and public health policies largely shaped within California. The implications of these uncertainties and their interactions regarding opportunities for profitable agricultural exports, the balance of costs and benefits – for the state as a whole and for the profitability of the agriculture sector in particular -- of different policy strategies, and the prospects for technological and institutional innovation necessary for adaptation are explored in the scenarios in Chapter 6.

2.0. Introduction

The remarkable increase in human population over the last 100 years and the even more dramatic growth in average wealth per capita have been the two dominant underlying drivers of changes in ecosystem services around the world (Millennium Ecosystem Assessment 2005, p74). Ecosystem services related to nitrogen (N) in California are no exception. Many of the underlying drivers of changes in nitrogen flows within California have originated outside the state because of California's economic connections with the rest of the world. The underlying drivers considered in this chapter are emphasized because of their importance in shaping the direct drivers covered in Chapter 3. Agriculture and fossil fuel combustion are the human activities that have brought the largest increases in flows of nitrogen in California over the past 50-60 years. (Apart from these and biological nitrogen fixation, other activities that have significantly shaped California's nitrogen flows are sewage treatment and, to a lesser extent, land use change.)

Specifically, in this chapter we review four key underlying drivers of changes in nitrogen flows arising from agricultural production and fossil fuel combustion in California: human population and economic growth, market opportunities for California agriculture, agricultural production costs and technological change, and public policies, though few have targeted nitrogen pollution directly.

- **Global increases in human population and income** have driven up global demand for food, creating market opportunities for agricultural products (section 2.1).
- **Increasing demand for food in the US and elsewhere** has been particularly strong for agricultural products in which California excels (section 2.2).
- Meanwhile, economic growth *within the state* has affected the costs of California's land and water resources. Competition for these limited resources between agriculture and other uses has played a central role in shaping the economic incentives facing California farmers. Fortunately, **agricultural research and development** (R&D) have greatly enhanced agricultural productivity in California, helping to preserve the state's comparative advantage in a wide range of commodities (section 2.3).
- Particularly since the 1970s, **federal, state, and local environmental policies and regulations** have curbed some of the unintended flows of nitrogen—most significantly regarding surface water and air pollution. Most of the regulations that affect nitrogen in California (either directly or indirectly) arise from regional or federal policies (section 2.4).

We can draw on well-established data series on human population, global economic growth, and patterns of food demand. Although there is some uncertainty going forward, it is likely that all of these will continue to drive nitrogen flows higher in California. On the other hand, future prospects for agricultural R&D and for environmental policy, particularly federal and/or state-level regulations aimed specifically at nitrogen pollution, hold the greatest uncertainty. In combination, the mix of agricultural innovations and public policies will play powerful roles in determining levels and management of nitrogen in California in the decades ahead; these interacting areas of uncertainty are the focus of the scenarios presented in Chapter 6.

2.1. Human population and economic growth

Worldwide increases in population and economic activity have increased global demand for food and, with that, a corresponding demand for nutrients such as N. Large increases in per capita income in parts of the world have resulted in shifts in diet composition towards more protein and, in particular, more animal protein, which also affects N flows both through greater derived demand for feedgrains and through increasing animal manure production. The extent to which agricultural producers in California are affected by the global rise in food demand depends on the response of producers in other parts of the world, the United States (US) included, as well as factors affecting trade, including both transportation costs and trade policies (see sections 2.2 and 2.3). Levels and relative magnitudes of N flows are calculated in Chapter 4.

In the fifty years between 1960 and 2010, world population more than doubled, increasing from 3.03 to 6.92 billion people (United Nations ESA 2012). By 2050, the medium variant projection for global population exceeds 9.5 billion (the range - low and high variants – of these UN projections is 8.3 to 10.9 billion). Much of the population growth on the planet has been in East and South Asia which, with a combined 3.9 billion people, constituted the most populous region on Earth in 2010. This pattern reflects population growth rates which have been and are forecasted to remain higher in Asia than in other regions of the world except sub-Saharan Africa.[1]

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[1] These projections are from the 2010 revisions by the United Nations Population Division http://esa.un.org/unpd/wpp/Excel-Data/population.htm.

In addition to population size, gross domestic product (GDP) is a fundamental indicator of the size of economies and, as discussed below, also is a key determinant of food demand. Between 1970 and 2013, the world's gross domestic product increased six-fold, from $11.9 to $65.1 trillion (constant 2005 US$) (World Bank 2010). Most of this economic growth has been located in Europe, the United States, and Asia. The rapid growth in the gross domestic product of Asia seen during the last decade is forecast to continue, which could bring Asia's share of world economic activity to about one-third by 2030 (World Bank 2010).

2.1.1. Income growth and patterns of demand for food

Income affects food consumption. In general, and especially in developing countries, increases in per capita income increase demand for food measured both in expenditure and in calories (Box 2.1). Income increases also tend to change diet, including increases in protein consumption, increases in the share of animal protein in total protein consumption, and other changes related to perceived diet quality (Alderman 1986; Griggs 1995).

[Box 2.1]

The well-established negative relationship between income and share of food in household expenditures is known as Engel's Law (i.e., the share of food in total expenditures decreases as income increases). One consequence of Engel's law is that although increases in per capita income can lead to large increases in demand for food at very low incomes, this effect attenuates as income grows. In the United States, where shares of disposable income spent on food fell from about 18% in 1960 to about 10% in 2009 (USDA ERS 2011a; USDA ERS 2014a), most of the overall decrease in share of food expenditure reflected a reduction in the share of food eaten at home, whereas the expenditure on food eaten away from home increased between 1960 and 2012 (Figure 2.1).

[Figure 2.1]

In addition to the trend toward eating out, other expected changes in diet (increases in consumption of fruit and vegetables and meat, as well as luxuries such as wine) still are unfolding in the United States, despite already high income levels. Per capita consumption of fresh fruit and vegetables in the United States increased moderately since 1970 (Figure 2.2). Consumption of wine and tree nuts, two commodity groups in which California leads the nation, almost doubled over the same period. The composition of animal products consumed in the US also has changed significantly (Figure 2.3). Chicken consumption per capita more than doubled between 1970 and 2012, whereas the consumption of other meats diminished slightly over that period. Dairy consumption per capita has remained relatively constant. Overall these figures show fairly typical patterns of demand for a high income country.

[Figure 2.2]

[Figure 2.3]

The current mix of California commodities corresponds predominantly to the diet of regions with high income per capita. Accordingly, the dominant underlying drivers of food demand facing California are to be found in the population growth of high-income countries and the increase in the proportion of relatively higher income households in regions such as East Asia.

2.1.2. Population and economic growth in California

The tremendous growth in California`s human population and economy over the last century has resulted in large increases in both intended and unintended flows of nitrogen. The conversion of land to urban uses and the treatment of sewage and other urban waste, as well as the fixation of nitrogen during fossil fuel combustion, are the main drivers of nitrogen flows that have resulted from a larger and wealthier California economy.

Furthermore, increased use of land for urban purposes has not only increased the cost of land as an input for agriculture but also has increased the occurrence of externalities between land uses. For example, the conflict between the Chino dairy industry and urban residents, in which residents protested against degraded air quality, is one of the most prominent cases involving nitrogen pollution and the demand for environmental quality (see, for instance, Hughes et al. 2002).

Between 1960 and 2010, the population of California increased from 15.7 to 38.7 million (Commerce 2011). This growth has been the combined result of a birth rate exceeding a death rate, migration from other states, and immigration from other countries, both legal and illegal. The Department of Homeland Security estimated that in 2011, 2.8 million unauthorized immigrants resided in California (Hoefer et al. 2012).

Although the increase in California's population has been concentrated in the areas around Los Angeles, the San Francisco Bay and parts of the Central Valley, the population of every one of the 58 counties increased during the last 50 years (Commerce 2011).

According to 2008 estimates of the California Department of Finance, California's population will increase to about 46 million by 2025, with 30% of the state's population born in foreign countries (PPIC 2008). Available data since 1985 demonstrates that income per capita in California has been slightly above that of the US average (Figure 2.4). High incomes per capita and the demand for labor have contributed to sustained legal and illegal immigration into California from other states and other countries, with Mexico providing a large share of immigrants.

[Figure 2.4]

2.1.3. Global population and incomes are increasing: so what?

Rising population and especially rising incomes in the rest of the world will continue to drive up demand for food, particularly for commodities in which California agriculture excels. This is very likely to be reinforced by growing population and incomes within California. These drivers will tend toward expanding agricultural production in California, and hence toward continued increases in nitrogen flows.

2.2. Markets for California’s diverse commodity mix

Given available natural and human resources, market incentives (as conditioned by regulations) drive agricultural production in California and, hence, shape important N flows. The diversity of California’s agriculture reflects the diversity of marketing opportunities for its products as well as the diversity of its soils and climates. Over the last fifty years, large changes in market prices for the commodities that can be produced in California have resulted in correspondingly large changes in the composition of California’s production. In addition, some reductions in transportation costs and in government-set barriers to trade have increased marketing opportunities for California commodities.

This section presents indicators for the parallel changes in commodity prices and production mix that have occurred in California over the last 50 years. The patterns of trade that underlie marketing opportunities for California’s commodities, as well as the factors that have resulted in a reduction in trade barriers, are then described.

2.2.1. Market prices and California’s commodity mix

California`s agriculture is diverse and responsive to changes in market incentives - the ranking of the top fifteen commodities by cash receipts has changed significantly and rapidly over the last fifty years (Table

2.1). Although the ranking of some commodities, such as grapes and dairy products, has remained relatively stable over time, the ranking of many other commodities has changed. Cash receipts for some commodities such as almonds, greenhouse and nursery products, and strawberries have risen rapidly whereas others, such as cotton, oranges, potatoes, or barley have decreased.

[Table 2.1]

These changes in California's commodity mix reflect changes in farm profits more than the patterns in commodity prices. Prices for agricultural commodities have generally fallen relative to prices for other products and services over the last several decades (Anderson 1987). The prices of commodities that have risen in importance, such as almonds and strawberries, have seen smaller declines than the prices of commodities such as oranges (Figure 2.5). These cross-commodity shifts affect N flows because of different fertilizer use rates and management practices. The indexed prices for beef and milk have fallen more than crop indexed prices. However, dairy products, and to a lesser extent cattle and calves, have maintained their ranking through large increases in production (see Chapter 3).

[Figure 2.5]

2.2.2. International trade in California's commodities

A large share of California's agricultural products is consumed outside of California, both in other states and in other countries. There are however no data on California's consumption of food production; available data are only nationwide and sometimes broken down by demographic group. Brunke et al. (2004) estimated that using these demographic data to correct for difference in food consumption related to the demographic characteristics of California did not generate a significantly different estimate than simply assuming that California's consumption patterns resemble national patterns.

Accordingly, we calculated that about 13% of consumption occurs in the state for each commodity (Table 2.2). Of course, even when California produces more than 13% of the national total of one commodity, California ships food products both in and out, reflecting differences in seasonality and specific food characteristics. For instance, table grapes are imported from Mexico when not in season in California. Long grain rice is shipped from the South of the United States whereas California exports short and medium grain rice around the world.

[Table 2.2]

About 21% of the value of California's agricultural production is exported outside the United States, but the shares of exports range from a low of about 2% for hay to about two thirds or more for almonds (Matthews et al. 2011). In 2012, almost half of California's international exports went to Canada and the European Union and another 35% went to Mexico, Japan, and China (Figure 2.6). Export patterns vary from crop to crop, reflecting differences in transportation costs, among other factors. For instance, in 2012 Europe represented 31% of almond exports whereas almost half of the hay exports were destined to Japan. Agricultural export earnings totaled about $18.2 billion in 2012. More than half of the state's production of almonds, walnuts, pistachios, beans, plums, and cotton was exported in 2012, and California produces a significant share of the world's tree nuts (AIC 2012a).

[Figure 2.6]

For the commodities for which California is a large producer nationally or internationally, the prices received by producers are driven by changes in national or global demand, conditioned by trade barriers. In contrast, when California farmers face competition from producers from other states or countries, market prices result from both demand changes and changes in the response of these competing producers.

The market competitors of California agriculture are dispersed all over the world (Table 2.3). European countries are large producers of several commodities such as wine and dairy, countries with Mediterranean climates are competitors for almonds, and China is a large producer of many crops grown in California, with large shares of the world's production of lettuce and processed tomato. The geographic diversity of the competition facing California agriculture reflects the diversity of its commodity mix. This diversity in competition has made the demand facing California growers dependent on the economic growth of many disparate regions of the world.

[Table 2.3]

2.2.2.1 The importance of exchange rates

Bilateral exchange rates measure fluctuations between the US dollar and foreign currencies and have a powerful effect on the competitiveness of US agriculture (including California). When the US dollar appreciates, prices for US exports, including agricultural products from California, become less competitive in world markets. The top four destinations for California agricultural exports are Canada, the European Union, China, and Japan (AIC 2012a). Since 1999, there have been large fluctuations in the exchange rates for all these destinations, some of which have been joint movements and some seemingly independent (Figures 2.7 and 2.8). The Canadian dollar and the Euro both appreciated significantly against the US dollar. Canada receives a variety of California agricultural exports, especially fresh fruits and vegetables, and Euro zone countries are major importers of tree nuts and wine, among other products. After fluctuating over the first seven years of the period, the Japanese Yen has appreciated against the US dollar since January 2012. Japan is a major destination for tree nuts, citrus, and rice, which are shipped under an import arrangement and not sensitive to price. The Hong Kong dollar has been pegged to the US dollar during this period, as was the Chinese Renminbi (RMB) until the middle of 2005. Since that time, the RMB has appreciated about 21% against the US dollar. Exchange rates affect not only bilateral trade between regions, but also trade patterns with third countries. For example, a falling US dollar relative to the Korean Won helped the competitive position of US beef exports to Korea relative to the Australian exporters, because the Australian dollar has been strong relative to the Won.

[Figure 2.7][Figure 2.8]

2.2.2.2 Transportation costs for agricultural commodities

The reduction of transportation costs resulting from technological improvements has often been cited as a large driver of the increase in international trade since the 1950s (Hummels 1999). However, data on transportation costs have not provided unconditional support for that hypothesis (Hummels 2007). For example, an examination of maritime transportation prices from 1950 to 2004 reveals that the index based on the US GDP deflator indicates a large decrease in transportation costs, while the index that is deflated on commodity prices reveals no visible downward or upward trend (Hummels 2007). Although a ton of wheat became cheaper to ship, a dollar worth of wheat did not (Hummels 2007). That is, the real price of wheat fell even faster than the real price of shipping over the last half-century.

For more recent trends, the US Bureau of Labor Statistics (BLS) publishes national producer price index data for truck, rail, air, and deep sea transportation (Figure 2.9). For all four modes of transportation, shipping costs increased over the period covered by the data. Although most exports to Asia and Europe are shipped by sea, a few high-value crops, such as cut flowers and strawberries, are also air-shipped (Governor's Office of Planning and Research 2003).

[Figure 2.9]

BLS transportation price data do not capture variations that affect California or food products specifically. For instance, shipping costs from California to Asia tend to be lower than average shipping costs for comparable distances because of the backhaul of ships importing Chinese products into the US. The USDA publishes transportation data per commodity but the span of these data is insufficient to evaluate trends. There is no study or data set available that report the time series pattern of transportation costs that affect California agricultural commodities specifically.

