Robert Mondavi Institute
Center for Wine Economics

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Julian M. Alston, Abigail M. Okrent, and Joanna Parks

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Julian Alston is a professor in the Department of Agricultural and Resource Economics and Director of the Robert Mondavi Institute Center for Wine Economics at the University of California, Davis (UC Davis), and a member of the Giannini Foundation of Agricultural Economics. Abigail Okrent is an economist at the U.S. Department of Agriculture Economic Research Service. Joanna Parks is an Associate Research Economist with Precision Health Economics LLC. Co-authorship of this study is equally shared.

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ABSTRACT. How much has food abundance, attributable to U.S. public agricultural R&D, contributed to the high and rising U.S. obesity rates? In this paper we investigate the effects of public investment in agricultural R&D on food prices, per capita calorie consumption, adult body weight, obesity, public health-care expenditures related to obesity, and social welfare. First we use an econometric model to estimate the average effect of an incremental investment in agricultural R&D on the farm prices of ten categories of farm commodities. Next, we use the econometric results in a simulation model to estimate the implied changes in prices and quantities consumed of nine categories of food for given changes in research expenditures. Finally, we estimate the corresponding changes in social welfare, including both the traditional measures of changes in economic surplus in markets for food and farm commodities, and changes in public health-care expenditures associated with the predicted changes in food consumption and hence obesity. We find that a 10 percent increase in the stream of annual U.S. public investment in agricultural R&D in the latter half of the 20th century would have caused a very modest increase in average daily calorie consumption of American adults, resulting in very small increases in social costs of obesity. On the other hand, such an increase in spending would have generated very substantial net national benefits given the very large benefit-cost ratios for agricultural R&D.

1. Introduction

Obesity is a big business. The prevalence of obesity has increased rapidly in the United States—the average American adult added 9–12 pounds during the 1990s (Ruhm 2007)—and the related health concerns are priority issues for the U.S. government and the medical community.[1] In addition to the substantial personal costs they bear, obese and overweight people generate large additional direct and indirect health-care expenses. Finkelstein et al. (2009) estimated that the increases in the prevalence of obesity in the United States accounted for 37% of the rise in inflation-adjusted per capita health-care expenditures between 1998 and 2006. Cawley and Meyerhoefer (2012) estimated that obesity accounted for $185.7 billion (in 2008 dollars) or 16.5% of total medical expenditures in 2008. More recently, Parks, Alston and Okrent (2013) estimated that $166.8 billion or 15.3 percent of public medical expenditures in 2009 could be attributed to obesity. These costs will increase with increases in the U.S. prevalence of obesity, especially severe obesity, which is projected to continue to rise (e.g., see Ruhm 2007).

The U.S. government has a stated objective of reducing obesity but the appropriate policy is not clear.[2] Some potential policies work through the use of food prices as incentives. Non-economists and economists alike appear to take the view that food prices should matter for consumption choices and the resulting obesity outcomes. Such thinking underpins various proposals for introducing tax or subsidy policies to discourage less-healthy and encourage more-healthy consumption choices.[3] The same thinking is implicit in the popular idea that American farm subsidies contribute significantly to obesity and that reducing these subsidies would go a

[1] This phenomenon is not unique to the United States. The proportion of the adult population classified as overweight or obese is high and has grown rapidly throughout much of the world (World Health Organization, 1997; International Obesity Task Force, 2005).

[2] Alston, Okrent and Parks (2013) discuss the issues and review the relevant literature.

[3] Taxes on sugar-sweetened beverages, as obesity policy, have been implemented in various U.S. jurisdictions and fat taxes were tried in Denmark but abandoned in 2012.

long way towards solving the problem (e.g., Pollan 2003). However, economic studies have consistently found that farm subsidies have had negligible impacts on U.S. obesity patterns.[4]

A related and more plausible idea is that other Farm Bill policies, such as public agricultural research and development (R&D), have contributed to obesity by making farm commodities cheaper and more abundant (e.g., see Alston, Sumner, and Vosti 2008; Alston, Rickard and Okrent 2010). For this to be true, first, public agricultural R&D must have made farm commodities that are important ingredients of relatively fattening foods significantly more abundant and less expensive. Second, the lower commodity prices caused by R&D must have resulted in significantly lower costs to the food industry, cost savings that were passed on to consumers in the form of lower prices of relatively fattening food. Third, food consumption must have changed significantly in response to these policy-induced changes in the relative prices of more- versus less-fattening foods and other goods. The primary purpose of this paper is to investigate this scenario, which is plausible given the very substantial increases in production and declines in farm commodity prices attributable to agricultural R&D.