International shipping costs, at least by sea, often represent a relatively low share of commodity prices and therefore play only a secondary role in California agricultural trade patterns. For instance, shipping costs for almonds represented 2.4% of cargo value when going to Hong Kong and 5.4% when shipped to the United Kingdom. For bottled wine however, the share of shipping costs in cargo value was 10% for Hong Kong and 22% for the United Kingdom.[2]

2.2.3 Agricultural and trade policies affecting California commodities

California agriculture has been affected by federal trade policies including those of the Farm Bill and of federal legislation implementing trade agreements. Commodity subsidies have focused on grains, cotton, and oilseeds and have had a small effect in California relative to other states because these crops accounted for less than 5% of the value of production in California in 2008 (USDA ERS 2008). Analysis of the implications for 2014 Farm Bill by Lee and Sumner (2014), which they refer to as "business as usual," reconfirmed this conclusion. Other programs such as crop insurance, specialty crop block grants, soil conservation programs, and school nutrition have likely had some effects on California

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[2] Author's calculations from shipping cost information obtained at https://www.freight-calculator.com/ex_apxocean_cal.asp and price information obtained from the United States International Trade Commission (USITC) for 2009 and 2010. All shipping costs were calculated from California.

agriculture. These effects are not well established, but crop insurance is considered briefly in Section 2.2.3.2.

2.2.3.1 Commodity policies of the US and major trading partners

Agricultural policies in the United States have supported farm prices for US farmers and ranchers since the 1930s. Yet California's most important crops in terms of value are specialty crops for which there are few subsidies. In California agriculture, rice, cotton and dairy operations are the most influenced by commodity programs. In addition, livestock in California is indirectly affected by the programs and mandates for biofuels that influence the prices of grains, oilseeds, and grain commodities.

In the United States, government payments to agriculture have continued to increase over the last few decades but at a slower pace than total agricultural revenue, resulting in a decrease in the ratio of subsidies per dollar of revenue (Figure 2.10 a,b). In addition, the nature of these payments and their effect on farmers' production incentives has changed with development and expansion of payments that are not based on current production or prices. A second important trend in payment composition is the growth of funding for subsidies with environmental linkages such as the Environmental Quality Incentives Program (EQIP). Such programs provide fewer direct incentives for production, but they also may stimulate agricultural production, for example, by helping cover the costs of complying with regulations that farmers face whether these subsidies are in place or not.

[Figure 2.10a][Figure2.10b]

No estimate of the effects of federal farm support on the size and composition of California agriculture have been published, but these effects are likely relatively small, with the exception of a few commodities such as rice and cotton.

Agricultural subsidy rates and composition in other developed regions such as Europe, Canada, Japan, Korea, and Australia have followed trends similar to the ones in the United States (Tangermann 2010). The effects of subsidy reductions in other countries on California agriculture as a whole are likely to be positive and small, given that these subsidy decreases and decoupling, although not complete, have reduced the production incentives of some of the competitors of California farmers.

2.2.3.2 US crop insurance policy

Subsidies for crop yield and revenue insurance encourage the planting of crops with more variable yields and returns. However, no evidence is available on specific impacts on cropping patterns within California. Despite high subsidy rates, participation in the program varies widely across crops in California with 13% participation rate in rice and less than 40% for most other crops (Table 2.4). In contrast, participation is almost universal in regions growing rain fed crops such as the Midwest.

[Table 2.4]

2.2.3.3 International trade barriers

Reductions in trade barriers, such as those facilitated by multi-lateral trade agreements, generally have positive impacts on the prices of California commodities and on the revenues of California producers. Lower trade barriers open new market opportunities for agricultural exports. However, such agreements can also result in increased competition on domestic markets from foreign producers. Because of the diversity of California's commodity mix and export destinations, single agreements have differential effects on different crops. For instance, the North American Free Trade Agreement of 1994 has had a positive effect on California strawberry and lettuce producers and a negative effect on California avocado producers (Brunke & Sumner 2002). The effect of the general trend towards trade liberalization on California agriculture has not been evaluated. A full model of the details of California would need to be embedded in models of global agriculture, such as the one developed by Rae and Strutt (2004), in order to accurately assess the magnitude of the production and price effects and the corresponding nitrogen balances of trade agreements on California agriculture.

2.2.3.4. California's agricultural sector is expanding: so what?

Trends in trade policies – both domestically and internationally – have generally accommodated expansion of California's agricultural sector. This supportive export environment for California agriculture could reverse quickly if global trading regimes unraveled, but it is difficult to determine whose overall interests would be served by this and it is impossible to predict. Hence, trade policy is an important source of uncertainty regarding future prospects for California's agricultural exports. Similarly, currency exchange rates have a powerful effect on profitability of California exports, but these are driven by monetary and political factors outside the agricultural sector (and outside California) that are difficult (or impossible) to predict. Thus, opportunities for trade and the profitability of trade, as conditioned by exchange rates, is a major source of uncertainty regarding the future of California agriculture and, in turn, the drivers of attendant nitrogen flows. Because of this high level of uncertainty, these issues are taken up in the scenarios in Chapter 6.

2.3 Inputs, resources, and technology in California agriculture

In addition to commodity market prices, returns to agricultural production in California depend on the cost of the inputs and resources that are used in growing crops and raising livestock, as well as on the technologies, such as breeds and varieties, that are available to farmers.

Inputs of California's resources, such as land and water, and their cost to farmers are driven by economic and regulatory forces at work within California. In contrast, inputs such as fertilizer, fuel, and labor are, for the most part, imported into California and their cost is mainly driven by their global demand and supply. For instance, fertilizer prices have depended on the relationship between global fertilizer demand and supply. For traded inputs, market prices provide good indicators of costs although other components of opportunity cost, such as the farmer's management effort, may be important in some cases.

Agricultural research and development by both individual farmers and organized institutions have determined the technologies, varieties, and breeds available for agricultural production in California. Research and development efforts within California and externally have had important impacts on technological improvements, although the predominance of specialty crops in California's agriculture has made the transfer of technologies from other regions less immediate and widespread than in agricultural regions that grow commodity crops such as corn and soybeans.

Changes in the costs of specific inputs that represent a large share of production costs have correspondingly great consequences on agricultural production and practices. Hired labor (expenditure share of almost 30%) and purchased feed (expenditure share of about 12%) represented the two largest expenditures between 1994 and 2007 (Table 2.5). Other inputs such as fertilizer, fuel, pesticides, and land each represented between 3% and 6% of farm expenditures. These average shares across all agricultural commodities mask very large variations that exist among commodities. Furthermore, it is especially difficult to measure the average cost of irrigation water and its cost share for California as a whole even though some of the energy and capital expenditure reported in Table 2.5 account for water pumping costs.

[Table 2.5]

Changes in the cost of inputs trigger substitutions between inputs for a given commodity towards relatively less expensive inputs. Moreover, changes in input costs trigger shifts in the commodity mix towards commodities that make the most productive use of more expensive inputs. Although these effects have been well studied and models are available to estimate them, there are few published studies that assess the impact of input costs on nitrogen flows related to agricultural production. Available estimates suggest that nitrogen fertilizer prices would have to increase a great deal indeed in order to have a significant effect on N pollution. In the Tulare Basin, for example, a recent modelling effort suggesting that a tax on nitrogen of nearly 150% would necessary to induce a 25% reduction in N leakage to the environment (Medellin-Azuara, et al. 2013, 508).

2.3.1 Cost of agricultural land

Availability of land for agricultural use in California is constrained by the spread of urban and residential areas and the degradation of land through increases in soil salinity in some regions (e.g., near the Salton Sea and some zones of the Central Valley). Land conversion from agricultural uses to urban uses is driven by population and economic growth as conditioned by zoning policies. Salinity-related degradation is the result of agricultural production and water management.

The average real value of an acre of farm real estate in California has been higher and increased more rapidly than the national average (Figure 2.11). This pattern reflects the suitability of California's soils and climate for the production of high value crops as well as some effect of capitalized development value. Analysis by Fisher (2006, 5) indicated, unsurprisingly, that "climate-related variables such as degree days and available irrigation water" have the potential to affect California farmland values; however, no published evidence has emerged of negative effects of the current drought (going into its fourth year as this assessment is completed) on farmland prices.

In general during the second half of the 20th Century, the value of land for urban uses far exceeded the price of land for agricultural uses, except in some very specific premium wine growing areas of the Napa Valley. As a result, variations in land prices for agricultural uses had relatively little impact on the conversion to non-farm uses. Moreover, changes or differences in crop value per acre (including the effect of farm subsidies) had little or no influence on conversion of land to non-farm uses during that period (Kuminoff et al. 2002). These relationships have attenuated since the mid-2000s. The contraction in home construction brought by the Great Recession lowered demand for conversion of agricultural land to housing and other forms of suburban and urban development. Over the same period, increases in tree nut and other export commodity prices have driven significant increases in California agricultural land prices; it remains to be seen what effect the drought (ongoing at the time of this publication) will have on farm land values.

[Figure 2.11]

Public policies to affect farm land conversion have taken different approaches. Zoning regulations, farm land conservation easements, and related local policies such as the Marin Agricultural Land Trust, have had significant effects on land conversion (Sokolow 2006). Of particular note, the Williamson Act of 1965 was designed to enable local governments to establish contracts with private landowners in which landowners commit to restricting specific parcels of land to agricultural or related open space use. Landowners are compensated through lower property tax assessments. About 16 million acres have been enrolled in easement contracts under the Act. However, the Open Space Subvention Act (OSSA), which provided the funding for these easement contracts, was suspended during fiscal year 2009-2010. Federal funding is available through the federal Farmland Protection Program with a mandated budget of $743 million nationally for 2008-2012 (USDA ERS 2008).

2.3.2 Cost of irrigation water and water institutions

California's primary source for water is precipitation, which occurs largely in the north of the state. The diversion and conveyance of water in California is the responsibility of the Central Valley Project and the State Water Project. Much of the precipitation is stored as surface water in reservoirs or as groundwater. In a normal precipitation year, the state will receive a total of about 247 cubic kilometers (km^3) (200 million acre feet (maf)) of water, including 6 to 12 km^3 of imports from Colorado, Oregon and Mexico (DWR 2005). Of the total surface supply, about 60 % is used directly by native vegetation, pasture, or land used for crops, evaporates, or flows to salt sinks like the Pacific Ocean, saline aquifers and the Salton Sea. This water is mainly rain or snow that does not run off or percolates to aquifers. The remaining 40 %, or about 80 maf, is referred to as "developed" or "dedicated" and is distributed among agricultural, urban and environmental uses or is stored in surface or groundwater reservoirs (DWR 2005). About 42.2 km^3 (34.2 maf) is used for agricultural irrigation and about 11.0 km^3 (8.9 maf) is devoted to urban and industrial uses in a normal year (DWR 2005).

The Department of Water Resources occasionally publishes the results of surveys on agricultural water costs (DWR 2005). The complexity of water contracts makes systematic evaluation of cost trends difficult. Prices paid by farmers for irrigation water differ widely by water district and no summary measure is available to assess time trends. Variations across locations are easier to identify and the two most robust patterns are the gradient of increased prices from North and east to the South and coast, and the generally higher charges paid by urban users in given locations (AIC 2012).

The cost of water in California is often referred to as a central force in the development of both agriculture and urban areas (Hundley 1992). There is, however, no long term analysis of the effects of water costs and institutions on nitrogen use in agricultural production specifically.

2.3.3 California's climate: trends and variability

California's climate is a fundamental resource for agriculture and changes in climate that affect precipitation and water availability, chilling hours, and growing degree days have a large potential to change both the commodity mix and the practices of California's agriculture. In turn, climate is a central factor in both natural and anthropogenic flows of nitrogen in California. California's climate is diverse and provides appropriate growing conditions for a large number of crops. Future changes in climate, both in temperatures and precipitation, have the potential to affect agriculture in both positive and negative ways.

At a global scale, the IPCC Fifth Assessment (2014) found that "warming is unequivocal", including likely effects on the global water cycle, with "many of the observed changes unprecedented over decades to millennia." The most recent scenarios for climate change in the western United States show substantial uncertainty both for future temperatures and precipitation, but for each model simulation, the warming is unequivocal and large compared to historical temperature variations (United States Global Research Program 2013; Cayan et al. 2010). (See Vermeulen et al. 2012 for a global review of current understanding and evidence on trends and interactions between climate change and food systems.)

For some crops an increase in growing degree days or the occurrence of weather suitable for pollination may have positive impacts on agricultural production. Possible adverse effects of climate change include decreases in water availability and chilling hours, or increased occurrence of extreme events such as floods, storms, drought, heat waves, and spring frosts. As an example of the trade-offs that can occur, over the last century Yolo County has seen an 8% increase in growing-degree days which benefits alfalfa production, and a 13% decrease in chilling hours which can be detrimental to certain orchard crops (e.g., stonefruit) (Jackson et al. 2012; Figure 2.12).

Precipitation in the North and the Sierra Nevada mountains provide an indispensable source of water for agricultural, urban and industrial users. Due to California's Mediterranean climate, a large fraction of the annual precipitation falls during the winter season and is subsequently stored in reservoirs and as snowpack in the Sierras. State records indicate that mean annual temperatures have increased by 0.6 – 1.0°C during the past century, with the largest increases observed at higher elevations (DWR 2008). This warming trend has led to a 10% decline in Sierra snowpack over the same period, and a loss of 1.5 million acre-feet of snow water storage (Barnett et al. 2008; DWR 2008). Changes in the timing of snowmelt has also shifted periods of peak stream-flow to earlier in the spring, which has significant implications for storage infrastructure and surface water supplies in California (Purkey et al. 2007; Stewart et al. 2005).

[Figure 2.12]

At present, year to year variability and short climate cycles create variations in weather patterns that generally exceed the long term changes in mean temperature and precipitation that are occurring due to climate change. But despite the uncertainty regarding how climate change will impact various locations, there is a growing consensus that the impacts on California's water resources will be outside the range of past experience (Kiparsky and Gleik 2003; Milly et al. 2008).

California has received considerable attention nationally and internationally for its Climate Action Strategy, starting with the landmark Assembly Bill 32 passed in 2006 (CARB 2014). However, it is generally accepted that, even if completely successful, California's actions alone cannot significantly affect the course of global climate change; instead the strategy is to demonstrate leadership in seeking solutions that others may emulate at national and regional levels. Compared to AB 32 on mitigation, the counterpart adaptation strategy for the state launched in 2009 is in earlier stages of scoping and implementation (California Natural Resources Agency 2009) and, as such, there is little if any evidence on likely effectiveness of the proposed measures. California's Third Climate Assessment was intended to provide additional information on vulnerability and adaptation options discussed in the 2009 California Adaptation Strategy California Climate Change Center 2012. As part of that third assessment, a team led by Louise Jackson (Jackson et al. 2012) produced a seminal white paper on vulnerabilities and adaptation options in California agriculture., including a spatially explicit vulnerability index derived from 22 climate, crop, land use, and socioeconomic variables. This index highlighted particularly high vulnerability in the Sacramento-San Joaquin Delta, the Salinas Valley, the Merced-Fresno corridor, and the Imperial Valley. Overall, Jackson et al. 2012 (p. ii), found important differences across these regions in the underlying determinants of vulnerability and resilience and suggested that "future studies and responses could benefit from adopting a contextualized 'place-based' approach;" these approaches seem sensible, but while accepted they are unproven.

The California Water Plan (2014; pp. 22-23) describes how critical challenges for water resources management in the state already appear to be affected by changing climate: "California has undergone a warming trend over the past century…Summertime heatwaves are increasing. Over recent decades, there has been a trend toward more rain versus snow in the total precipitation volume over the state's primary water supply watersheds, and time of runoff has shifted to earlier in the year. The water management community has invested in, and depends on, a system based on historical hydrology, but managing to historical trends will no longer work because historical hydrology no longer provides an accurate picture of future conditions." Because of this uncertainty, the current California Water Plan (2014; pp. 6-7) calls for innovation and investment to mitigate risks of greater drought impacts, competing water demands, increasing flood risk, degraded water quality, aging infrastructure, groundwater depletion, land subsidence, and vulnerabilities to the Sacramento-San Joaquin Delta ecosystem that serves as an "essential water supply conveyance hub for more than half of the state's population and much of Central Valley Agriculture." Because most of the land of the Delta already is below sea level, this "essential hub" is especially vulnerable to the effects of continued sea level rise.

It is impossible to say with certainty that the drought that began in 2012, and which is ongoing as this assessment is being completed, is caused by changes in the state's climate. However, a long term analysis drawing on the record of blue oak tree ring growth and other data (Giffen and Anchukaitis 2014) concluded that while a number of other 3-year drought periods in California's history had less precipitation, the current drought is the worst in the last 1200 years and "is driven by reduced though not unprecedented precipitation and record high temperatures". New satellite-borne sensors that monitor small changes in Earth's gravitational fields provide unprecedented evidence of massive depletion of groundwater resources in the Central Valley (Borsa et al., 2014). The California Department of Water Resources (www.water.ca.gov/groundwater/) estimates that historically about 38% of California's water supply came from groundwater in an "average year" (and it is not clear what an "average year" means now). During dry years groundwater use rises to 46% or more of the total; however many individual communities rely on groundwater for up to 100% of their annual water needs.

Depending on the extent of climate change observed in different regions, agricultural producers will likely adapt by shifting to crops and production systems that are suitable to new growing conditions (Jackson et al. 2011). In California, these shifts in cropping pattern and management practice will have important, albeit uncertain, impacts on nitrogen use that merit further study. Richard Howitt's analysis of climate change scenarios to 2050 (Howitt 2014) indicates that despite possible "reductions in irrigated area and net water use, California agriculture can continue to grow in revenue value and employment." If this relatively optimistic conclusion is correct, innovations in water management and agricultural practices appear to be the keys to addressing water shortages arising from climate change and other stressors.

2.3.4 Cost of manure used as fertilizer

In contrast to synthetic fertilizer, manure fertilizer is not easily transported and the availability and cost of manure fertilizer for crop production depends on the proximity and size of concentrated livestock operations. Accordingly, the drivers of livestock production in California affect the use of manure application for crop production. The size and location of livestock operations, which have been affected by technological innovation and regulations, has had an effect on the availability of manure in different crop production locations. The ongoing increases in operation size and spatial concentration in the Southern part of the Central Valley have resulted in larger and more concentrated manure sources (see Chapter 3).

2.3.5 Synthetic fertilizer prices

Nitrogen fertilizer is an essential input of agricultural production and a large literature is dedicated to analyzing the factors that affect the use of fertilizer by farmers. Variations in fertilizer prices relative to crop prices have been shown to be one of the main underlying drivers of fertilizer use. Griliches (1958) showed that the drastic decline in the price of nitrogen amendments resulting from the development and commercialization of the Haber-Bosch process in the 1920s dramatically increased the supply of fertilizer and was the main factor behind the large and widespread increase of fertilizer use in industrialized countries.

The relationship between the quantity of fertilizer applied by farmers and the price has been quantified by many authors and estimates of demand elasticities (% change in the quantity of fertilizer used for a % change in price, holding all other variables constant) display a wide range. Larson and Vroomen (1991) used data from five corn growing states and found fertilizer price elasticities ranging from -0.23 to -0.85 with variations across states and across the time period covered by the data (Table 3 p. 361).[3] They also found that fertilizer demands have become less responsive to own-price changes over the period 1964-1989. Denbaly and Vroomen (1993) differentiated the long and short run response of farmers to fertilizer price changes and estimated a price elasticity of -0.21 for the short run compared to -0.41 for the long run (Table 2 p.207).

Most of the fertilizer demand studies focus on corn growing regions and estimates for California as a whole are rare. Carman (1979) estimated fertilizer price elasticities for the western United States and found California's elasticity of -0.204 to be lower than other states (Table 2 p.25).

Nitrogen fertilizer has been traded and shipped across continents since the 19th Century and therefore the price of fertilizer to California producers has been driven by international supply and demand essentially throughout the era of rapid development of the agriculture sector. In addition to decreasing the price of nitrogen fertilizer for growers, the development of the Haber-Bosch process in the early 20th century coupled the cost of fertilizer production to the price of natural gas, and indirectly to the price of other energy sources (United States General Accounting Office 2003). In addition to shifts in the production costs of fertilizer, changes in the demand for fertilizer from farmers both in the US and in the rest of the world result in changes in fertilizer prices for California growers. For instance, Huanf (2009) found that a price spike in 2008 reflected the inability of the US fertilizer industry to quickly adjust to surging demand or sharp declines in international supply. Importantly, the increase in demand for nitrogen fertilizer by China has shaped the international trade of fertilizer in the last few

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[3] Demand elasticities are negative because a price increase results in a quantity decrease.

decades, with China's share of world fertilizer consumption growing from 11% to 34% between 1970 and 2008 (World Bank 2010).

In the latter part of the 20th century, variations in the price of fertilizer were comparable in timing and magnitude to variations in agricultural commodity prices. From 1960 until about 2005, price indexes for both fertilizer and crops in the US followed similar patterns, with a dramatic rise during the 1973 oil crisis and a steady increase thereafter. However, during the rest of the 2000's, prices for fertilizer increased faster than crop prices (Figure 2.13). Recent data continue to suggest that prices paid for fertilizers may no longer be as tightly coupled to prices received for crops (NASS 2015; USDA ERS 2015).

[Figure 2.13]

There is no federal or state policy that affects directly and significantly the price of fertilizer to California growers. In 1945, the state of California adopted Regulation 1588 which restated a pre-existing exemption of the sales tax for fertilizer and seeds. A small tax of $0.0005 per dollar of fertilizer sale was established in 1990 in order to fund research efforts related to nitrate pollution in California.

In addition to fertilizer prices, several other factors influence fertilizer use. In particular, variations in crop yields or profitability, due to weather for instance, play an important role in farmers' behavior and a large literature has developed focused on the impact of risk and variability on fertilizer use (Boyer et al. 2010; Rajsic et al. 2009; Carriker 1995).

2.3.6 Energy prices

Social Accounting Matrix analysis by Roland-Horst and Zilberman (2006) identifies three distinct groups of California's agricultural products regarding vulnerability to energy prices: livestock and low value per volume field crops are most vulnerable and high value nursery products and flowers are least vulnerable, with fruit, vegetables, and poultry in between. The oil crisis of the early 1970s led to sharply higher prices for gasoline and diesel through the early 1980s (Figure 2.14). From the mid-1980s until around 2003 prices did not show any particular trend despite some large fluctuations. However, between 2003 and 2012, the price for gasoline increased more than fivefold and the price for diesel increased more than six fold. Between June and December 2014, gasoline retail prices had fallen by approximately 30% (US EIA 2015), suggesting continuing variability and possibly increasing uncertainty regarding the future course of energy prices rather than the secular adjustment to high energy prices expected by some in the 2000s.

[Figure 2.14]

Relative to other states, fuel is more expensive in California because of mandated blend standards. For instance, in 2007 the California Air Resources Board adopted a new standard to set the minimum content of ethanol at 10% for gas sold in California starting in late 2009. Moreover, both the state and federal government collect fuel taxes on diesel and gasoline. In 2013, California's gasoline taxes ($.719 per gallon) were the highest in the country, followed by the states of New York ($.682) and Connecticut ($.677) (API 2013). California's diesel taxes ($.749 per gallon) were also the highest, followed by the states of Indiana ($.742) and New York ($.74) (API 2013).

2.3.7 Labor costs and agricultural labor institutions

The cost of labor is a crucial driver of agricultural production in California in particular for the many crops that require manual thinning, weeding, and harvesting. According to the Census of Agriculture (USDA 2007), in 2007, California had the highest number (about 450,000) of hired farm workers, followed by Washington and Texas with about 250,000 and 150,000 hired workers respectively. Martin (2001) estimated that in 1999 the average monthly employment on California farms was 418,000 with large yearly variations due to seasonality. Changes in labor costs have resulted in changes in the commodity mix. For instance, Martin et al (2011) show that the decline in asparagus production in California has been driven by availability of labor.

Immigration is the main driver of the availability and cost of farm labor and according to the Public Policy Institute of California (PPIC), in 2009 immigrants accounted for nearly 37% of the labor force in California, up from 11% in 1970.

In California, the legal minimum wage was $8.00 per hour in 2011 which is higher than the federal minimum wage ($7.25) (US Department of Labor 2011). In 2011, Texas's minimum wage was the same as the federal minimum wage, whereas Washington was higher than California at $8.67 per hour (DOL 2011b). California's minimum wage regulation is binding for some operations such as weeding and thinning but harvest workers are often offered incentives based on harvested prices that can result in higher wages (Martin 2001).

2.3.8 Development and adoption of new technologies

Innovation by individual farmers and by research and development institutions are an important driver of agricultural productivity, often described as the ratio of measures of the quantity of outputs produced to the quantity of inputs used. Because of the predominance of specialty crops in California's agriculture and because of California's unique soils and climate, both private and public research and development efforts organized through federal and state programs have been significant sources of technological change in California.

Although agricultural productivity has increased over the last several decades, the average annual productivity growth rates in California and US agriculture have declined since the 1980s and rates of productivity growth have fallen below what they were in the 1950s and 1960s (Table 2.6).

[Table 2.6]

The growth in the amount of resources dedicated to agricultural research and development in the United States has shown a similar pattern. After a period of steady growth from 1950 until around 1980, both public and private research and development expenditures grew much more slowly through 2007 (Figure 2.15). In 2007, more than 51 percent of agricultural research and development was undertaken by the public sector. Universities and colleges represented about 35% of this research expenditure and federal government research laboratories another 16.7% (Alston et al. 2010). California's public research on agriculture is performed by the California Agricultural Experiment Station of the University of California, Division of Agriculture and Natural Resources (UC ANR). Cooperative Extension constitutes the ANR's main outreach program, with about 350 specialists and advisors dispersed throughout the state in 2013. The annual expenditures for both Cooperative Extension and California Agricultural Experiment Station increased between 1993 and 2007 in nominal dollars, however in inflation-adjusted dollars both expenditures have declined slightly since 2002 (UC AIC, 2009).

[Figure 2.15]

Overall, agricultural biotechnology patenting in the US has been increasing, and at a faster rate than patenting of other sectors (US Patent and Trademark Office 2009). Commercial firms, followed by US nonprofits and universities, receive the majority of agricultural biotechnology patents. In 2004, California was issued more agricultural biotechnology patents than any other state. Of the 7,097 such patents issued in the United States that year, California received 1,506Private research tends to focus on patentable innovations rather than general productivity-enhancing improvements (Alston et al. 2010).

[Figure 2.16]

Transfers of biotechnologies from outside of California have also played an important role in increasing California's productivity. For example, agricultural research and development of the Spanish region of Valencia have affected citrus production in California, where local research, development and extension have contributed to adapting Spanish varieties to California conditions.

2.3.9. Research and development has enhanced productivity in California: so what?

There is great uncertainty regarding future climate, water supply, prices of energy (and hence synthetic fertilizer), and labor costs faced in California; similarly there is great uncertainty about the patterns of technological change. The point here is not to yearn for precise long term forecasts, which are impossible, but to consider how technological change can drive adaptation in the context of climate, water supply, energy price, and labor costs and availability. Although largely speculative, Howitt's (2014) conclusion that agriculture can continue to grow in revenue value and employment is consistent with past performance of California agriculture. From this, it would follow that our focus should be on investing to increase this capacity for innovation and adaptation that underpins resilience to various input supply and price shocks.

2.4 Policies affecting nitrogen flows in California

This section focuses on nitrogen-related policies that have had measurable effects on nitrogen flows over the last several decades. Chapter 8 provides the details and analysis of policy responses to changes in nitrogen flows, focusing primarily on flows associated with agriculture.

Nitrogen pollution has been a target of numerous policies and regulations for several decades in California and the United States. For the most part, policies have targeted the degradation of individual resources. As a result, regulations affecting different media have generally evolved independently and there is no federal, state, or local integrated nitrogen policy. The extent to which nitrogen flows have been affected by environmental policies varies widely by resource.

Of all the human activities that contribute to nitrogen pollution, the combustion of fossil fuels and the management of human and animal waste have been the most strongly affected by policies, most of which have taken the form of regulations. However, there are currently no direct regulatory restrictions or reporting requirements for nitrogen management in crop production when manure is not involved. Across activities and across resources, there has been a visible trend towards more widespread and binding regulatory policies, with economic incentives and other policy instruments having played a much smaller role so far.

Regulations for surface water, under the Clean Water Act of 1972 and its subsequent amendments, have contributed to an observed decrease in nitrogen concentrations in many but not all watersheds in California (National Water-Quality Assessment Program of the US Geological Survey, 2010). Point sources such as sewage collection and treatment plants, industrial facilities, and confined animal facilities have been the main targets of surface water policies.

The Clean Air Act of 1963 initiated a nationwide effort to regulate air quality with a focus on fossil fuel combustion and has resulted in reducing or curbing concentrations of NO_x in several air-sheds in California. Some of the local air districts that are responsible for the implementation and enforcement of air quality standards have targeted air pollution from farming in order to reduce concentrations of particulate matter, for instance. Yet, dairies and other confined animal facilities were exempt from regulation by the state of California until 2003. Establishing regulations for emissions of ammonia from concentrated dairy operations has received increased attention nationwide. Conservation programs of the Farm Bill have had some impact on farming practices with the distribution of subsidies encouraging the adoption of conservation practices, including manure management.

The impact of policies on nitrate leaching to groundwater has been limited. California`s water quality regulations differ from federal regulations by including both surface and groundwater objectives in the main law, the Porter-Cologne Act of 1969. However, until recently agriculture has been exempt from regulations related to groundwater through local agricultural waivers. These waivers, which affect both surface and ground water pollution, are in the process of being publicly revised in several administrative water regions.

Policies targeting emissions of nitrogen greenhouse gases (GHG) are at early stages of development and implementation. California`s Global Warming Solutions Act, or Assembly Bill 32 (AB32), was passed in 2006. AB32 allows for the development of agricultural offset programs from livestock and crop operations but does not include California`s agricultural sector in its central cap-and-trade and other measures.