In real terms, the prices of major agricultural commodities have fallen by 50 percent or more since 1950, and agricultural R&D has been credited as the primary engine for those changes (e.g., Alston, Pardey and Beddow 2009). In turn, these productivity gains have been reflected in lower prices of retail food products (e.g., Lakdawalla, Philipson and Bhattacharya 2005; Miller and Coble 2007, 2008). Lower food prices alone would be sufficient to encourage some increases in food consumption, but relative prices moved in favor of the production and consumption of "unhealthy" foods that use field crops and livestock as ingredients, potentially making matters worse. Some authors have argued that this is because productivity gains for fruit

[4] For instance, see Cutler, Glaeser, and Shapiro (2003a, 2003b), Alston, Sumner and Vosti (2005), Miller and Coble (2007), Alston, Sumner and Vosti (2008), Okrent and Alston (2012) and Rickard, Okrent and Alston (2012).

and vegetable farm commodities have been somewhat slower than those for field crops and livestock (e.g., see Drewnowski and Darmon 2005, Drewnowski and Specter 2004, Popkin 2010), but the detailed empirical analysis by Alston and Pardey (2008) does not support that view.

A corollary idea is that, looking forward, the agricultural research portfolio could be tilted more in favor of healthy foods, and away from less-healthy foods. Some such policies have been initiated. In the 2008 Farm Bill the U.S. government introduced the Specialty Crops Research Initiative, mandating funding of $50 million per year for FY 2009–12 and authorizing additional annual appropriations of $100 million for a new program of competitive research grants. More recently, a report by the Institutes of Medicine (2012) recommended that the American Congress and the Administration "should ensure that there is adequate public funding for agricultural research and extension so that the research agenda can include a greater focus on supporting the production of foods Americans need to consume in greater quantities according to the Dietary Guidelines for Americans" (p. 435). Such recommendations have also been echoed within the medical community (e.g., Grandi and Franck 2012) as well as by policymakers (e.g., Whitehouse Taskforce on Childhood Obesity Report to the President 2010).

Whether the R&D portfolio should be tilted to favor products that are ingredients of a healthy diet is a complex question that was addressed briefly by Alston and Pardey (2008) and Alston and Okrent (2010). Pertinent issues are (a) the extent to which it is possible to achieve public purposes related to obesity by changing the agricultural R&D portfolio, (b) the opportunity cost of conventional research benefits that must be foregone, through changing the mixture of research investments, in exchange for a given reduction in prevalence of obesity, and (c) the extent to which these gains might be achieved at lower cost through the use of other policy instruments, more directly targeted at the problem of obesity.   Economic assessments consistently show remarkably high rates of return to public investments in agricultural research (e.g., see Alston, Andersen, James and Pardey 2010, 2011), with benefit-cost ratios in the range of 20:1 or 30:1.[5] These high benefit-cost ratios indicate that the total R&D portfolio is too small, and suggest that distorting that already-too-small portfolio with a view to achieving obesity objectives might impose very large social opportunity costs. On the other hand, obesity costs are also very high, and other instruments are lacking, such that in principle some shift of the portfolio towards ingredients of a healthier diet could enhance national welfare.[6]

An informed answer to these policy questions requires information on the impacts of past and prospective public agricultural R&D investments on prices and food consumption, and thus on obesity and its social costs. In this paper we examine the effects of U.S. public investments in agricultural R&D on obesity and social welfare in the United States. The work involves several elements. First, we estimate an econometric model linking prices of ten categories of farm commodities to measures of agricultural knowledge stocks based on past investments in agricultural R&D. Section 2 of the paper describes the relevant aspects of the U.S. public agricultural research system, the data on commodity prices and data on research spending used to construct the knowledge stocks used in the analysis, and the estimation results. The estimated model parameters are used to project the changes in the farm prices of the commodities that

[5] Alston, Andersen, James and Pardey (2010, 2011) modeled state-specific U.S. agricultural productivity for the period 1949–2002 as a function of public agricultural research and extension investments over 1890–2002. The authors found that marginal increments in investments in agricultural research and extension (R&E) by the 48 contiguous U.S. states generated own-state benefits of between $2 and $58 per research dollar, averaging $21 across the states. Allowing for the spillover benefits into other states, state-specific agricultural research investments generated national benefits that ranged between $10 and $70 per research dollar across the states, with an average of $32.