Other environmental policies have likely had some local effects on the management of nitrogen pollution but there is no published analysis of their impact on nitrogen in agriculture. For example, the federal Endangered Species Act of 1973 has regulated actions that threaten the survival and the habitat of listed species, which includes the Delta Smelt. State and local programs have also been developed over the last few decades to tackle nitrogen pollution but no estimate of their impact is available. The Fertilizer Research and Education Program (FREP) was created in 1990 and implemented by the California Department of Food and Agriculture to tackle nitrate pollution from animal waste management and fertilizer use. It is funded on a tax of $0.0005 per dollar of fertilizer sales in the state and funds research and education programs.

2.4.1 Water quality policies

The Porter-Cologne Act is the backbone of water quality regulation and policy in California. The goal of the Porter-Cologne Act is to prevent the loss of beneficial uses of water both from surface and ground resources. It applies federal regulations of the Clean Water Act to the state and provides the framework for the actions and rulings of local water boards that are in charge of implementing quality standards. The Clean Water Act does not directly address groundwater contamination, which is regulated federally by the Safe Drinking Water Act and the Resource Conservation and Recovery Act of 1976 which regulates the disposal of hazardous waste.

2.4.1.1 Surface water regulations

The two central measures of the Clean Water Act are the definition of Total Maximum Daily Loads (TMDL) and the establishment of the National Pollutant Discharge Elimination System (NPDES) permit program. These programs have targeted nitrogen in surface water through their quality standards on dissolved oxygen, which is depleted when nitrogen pollution favors algal development. In addition, the Coastal Zone Act of 1972 and the Coastal Zone Act Reauthorization Amendments (CZARA) of 1990 are federal regulations targeting the pollution of coastal waters from non-point sources. In California, the coastal zone includes the entire state and the regulations require that the state submit and implement a non-point source program.

The impact of surface water quality regulations on livestock operations is less clear and has likely been less widespread. The qualification of livestock operations as point sources, and therefore the applicability of regulations, depend on herd size and records of emissions, and vary across jurisdictions (Morse 1995). ~~The regulation of nitrogen pollution to surface and ground water is still in development. For instance, the~~In 2007 the ~~-~~Central Valley Regional Water Quality Control Board ~~is currently developing~~

~~a~~ issued a ~~general~~ Waste Discharge Requirements (WDR) General Order to ~~regulate dairy operations~~for Existing Milk Cow Dairies (CA SWRCB 2007).

Crop production, which qualifies as a non-point source, has been the target of regulations for surface water pollution but regional exemptions, called agricultural waivers, have limited the actual implementation and effect of these regulations.[4] The ongoing process of revision of the agricultural waivers may result in significant changes to cropping practices that affect nitrogen pollution, such as tail-water recycling and fertilizer application rate and timing.

Manure application to crop fields, which lies at the interface between livestock and crop production, is in the process of being regulated through the implementation of Nutrient Management Plans. Although reporting by farmers of nutrient management plans is now mandatory, application rates per acre are only subject to recommendations with no enforceable standard.

2.4.1.2 Groundwater regulations

The Safe Drinking Water Act is the federal regulation that affects nitrate pollution in groundwater most directly. However, the regulation determines the quality standards allowable for drinking water without a direct mandate for the degradation of the quality of aquifers. The California Department of Public Health is the state agency responsible for monitoring and enforcing quality standards for the water provided to the public by utilities and municipalities.

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[4] The definition of point or non-point sources varies across texts and regulations. Segerson (1988) provides a general definition by noting that the policies designed for point source pollution such as taxes or emission regulations fail when it is impossible to observe the abatement or emissions of any individual suspected polluter.

Drinking water standards, for nitrates as well as for other contaminants, have resulted in water providers investing in water treatment equipment as well as switching from groundwater to surface water sources.

Although the Porter-Cologne Act was designed to address both surface and ground water pollution, the effect of policies on nitrate leaching to groundwater in California has been limited. Policies that target both crop production and livestock operations are in the process of being developed. For instance, the current revisions of the agricultural waiver of the Central Coast water region include provisions for both surface and ground water (see Chapter 8).

2.4.2 Air quality policies

The Clean Air Act (1970) is the air counterpart of the Clean Water Act. The federal Environmental Protection Agency (EPA) establishes air quality standards and enforces their application by states and local air districts using attainment criteria on which federal funding is conditioned. The California Air Resource Board is responsible for monitoring the regulatory activity of the 35 California air districts.

Other federal regulations such as the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA or Superfund) and the Emergency Planning and Community Right-to-Know Act (EPCRA) have also targeted air quality in livestock operations and require reporting of ammonia emissions.

The Clean Air Act has contributed to large reductions in air emissions from fossil fuel combustion and improvements of air quality in regions such as the Los Angeles area. The EPA estimated that between 1970 and 1990 the costs of achieving the pollution abatement dictated by the Clean Air Act were $523 billion for the country, compared to an estimated $22 trillion in avoided health and environmental costs (EPA 1997).

Agriculture has been, for the most part, exempt from air permitting requirements until recently. Livestock operations, some of which are subject to air quality regulations according to the EPA, were exempted from state-level air emissions permitting until 2004 and the implementation of Senate Bill 700 (SB 700, Chapter 479, Florez, Statutes of 2003). The EPA designated non-attainment areas in California related to volatile organic compounds (VOCs) from agricultural operations and put the state on official notice to change its regulation of livestock operations. The change in regulations has resulted in districts establishing rules for livestock operations. For instance, in June 2006 the Air Pollution Control District of the San Joaquin Valley adopted a rule mandating the adoption of conservation management practices by dairy operators (Rule 4570). These practices include dust control, manure handling and treatment, and silage management.

In addition to federal regulations, policies implemented by regional air districts have also had an impact on nitrogen flows to the air. For instance, the Connelly-Areias-Chandler Rice Straw Burning Reduction Act limits the burning of rice residue in the northern region of the Central Valley.

Over the last three or four decades of federal and state policies, air quality regulations have had larger and more costly impacts on emitting activities outside agriculture. The trend towards a more stringent application of federal regulations and standards to agriculture, and livestock production, is discussed in Chapter 8.

2.4.3 Climate change policies

Although regulation of emissions of greenhouse gases has been the topic of policy discussions for almost two decades, California Assembly Bill 32 (AB32) is one of the first policies to set regulatory objectives for greenhouse gas emissions. Specifically, AB32 aims to reduce statewide GHG emissions to 1990 levels by 2020, and a further 80% by 2050 (California Air Resource Board 2008). Agriculture contributes roughly

6% to California's overall GHG emissions and its role in the new climate policies are minor relative to the energy, transportation and industrial sectors (See Chapter 4).

The state's cap and trade program, which started in 2013, does not require agricultural producers to report emissions, nor does it place a cap on emissions from agriculture. Instead, California's climate change scoping plan encourages agricultural producers to mitigate emissions on a voluntary basis, with the adoption of manure digesters a main target for action (California Air Resource Board 2008). In contrast, energy producers, food processors, and others in the industrial sector face a mandatory cap on emissions, a policy that is likely to have important, albeit uncertain, economic effects on agriculture (Sumner and Rosen-Molina 2010; Haden et al. 2012). At present, few studies have examined the breadth and magnitude of these effects on California agriculture.

The cap and trade program does allow capped industries to purchase carbon credits from mitigation projects that meet the criteria of being real, additional, permanent, quantifiable, verifiable, and enforceable (Niemeier and Rowan 2009). Some offset protocols may involve agriculture and thus provide economic incentives to farmers who adopt practices and technologies that mitigate emissions or sequester carbon in soils or vegetation. For example, offset protocols for dairy manure digesters and rice cultivation are already under development and will soon be evaluated for inclusion in the cap and trade program (Sumner and Rosen-Molina 2010; Climate Action Reserve 2011). A voluntary offset protocol for nitrogen management is being developed for corn in the Midwest, but this does not currently apply to California crops (Climate Action Reserve 2012). Given that these agricultural offset protocols are currently under development, it will likely take several years before agricultural offsets become a large part of California's carbon market.

While state agencies have provided a framework for these climate policies, much of the responsibility for the implementation of AB32 has been delegated to local governments. For example, AB32 and the California Environmental Quality Act (CEQA) now require local governments to develop detailed plans to mitigate climate change whenever they update their general plan (California Attorney General's Office 2009). Local "climate action plans" generally include an inventory of 1990 and present-day emissions, specific plans to mitigate future emissions, and in some cases strategies to adapt to the impacts of climate change (Wheeler et al. 2008; Jackson et al. 2012).

At present, there is a great deal of uncertainty about how these new climate policies will impact the use of N in agriculture, as well as various benefits and tradeoffs for stakeholders and the environment. The use of inventory methods and GHG modeling tools that can accommodate both state and local data on agricultural emissions sources is becoming more commonplace among state and local agencies serving rural communities in California (Haden et al. 2012; CSU 2012). For example, Haden et al. (2012) found that prior to AB32, N_2O emissions from agriculture in Yolo County had already decreased by more than 20 % since 1990, due to a combination of declining cropland area, a market-driven shift toward crops that require less N (e.g., grapes, alfalfa), and improved N management for certain crops. They also report that conversion of cropland to urban uses results in a 70-fold increase in total emissions per unit area when transportation and energy-consumption-related emissions are accounted for.

These findings indicate that policies to preserve farmland and encourage "smart growth" in California are complimentary to the overall goals of AB32, and that by keeping land in agriculture further reductions in N_2O emissions may be achieved by supporting and incentivizing stakeholder efforts to optimize N management through incremental adoption of recommended fertilizer regimes and improved technology. That said, considerable uncertainty remains regarding how these policies, and the associated costs to producers, will influence agricultural production both in California and elsewhere. The possibility of "leakage", where agricultural production of certain commodities is shifted to other states or countries with less stringent regulatory policies, has not been adequately studied in the context of AB32 (Peters et al. 2008). Future research in California should examine the effects of leakage from the perspective of impacts on California's agricultural economy and the overall effects on "exported" emissions to other regions (Davis and Caldeira 2010).

2.4.4 Federal conservation programs

Over the last two decades, conservation programs have grown in importance and funding within the Farm Bill. Although the Conservation Reserve Program (CRP) has been a central feature of federal agricultural conservation since its establishment in 1985, programs that target conservation practices on land that is maintained in production have had a relatively greater impact in California, where land retirement remained minimal. In California, land retirement programs are of minor importance. California landowners enrolled only about 138 thousand acres in the CRP. California represented only 0.4 percent of the national CRP acreage and the CRP in 2007 represented only 1.25 percent of cropland within California, compared to about 8 percent of the cropland nationally (USDA Farm Service Agency 2007). The CRP originally focused on soil erosion, which is less of an issue for most of California cropland. In addition, land values in California are relatively high. Accordingly, cost per acre of land retirement is high, especially for irrigated cropland, which makes up the largest share of cropland in California.

Working land programs provide subsidies and technical assistance through the Natural Resources Conservation Service in order to encourage adoption of conservation practices in both crop and livestock production. The Environmental Quality Incentive Program has been the most important working land program in terms of scope and funding. The ability to maximize environmental benefit per dollar of subsidy was made more difficult by a restriction in the 2002 Farm Bill that eliminated the option for farmers to increase the likelihood of their project being funded by indicating a willingness to accept lower cost share percentages (USDA ERS 2006). There is no published analysis of the impact of working land conservation programs on nitrogen flows in California.

2.4.5 Other environmental policies

The California Environmental Quality Act (CEQA) of 1970 is a regulation that requires state and local agencies to identify the environmental impacts of their actions and to avoid or mitigate those impacts, if feasible. CEQA, through its regulation of construction and extension of livestock facilities, has had an impact on the size of herds by making adjustments more costly (Deanne Meyer, personal communication). There are no estimates on the net effect of CEQA on livestock related nitrogen pollution.

The Endangered Species Act of 1973 regulates actions that may affect threatened and endangered plants and animals. The policy is administered by the EPA and the US National Oceanic and Atmospheric Administration. For example, the habitat of the Delta Smelt, listed as a threatened species, has been the target of conservation efforts which include the improvement of water quality related to nitrogen.

2.4.6. Current N policy is fragmented across resources and flows: So what?

In contrast to emissions from motor vehicles, no current policies exert a strong direct effect on nitrogen flows in California agriculture. One concern voiced by farmers is the proliferation of conflicting and at times perverse regulations across different issues. Expectations of some regulation of nitrogen is a source of uncertainty in the state's agricultural sector. The novelty and great uncertainty in what policy strategies will be pursued regarding nitrogen is taken up in the scenarios in Chapter 6 and the analysis of policy and institutional options in Chapter 8 .

2.5 Conclusion

The tremendous economic and population growth that have occurred over the last decades both throughout the world and in California have affected nitrogen flows in California through a large number of interrelated effects. The effect of population and income increase in California on fossil fuel combustion in the state, and the corresponding consequences on NO_x, NH_3, and N_2O emissions is relatively clear (see Chapter 5). In contrast, understanding the underlying drivers of nitrogen flows related to nitrogen in agriculture is more challenging because of the many connections that California agriculture has with the global economy. Economic forces and trends far from California affect both the demand for California's products and the supply of inputs such as fertilizer, fuel, or labor. These effects vary across the large spectrum of commodities grown in California, as will be discussed in the next chapter on direct drivers of crop choice and production technique. The strength of these economic connections also varies across crops according to specific changes in transportation costs and trade barriers. As a result, the full effect of the policies on nitrogen flows related to agriculture in California can only be estimated by carefully accounting for the impact these policies have on the behavior of California's producers, which is the focus of Chapter 8. In the past, California's producers have readily adjusted the commodity mix to changes in economic incentives and it is likely that they will continue to do so.

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Box 2.1. Income and patterns of demand for food [Navigate back to text]

Elasticity estimates provide an indicator of the relationship between income per capita and food demand which take into account variations in food prices. Alderman (1986) compared 15 studies, covering 11 countries, concluding that while consumers readily change consumption patterns when prices for food items increase, the poor are more likely to make such substitutions than the well-off. Such substitutions are in addition to changes in food consumption that the poor make following increases in prices that are attributable to a reduction in real income.

For the United States, it is provisionally agreed by most that consumers' responses to changes in income, approximated by changes in food expenditures, vary by commodity and are high for foods that have high price elasticities (e.g., fruits, vegetables, and juice) and low for foods that have low price elasticities (e.g. eggs), reflecting that consumers do not significantly change their consumption when the prices for these commodities change (Huang and Lin 2000; Okrent and Alston 2011).

The findings for low income countries are more speculative and subject to methodological debates over data aggregation and the timing of behavior changes. Alderman (1986) estimated that families that consume 1,750-2,000 calories per person per day will increase their food expenditure by 8.2% for an income increase of 10% - an income elasticity of 0.82. However, calorie intake will only increase by 4.8% as some of the increase in expenditure is used to increase perceived diet quality. In contrast, Dawson and Tiffin (1998) estimate an income elasticity of calorie intake of 0.34 for the period 1961-1992 in India.

Figure 2.1. US disposable personal income, food expenditure and share of disposable income, 1960–2012 (2005 current dollars). Source: USDA ERS 2014a. [Navigate back to text]

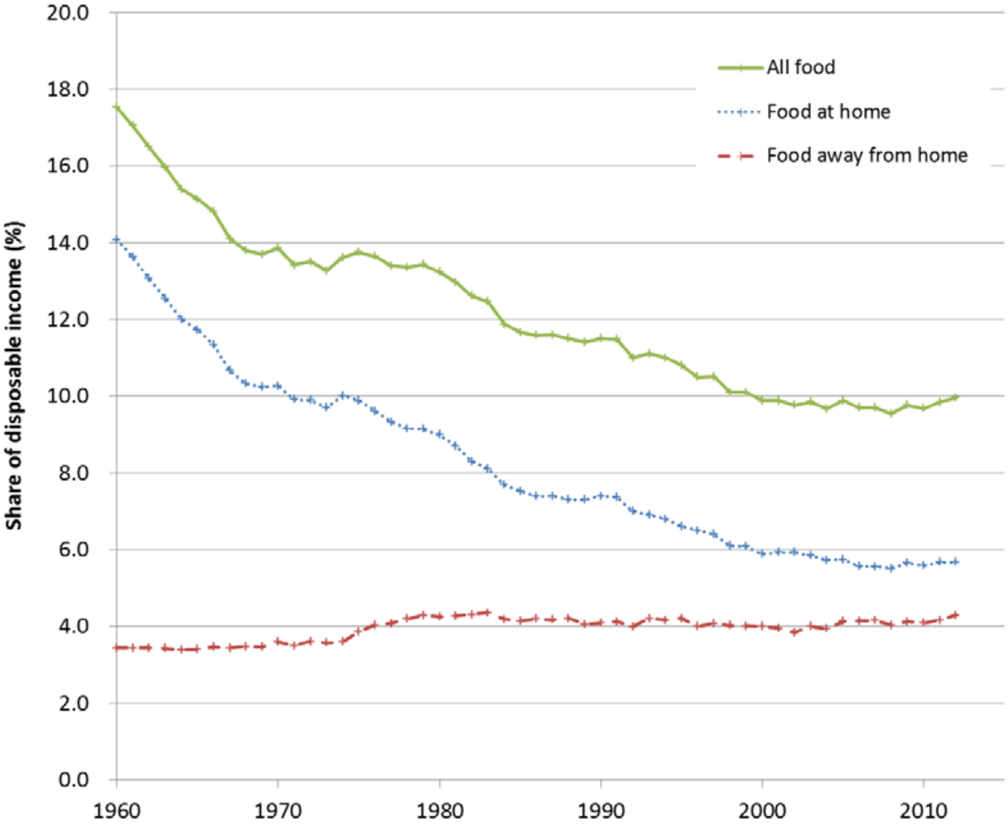


Figure 2.2. Index of fruit, vegetable, nut, and wine per capita consumption in the United States, 1970-2012 (1970=100). Source: USDA ERS 2014b. [Navigate back to text]

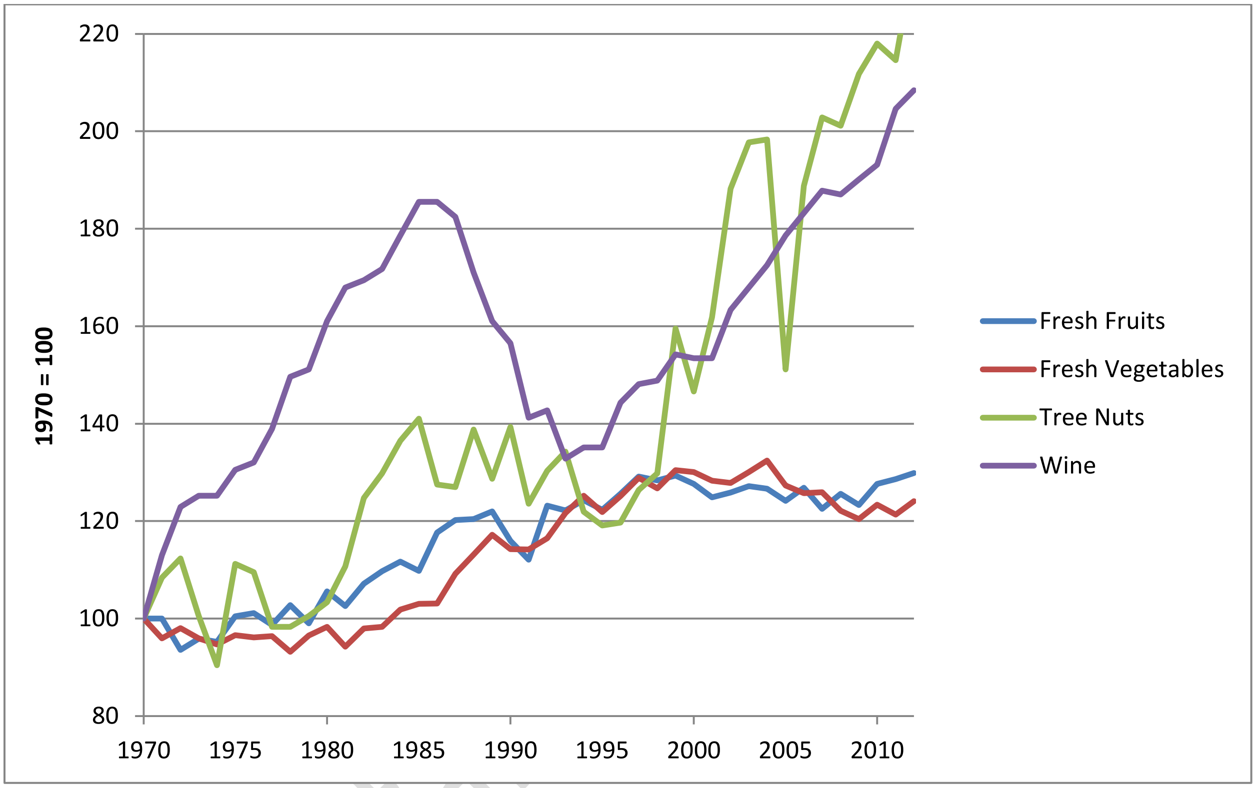


Figure 2.3. Index of meat, chicken, egg and dairy per capita consumption in the United States, 1970-2012, (1970=100). Source: USDA ERS 2014b. [Navigate back to text]

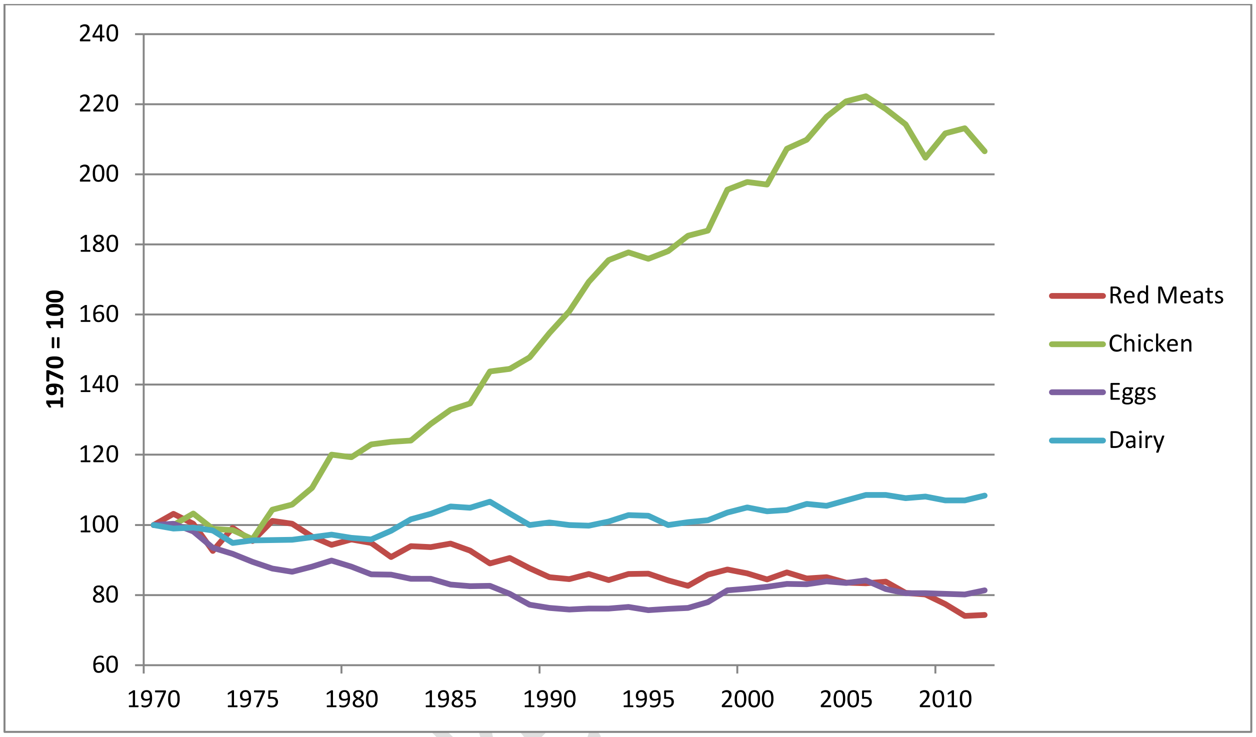


Figure 2.4. Inflation-adjusted gross domestic product per capita in California, US and world, by region, 1960-2013. Source: World Bank; CA DOF. [Navigate back to text]

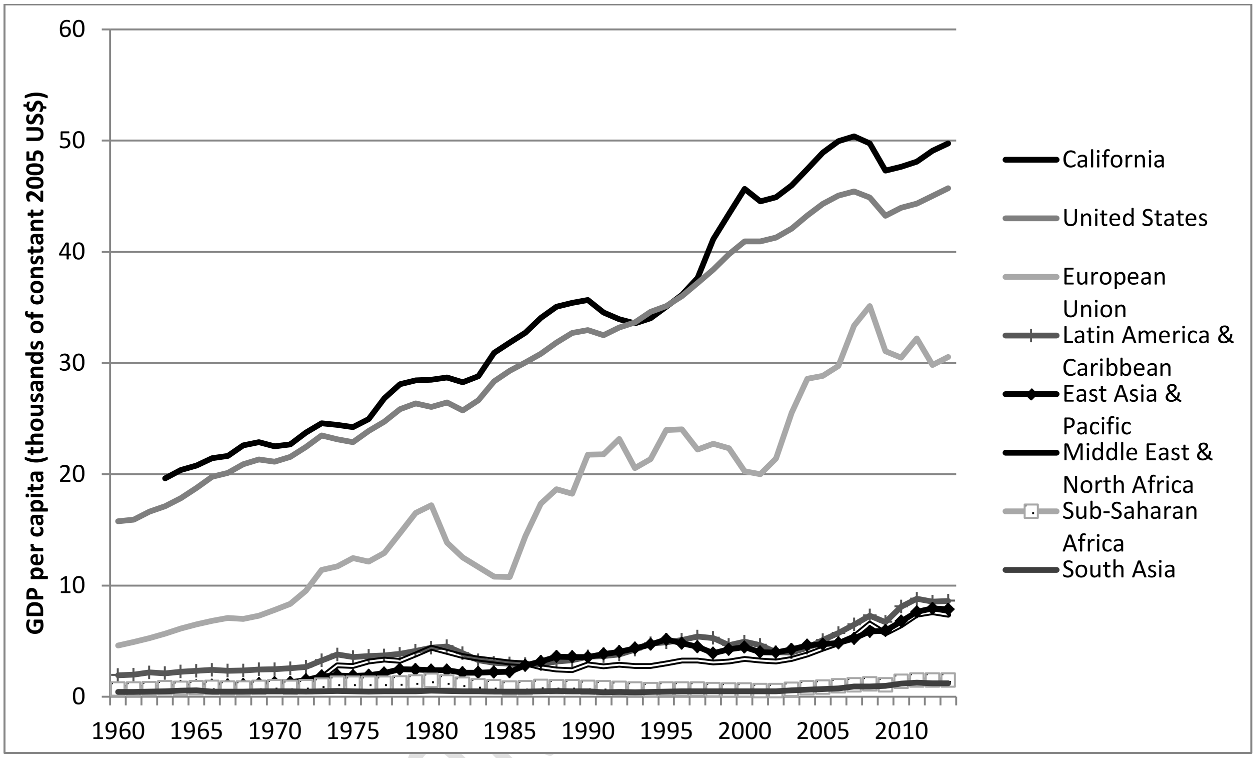


Figure 2.5. Index (1960=100) of prices received for select California commodities (in 2000 $US), 1960-2009. Source: USDA NASS 2010; Commerce 2010. [Navigate back to text]

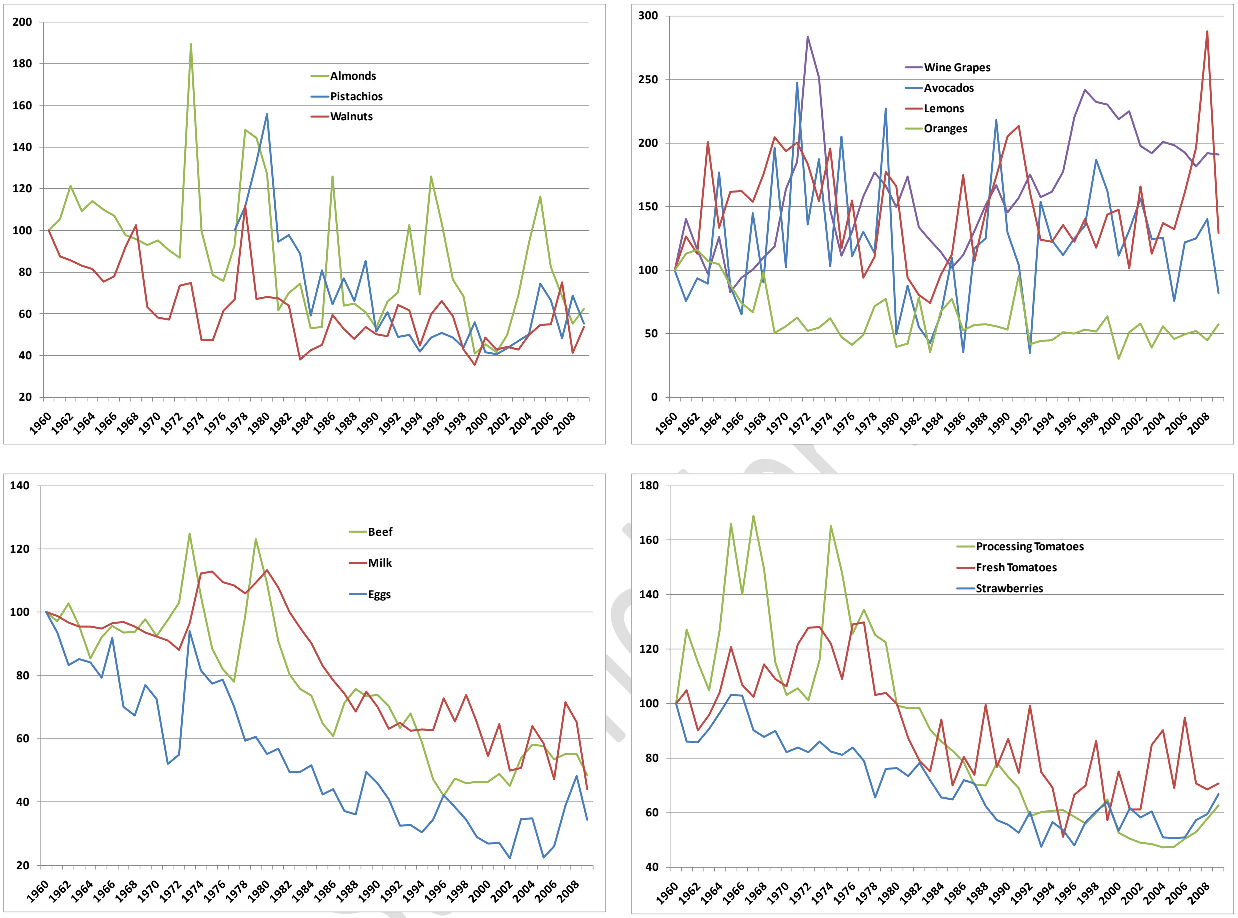


Figure 2.6. California agricultural exports to the top-10 destinations, by value, 2012. Source: AIC 2012a. [Navigate back to text]