[6] U.S. agricultural R&D has substantial international spillover effects on agricultural technology (e.g., see Alston 2001). If research-induced productivity gains contribute significantly to social costs of obesity, U.S. agricultural R&D might yield international spillover costs from obesity to count against the international spillover benefits reported in some of the literature on agricultural research benefits.

would be implied by specific counterfactual changes in public agricultural R&D knowledge stocks, as a basis for policy simulations. Section 3 of the paper describes the equilibrium displacement model (from Okrent and Alston 2012) that is used to link changes in commodity prices to changes in food prices, food consumption, and obesity outcomes. Section 4 describes the results from the simulation analysis in which we estimate the changes in quantities consumed of nine retail food products—as implied by the simulated changes in farm commodity prices resulting from alternative counterfactual patterns of research expenditures—and the corresponding changes in social welfare. These measures include both (a) the conventional measures of welfare changes from research impacts in commodity markets, and (b) changes in public health-care expenditures associated with the predicted changes in food consumption and the consequences for nutrition and health. Section 5 summarizes the key findings and concludes the paper.

2. Public Agricultural R&D, Productivity and Farm Commodity Prices

In real terms agricultural commodity prices trended down significantly during the past 100 years, reflecting growth in supply of agricultural products outstripping growth in demand that was fueled by increases in population and per capita incomes. The long-term trend in deflated prices has been remarkable. Over the period of 55 years between 1950 and 2005, ending just prior to the recent price spike, in real terms commodity prices fell at an average annual rate of 1.6 to 2.5 percent; over the 30 years between 1975 and 2005, at an average rate of 2.6 to 3.9 percent per year (Alston, Beddow, and Pardey 2009). Alston, Beddow and Pardey (2009) attributed these trends in prices primarily to growth in farm productivity—in terms of crop yields, broader partial productivity measures, and multifactor productivity measures—which they ascribed primarily to public and private investments in agricultural R&D.

While all food commodity prices have trended down in real terms, the movements have been uneven, with important differences among commodity categories. Figure 1, panels a and b show the prices received by farmers for the main product categories deflated by the implicit price deflator for gross domestic product (representing prices generally in the economy). The real prices of specialty crops have declined over the past 50 years, approximately 20 percent for fruit and tree nuts, and 10 percent for vegetables and melons between 1960 and 2010. The real prices of food grains (primarily wheat and rice) declined at a faster rate than the real prices of specialty crops; between 1960 and 2010, the real prices of food grains declined close to 50 percent. Likewise, the real prices of meat animals, poultry and eggs and dairy commodities, commodities that use feed grains as inputs to production, declined 40–60 percent over the period. Associated with these price changes have been substantial increases in quantities produced and consumed and shifts in the balance of consumption. The increase in consumption could be accounted for by the lower real price or growth in demand, or a combination of the two. The increase in production in spite of lower real producer prices indicates that supply must have increased.

[Figure 1: *Relative Prices of Selected Farm Commodities, 1960–2010*]

Alston, Andersen, James, and Pardey (AAJP, 2010, 2011) modeled the effects of U.S. public agricultural R&D on state-level and national aggregate farm productivity, but not on farm commodity prices. To measure the effects of agricultural R&D on food consumption and obesity, taking into account induced changes in relative prices of different farm commodities, requires a disaggregated model. In what follows we borrow heavily from the approach used by AAJP (2010, 2011) to develop a disaggregated model of national aggregate farm commodity prices as a function of public agricultural R&D spending. In this section we quantify the links between public agricultural R&D spending and the prices of ten categories of farm commodities (oilseeds, food grains, fruits and tree nuts, vegetables and melons, sugar, other crops, meat animals, poultry and eggs, milk, and fish), as a basis for an analysis of the implications for food consumption and obesity and its consequences.[7]

Models of Real Farm Commodity Prices and Public Agricultural Knowledge Stocks

The prices of the ten U.S. farm commodities of interest are determined in a complex of supply and demand interactions. Price movements over time reflect both shifts in demand for farm products at home and abroad and shifts in supply of U.S. farm products.[8] Reflecting these various influences, we propose a reduced-form model in which, in year *t*, the current price of agricultural commodity *l*, $W_{l,t}$, is a function of a commodity-specific public agricultural knowledge stock, $K_{l,t}$, a range and pasture index, R_t, indexes of the prices of energy, $\boldsymbol{E_t}$ and agricultural marketing inputs, $\boldsymbol{M_t}$, and a random error term, $\varepsilon_{l,t}$ as follows:

(1) $$\Delta \ln W_{lt} = \alpha_0 + \alpha_{Kl}\,\Delta \ln K_{l,t} + \alpha_{Ri}\,\Delta R_t + \alpha_{Ml}\,\Delta \ln M_t + \alpha_{El}\,\Delta \ln E_t + \varepsilon_{l,t}, \forall l = 1,...,L,$$

where all of the economic variables are defined in real terms in that nominal values of $W_{l,t}$, $\boldsymbol{E_t}$ and $\boldsymbol{M_t}$ are deflated by the implicit price deflator for GDP, and the knowledge stock variable, $\boldsymbol{K_{i,t}}$, is based on research spending data deflated by a research deflator series developed by Pardey, Chan-Kang and Anderson (in preparation), with specific details as described in Table 1. As shown in equation (1), we first-differenced all of the variables because we detected unit roots

[7] As documented by Pardey, Alston and Chan-Kang (2012), in 2009 the United States spent $11.1 billion on food and agricultural R&D, of which $6.3 billion (57.2%) was private investment and $4.8 billion (41.8%) was public. However, of the private investment, substantially more than half was devoted to food technology and other non-farm issues, and privately conducted farm-productivity-oriented research was devoted to proprietary technologies (such as seed, agricultural chemicals, and machines) that are sold to farmers such that the on-farm cost savings are smaller than for comparable research conducted in the public sector. Thus, public-sector research is expected to have had a larger impact on reducing farm costs.

[8] The shifts in farm demand reflect changes in population and income, other demographic changes and changes in consumer preferences, as well as changes technology and the prices of other inputs used in food manufacturing, processing, retailing, and food consumption at home and away from home. The shifts in supply of farm commodities result from changes in prices of inputs used by farmers, weather, and changes in farming technology reflecting the effects of other sources of new technology as well as the public agricultural research that is the focus of this analysis.

in half of the price and knowledge stock series using the augmented Dickey-Fuller test. We discuss the implications of this treatment of the data for the findings.

[Table 1. *Definitions of Variables used in the Regression Model of Commodity Prices*]

We computed the knowledge stock variable in equation (1) by applying the gamma lag distribution weights from the preferred model of AAJP (2011) to data on commodity-specific public research spending, developed for this purpose. With this lag distribution, a total of 50 years of lagged research affect current productivity and prices, although the effects are small after 40 years, with a peak impact after 24 years. To estimate such a model requires long time-series. The United States Department of Agriculture (USDA) compiles detailed data on public research spending by the 50 State Agricultural Experiment Stations (SAESs) and by the USDA itself in its intramural research. The USDA Current Research Information System (CRIS) data files include information on detailed categories of annual expenditure according to field of science, commodity orientation, problem focus, and so forth.

Useful data were available to us from CRIS for the years 1975 through 2009 (see Appendix A for details). This is an uncomfortably short series for estimating models with research impacts lasting 50 years, so we extrapolated the series back to 1929 using a regression approach based on measures of total U.S. public agricultural R&D spending, as described in Appendix A. The resulting data on commodity-specific public research spending were then used to construct knowledge stocks for the 38-year period 1969–2004. This period includes the volatile 1970s, with a large spike in commodity prices in 1973 and 1974 that was not related to U.S. farm productivity. We tried models that included the early years, with dummy variables for 1973 and 1974, and for a shorter 25-year period, 1980–2004, that did not include the influence of either the 1970s price spike or the more-recent price spike in 2008.

We estimated the model in equation (1) under the assumption that the elasticity of the commodity price with respect to its commodity-specific knowledge stock is the same across the ten commodities (i.e., $\alpha_{Kl} = \alpha_K, \forall l$), because it is challenging to estimate a separate elasticity for each commodity given the nature of the available data, and it is reasonable to assume that the elasticity of price with respect to the commodity-specific knowledge stock is comparable across commodities.[9] Thus the ten equations were estimated as system using a SUR model, with a cross-equation restriction on the elasticities associated with the knowledge stocks.