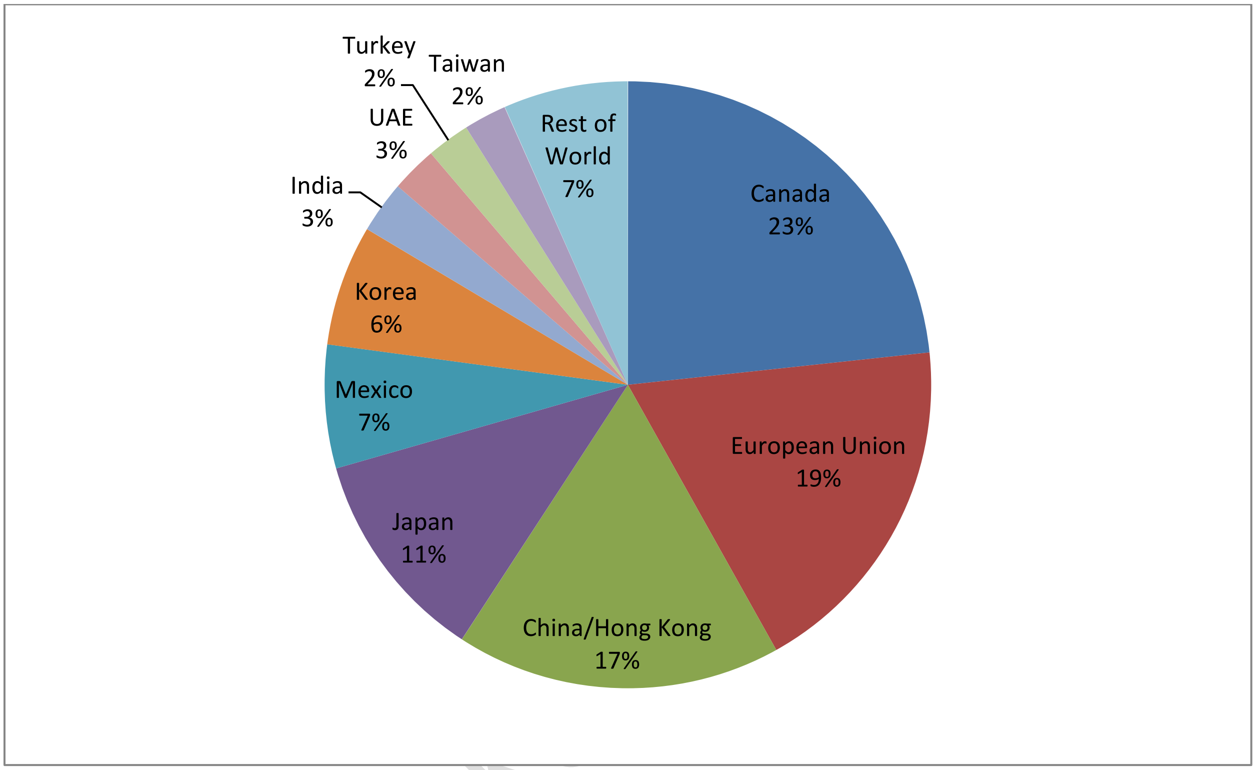


Figure 2.7. Indexed exchange rates for Canadian dollars, Euros, British pounds, and Mexican pesos against US dollar, monthly January 1999- December 2014. Source: USDA ERS 2014c. [Navigate back to text]

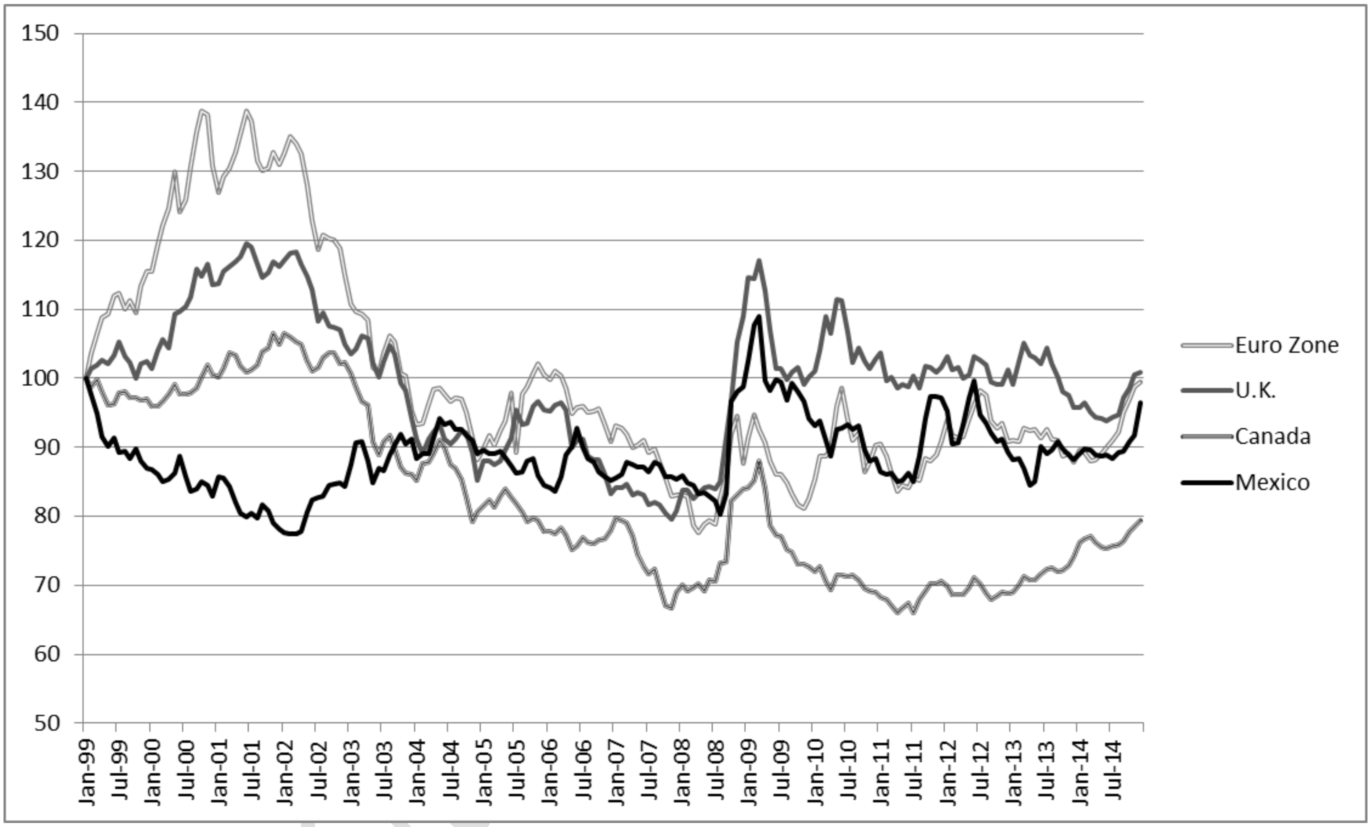


Figure 2.8. Indexed exchange rates for Japanese yen, China renminbi, Hong Kong dollar, and Korea Won against US dollar, monthly January 1999- December 2014 (Jan 1999=100). Source: USDA ERS 2014c. [Navigate back to text]

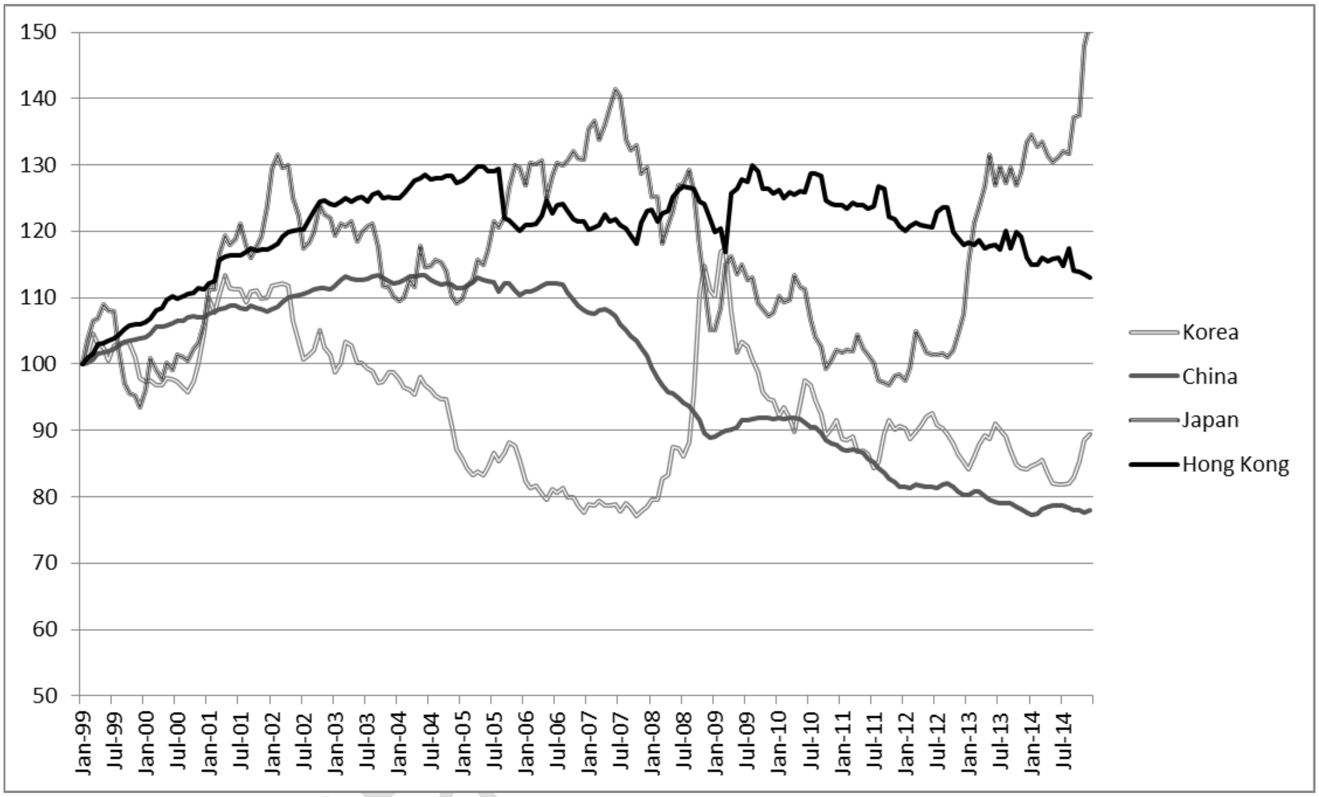
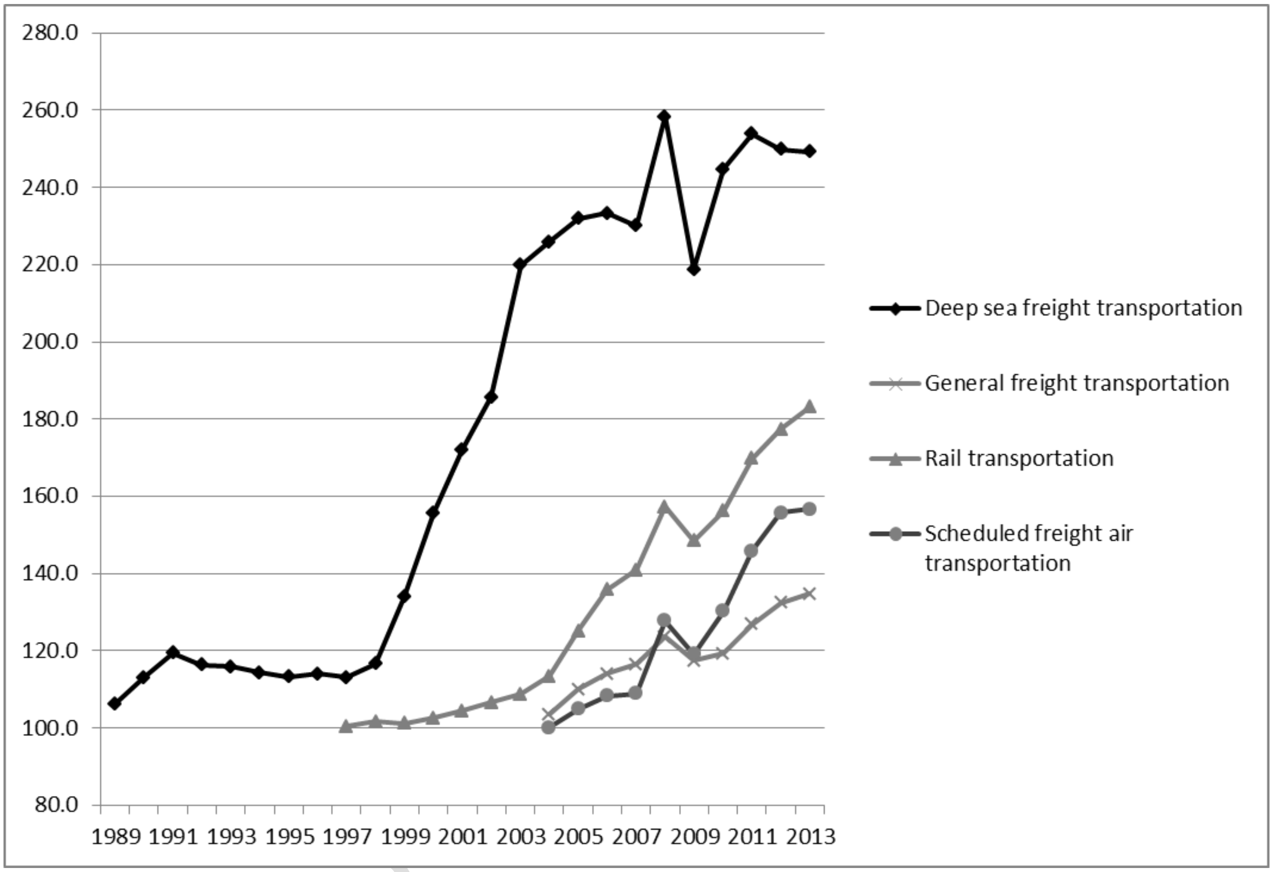


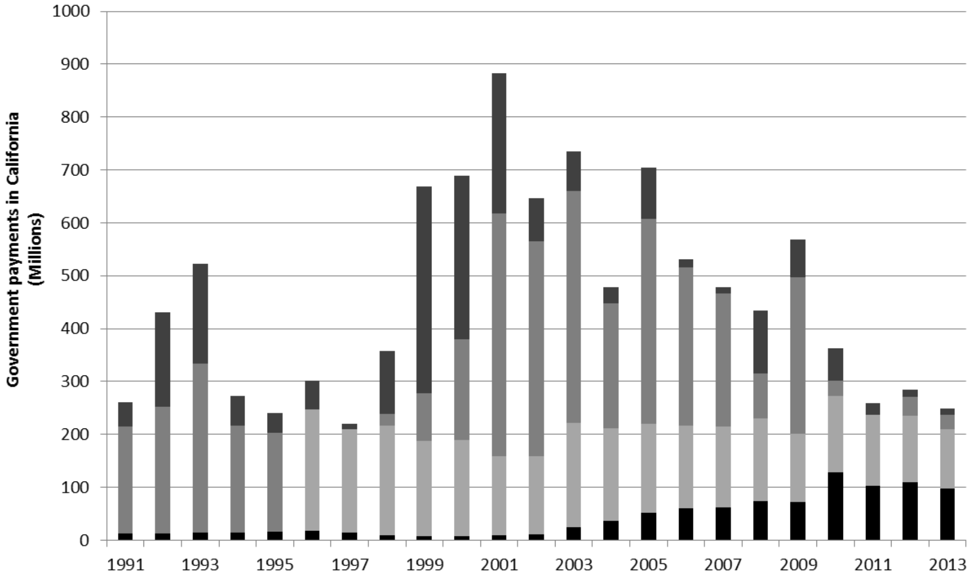
Figure 2.9. Deep sea, trucking, rail, and air transportation price indexes 1989-2013. Reference years for indexes: deep sea (1988=100), trucking (2004=100), rail (1997=100), air (2004=100). Source: DOL BLS 2014. [Navigate back to text]



Figures 2.10. Government payments to farmers in a) California and b) the United States by payment type, 1991-2013 fiscal years. All other payments include emergency payments. Conservation payments include the Conservation Reserve Programs and NRCS programs such as EQIP. Source: USDA ERS 2014d.

[Navigate back to text]

A.



B.

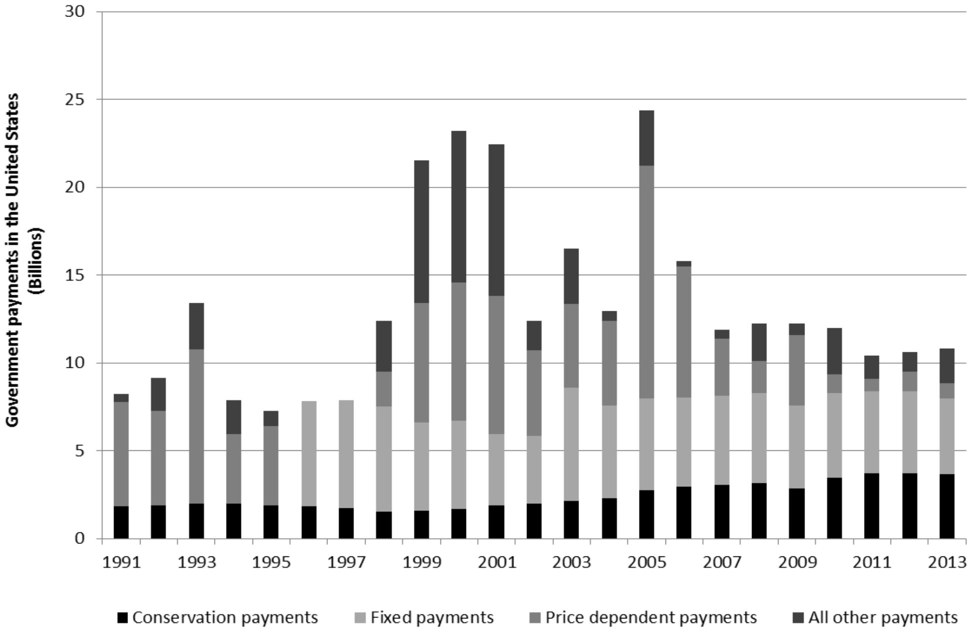


Figure 2.11. Average inflation-adjusted (real) value per acre of California and US farm real estate, 1950-2013. US values exclude Hawaii and Alaska; real values have been deflated by GDP deflator from the US Department of Commerce, Bureau of Economic Analysis, Table 1.1.9, 2014. Source: USDA ERS 2010c; USDA NASS 2014. [Navigate back to text]

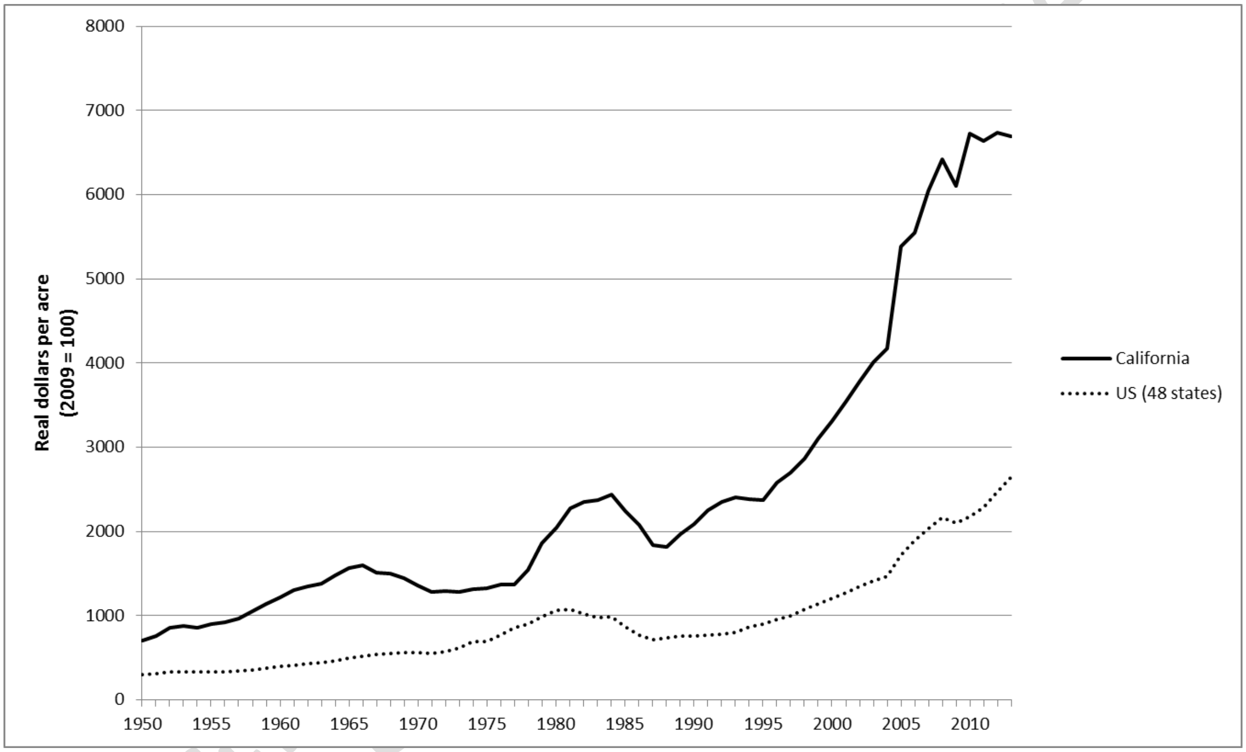


Figure 2.12. Historical chilling hours and growing-degree days in Yolo County, California, 1910-2000.

Chill hours are in red and growing degree days in green. Source: AIC 2011. [Navigate back to text]

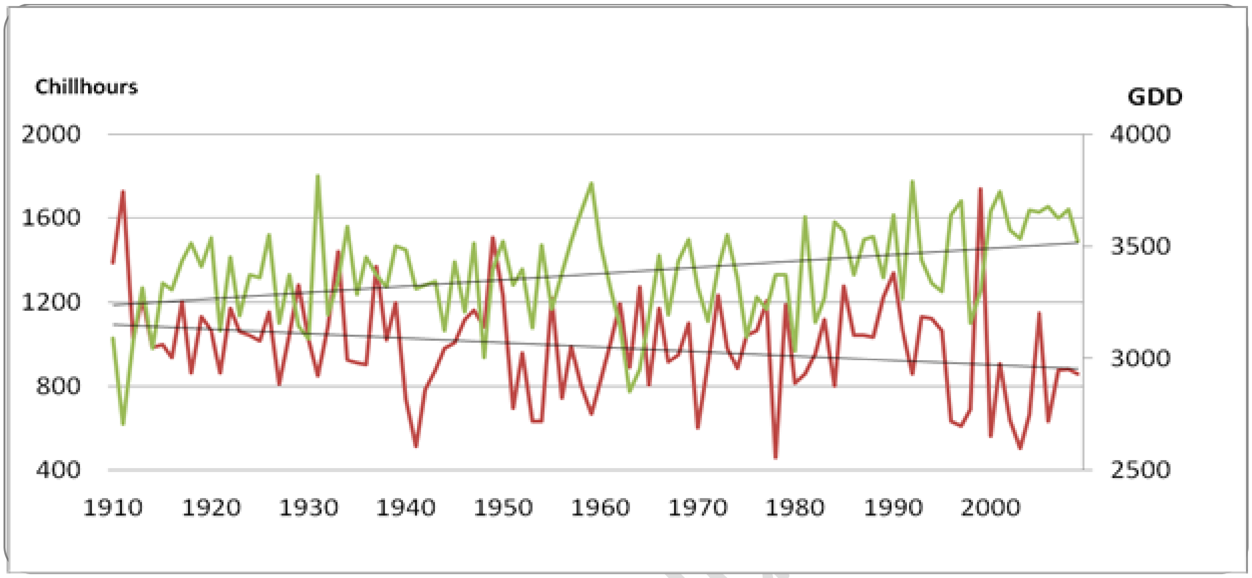


Figure 2.13. Producer price index for fertilizer and crops in the United States from 1960 to 2012 (1990-92=100). Source: USDA ERS 2013. [Navigate back to text]

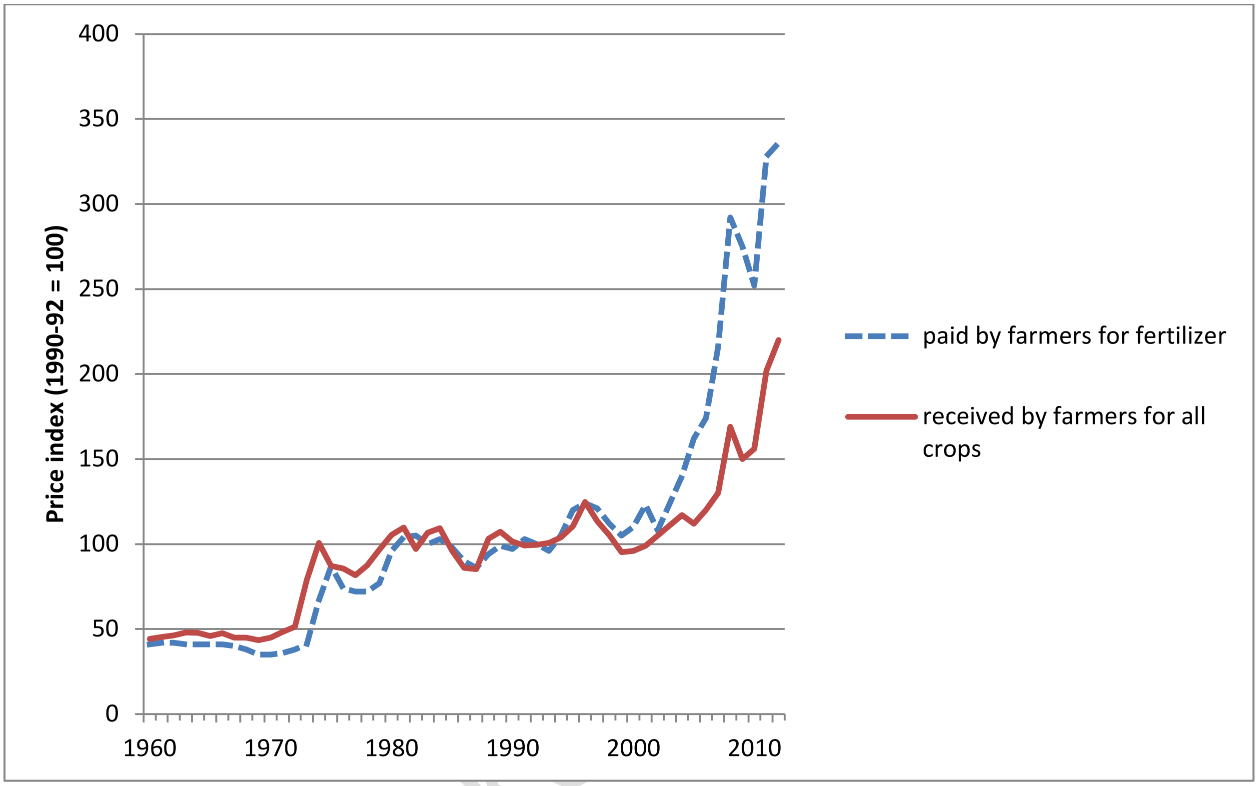


Figure 2.14. Index of US prices for gasoline and No. 2 diesel fuel, 1947-2013 (1982=100). Source: DOL 2014a. [Navigate back to text]

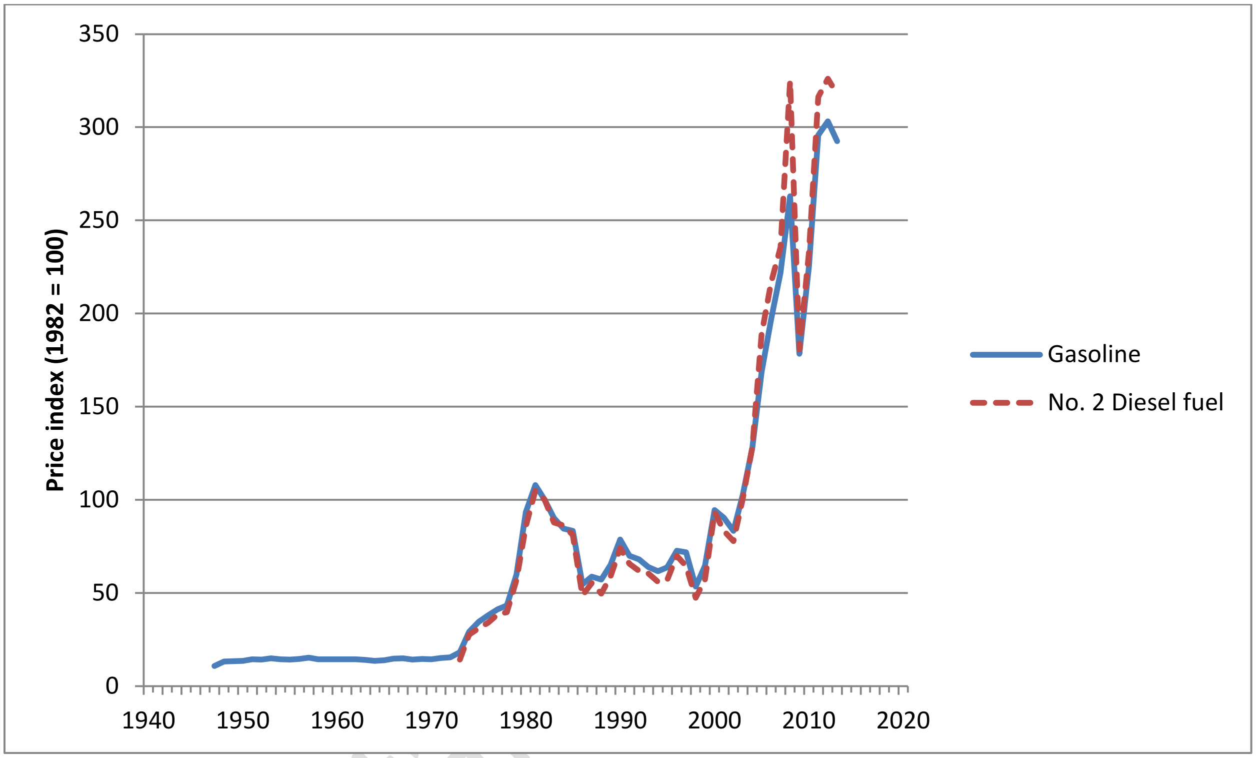


Figure 2.15. US Agricultural research and development expenditures, 1950-2007 (2000 prices). Source: Alston et al. 2010 (Figure 6.6; page 148). [Navigate back to text]

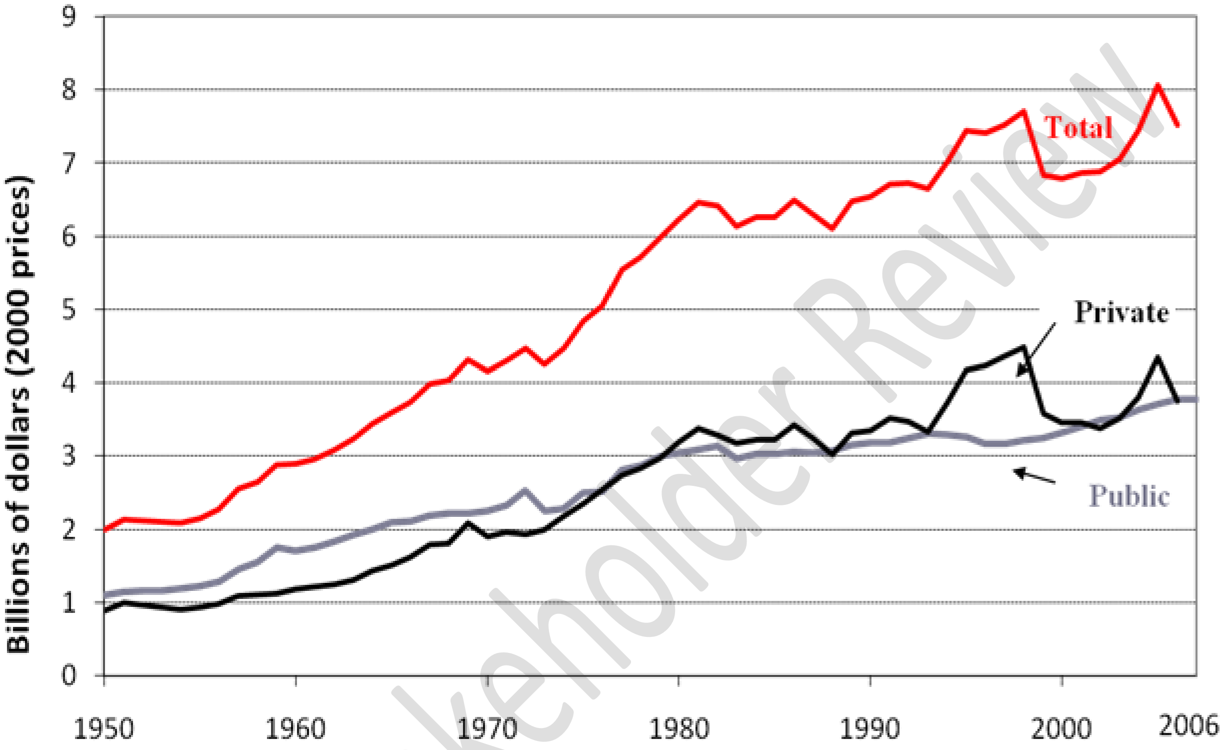


Figure 2.16. Issuance of patents to holders in California for selected agricultural technology classes, 1963-2013. Source: US Patent and Trademark Office 2014. [Navigate back to text]

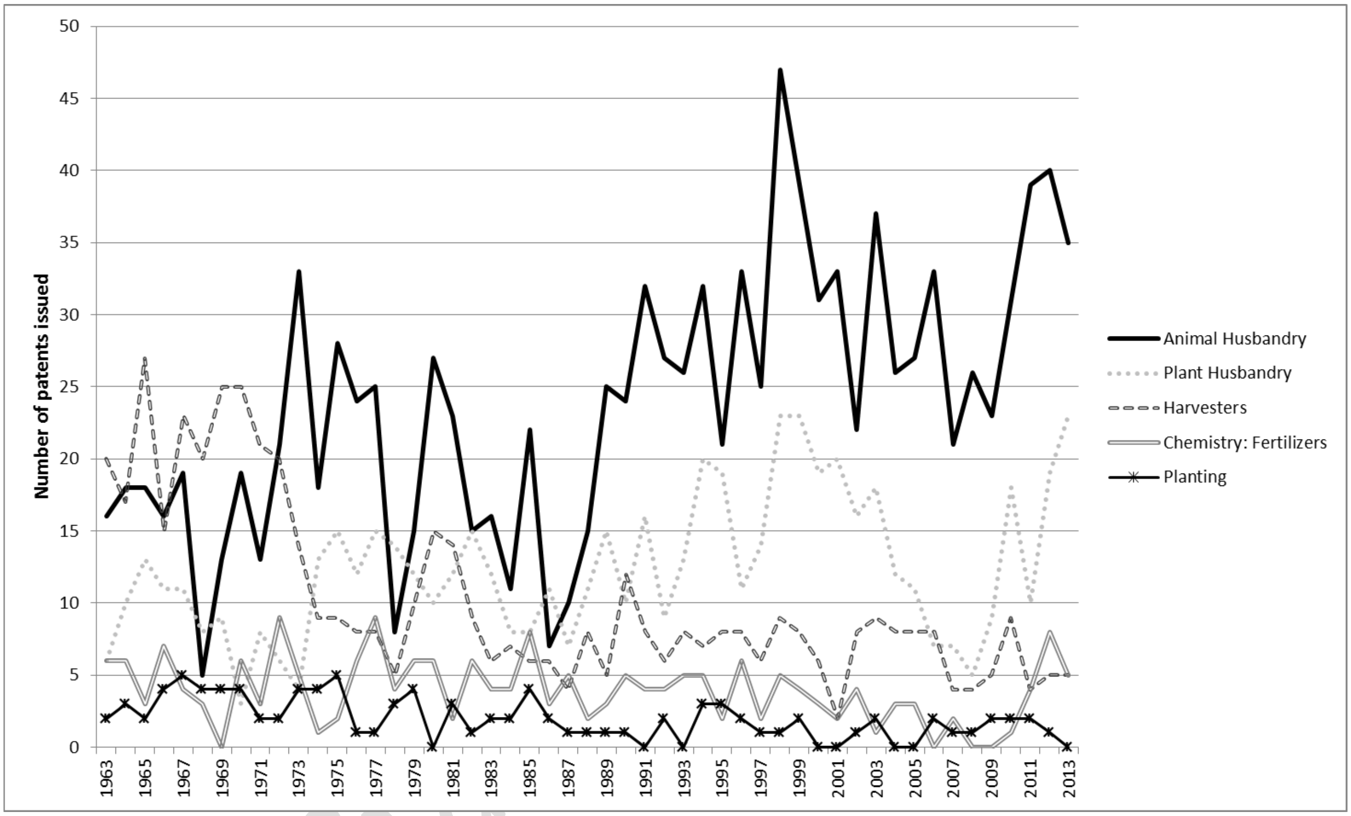


Table 2.1. Ranking of California's commodities by cash receipts in 1960, 1980, 2000 and 2010. Source: USDA ERS 2011b; USDA ERS 2013a.

Rank	1960	1980	2000	2010
1	Cattle and calves	Milk, wholesale	Milk, wholesale	Milk and Cream
2	Cotton	Cattle and calves	Greenhouse/nursery	Grapes
3	Milk, wholesale	Cotton	Grapes	Almonds
4	Chicken eggs	Grapes	Lettuce	Nursery
5	Grapes	Greenhouse/nursery	Cattle and calves	Cattle and calves
6	Oranges	Hay	Tomatoes	Strawberries
7	Hay	Tomatoes	Misc. vegetables	Lettuce
8	Tomatoes	Misc. vegetables	Strawberries, Spring	Tomatoes
9	Greenhouse/nursery	Almonds	Almonds	Pistachios
10	Potatoes	Rice	Cotton	Hay
11	Lettuce	Lettuce	Broccoli	Walnuts
12	Turkeys	Chicken eggs	Oranges	Flowers and foliage
13	Plums and prunes	Sugarbeets	Hay	Rice
14	Barley	Wheat	Avocados	Chickens
15	Milk, retail	Broilers	Celery	Oranges

Table 2.2. Cash receipts, share of California receipts, California share of US value, ratio of exports to production, and share of US in world production for major California commodities, 2008-2009 averages. Source: Matthews et al. 2011[1]; USDA ERS 2011c[2]; USDA FAS 2011[3].

Rank	Commodity	Value of receipts[2] *($1,000)*	Share of California receipts[2] *(percent)*	California share of US value[2] *(percent)*	Ratio of exports to production[1] *(percent)*	Share of US in world production[3] *(percent)*
1	Dairy products	5,730,646	15.6	19.4	18.7	15.3
2	Greenhouse/nursery	3,794,823	10.4	23.4	NA	NA
3	Grapes, all	3,095,432	8.5	88.0	29.8	5.8
4	Almonds	2,318,350	6.3	100.0	65.7	83.1
5	Cattle and calves	1,780,517	6.3	5.0	6.7	12.4
6	Lettuce	1,653,315	4.4	77.3	8.2	NA
7	Strawberries	1,651,704	4.4	79.7	10.9	NA
8	Poultry/eggs	1,384,002	3.7	3.9	NA	22.6*
9	Hay	1,205,391	3.8	20.9	2.3	NA
10	Tomatoes, process.	1,037,772	2.2	72.3	19.1	NA
11	Rice	877,158	2.1	24.4	54.9	1.4
12	Broccoli	680,848	2.1	106.9	14.2	NA
13	Walnuts	648,305	1.9	107.7	48.7	32.1
14	Oranges	607,397	1.7	30.6	42.8	15.6
15	Pistachios	581,375	1.6	102.0	96.6	39.7
	All commodities	**36,624,028**	**100.0**	**12.2**	**22.0**	

Table 2.3. Production shares for top 6 producing countries of major California commodities, 2000 to 2009 averages. Author’s calculations of data from FAOSTAT. Source: United Nations 2010.

	Dairy			Lettuce and chicory	
United States of America	18.5	%	China	49.2	%
(California's share of US)	(19)	%			
Germany	8.8	%	United States of America	20.9	%
			(California's share of US)	(73)	%
France	8.5	%	Spain	4.7	%
India	7.8	%	Italy	4.4	%
New Zealand	4.0	%	India	3.7	%
Netherlands	3.8	%	Japan	2.6	%
	Wine			Strawberries	
France	18.6	%	United States of America	28.1	%
			(California's share of US)	(61)	%
Italy	17.8	%	Spain	8.3	%
Spain	13.5	%	Republic of Korea	5.6	%
United States of America	8.8	%	Japan	5.5	%
(California's share of US)	(89)	%			
Argentina	5.2	%	Russian Federation	5.3	%
China	4.8	%	Turkey	5.3	%
	Almonds			Tomatoes	
United States of America	48.2	%	China	24.1	%
(California's share of US)	(100)	%			
Spain	12.1	%	United States of America	10.4	%
			(California's share of US)	(52)	%
Syrian Arab Republic	6.0	%	Turkey	7.9	%
Italy	5.9	%	India	7.1	%
Iran (Islamic Republic of)	5.2	%	Egypt	6.4	%
Morocco	4.1	%	Italy	5.4	%

Table 2.4. Federal crop insurance participation rates in California in 1999 (percent of acres in crop). Source: Adapted from Lee 1999.

Annual Crops	**%**
Tomatoes (fresh and canning)	35
Sugarbeets	26
Wheat (Durum only)	14
Rice	13
Cotton (Upland)	12
Total annual crops	**11**
Perennial Crops	
Raisins (Industry Estimates)	80
Prunes	45
Almonds	34
Figs	27
Navels and Valencia Oranges	26
Peaches (Cling)	14
Lemons	11
Plums	11
Grapefruit	10
Total Perennial Crops	**16**
Total Annual and Perennial Crops	**12**

Table 2.5. Shares of farm expenditures in California, 1994 - 2007, in year-2000 inflation adjusted dollars. Author's calculations of data. Source: AIC 2009.

	1994	1999	2004	2007	Average
			percentage		
Inputs and utilities					
Feed purchased	12.1	11.5	12.6	14.7	12.7
Livestock and poultry purchased	3.5	2.7	3.2	2.7	3.0
Seed purchased	2.6	3.4	3.9	3.6	3.4
Fertilizers and lime	4.1	3.6	3.8	4.3	4.0
Pesticides	4.9	4.8	4.3	4.5	4.6
Petroleum fuel and oils	2.3	2.3	2.9	4.6	3.1
Electricity	3.2	2.9	2.5	2.5	2.8
Total labor					
Contract labor	5.6	5.6	6.8	6.8	6.2
Employee compensation (total hired labor)	19	23.1	23.1	19.6	21.2
Marketing, custom work, other					
Repair and maintenance of capital items	4.2	4.2	4.7	4.4	4.4
Machine hire and custom work	4.7	4.7	3.1	2.4	3.1
Marketing, storage, and transportation	9.7	7.8	6.5	8.3	8.1
Miscellaneous expenses	11.1	11.8	11.6	10.5	11.2
Rent, taxes interests and fees					
Net rent received by non operator landlords	2.9	2.1	2.7	1.5	2.3
Real estate and non real estate interest	7.1	6.4	5.4	5.9	6.2
Property taxes, motor vehicle registration and licensing	3.1	3.1	3.0	3.6	3.2
Total farm expenditures	**100**	**100**	**100**	**100**	**100**

Table 2.6. Average annual multi-factor productivity growth rates in California and US agriculture, 1949-2002. Source: Alston et al. 2010 (Table 5.5, page 104). [Navigate back to text]

	1949-60	1960-70	1970-80	1980-90	1990-2002
California	1.66	2.22	2.84	1.01	1.24
US	1.89	1.69	2.46	2.07	0.97