We tried variants of the model that also included a linear time-trend variable, to capture the effects of other omitted variables as well as a model estimated with all the economic variables in logarithms, without first-differencing the data. The results of the preferred model, using the shorter series (1980–2004) and excluding the time-trend variable, are reported in Table 2. The upper half of Table 2 includes the results for the model estimated with the undifferenced variables and the lower half includes the results from the first-difference models, which are to be preferred given the results of the unit root tests. In this model, the elasticity of commodity price with respect to the commodity-specific knowledge stock is –1.93 and statistically significantly different from zero at the 1 percent level of significance. The corresponding elasticity from the model estimated without first differencing is much smaller, –0.55, but also statistically significant.[10] Both estimates are within a plausible range and broadly consistent with results from AAJP (2010, 2011) who reported elasticities of multifactor productivity with respect to the comparable public agricultural knowledge stock of about 0.33.

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[9] If research resources are allocated among commodities approximately according to the principal of equimarginal returns, the elasticities of prices with respect to the knowledge stocks should be broadly comparable.

[10] In the variant of this model that also includes the time trend variable, the elasticity is –1.57 (significant at 1 percent). If the longer time-series is used, the elasticity is –0.25 (significant at 1 percent) without the time trend but it becomes positive (0.11) but insignificant when the time trend is also included.

[Table 2. *Estimation Results from the Regression Model of Commodity Prices*]

Partly as a check on the commodity-specific analysis, we estimated a comparable model applied to aggregate data for the period 1980–2004—an index of the real price of U.S. agricultural output from AAJP (2010), regressed against various measures of the U.S. public agricultural knowledge stock based on the AAJP (2010) data and using the same 50-year gamma lag distribution. The results are reported in Appendix C. The elasticity of agricultural output price with respect to the total public agricultural R&D knowledge stock is –1.19 and statistically significantly different from zero in a model with undifferenced data (Table C.1-1).[11] In the comparable model using first-differenced data, the point estimate of the elasticity is –3.25, but is not statistically different from zero at the 10 percent level of significance (Table C.1-2).

Growth Accounting

Using the elasticity estimates from the commodity price model we can decompose the changes in prices into elements attributable to changes in knowledge stocks or other variables—analogously to growth accounting in models of production. Specifically, comparing 2004 and 1980, the total predicted proportional change in price of commodity *l*, is

(2) $$\Delta \ln \hat{W}_{lt} = \hat{\alpha}_{Kl}\, \Delta \ln K_{l,t} + \hat{\alpha}_{Ri}\, \Delta R_t + \hat{\alpha}_{Ml}\, \Delta \ln M_t + \hat{\alpha}_{El}\, \Delta \ln E_t$$

where, for each variable, the Δ ln refers to proportional change between 1980 and 2004. The proportional changes in prices attributable to changes in agricultural knowledge over the same time period are given by

(3) $$\Delta \ln \hat{W}_{l|\Delta R = \Delta M = \Delta E = 0} = \hat{\alpha}_{Kl} \Delta \ln K_l ,$$

[11] As with the commodity-specific analysis, we also tried models that included the early years, with dummy variables for 1973 and 1974 and models including a time trend variable. In the variant of the undifferenced model that includes a linear time trend, the elasticity of agricultural output price with respect to the source-specific knowledge stocks ranges from –0.83 to –0.38, but remains statistically insignificant.

and the share of the total predicted proportional change attributable to changes in agricultural knowledge stocks is given by taking the ratio of the result from equation (3) and the result from equation (2). We computed these measures using the econometric estimates in Table 2, and the results are shown in Table 3.

[Table 3. *Growth in Prices Attributable to Changes in Knowledge Stocks, 1980–2004*]

Panel a of Table 3 refers to the "growth accounting" results based on the regression analysis of commodity-specific prices, and Panel b refers to corresponding results from models of the aggregate price index for U.S. agricultural output. Column (1) shows the actual percentage changes in the prices over the interval 1980–2004, with decreases ranging from 19 percent for fruit and tree nuts up to more than 84 percent for sugar, food grain, and "other," compared with 64 percent for the aggregate index (in Panel b). Over the same period, in column (2), the commodity-specific knowledge stocks increased substantially but unequally, with increases ranging from 27 percent for dairy up to 241 percent for fish, but more typically in the range of 50 to 70 percent. In Panel b, various measures of aggregate public agricultural knowledge stocks (whether for SAES expenditures, USDA intramural research expenditures, the sum of SAES and USDA intramural expenditures, or the sum of public research expenditures and extension) all grew by between 40 and 70 percent with the slowest growth recorded for USDA intramural expenditure and the fastest for SAES expenditure.

Columns (3)–(5) refer to results from our preferred model, estimated with first-differenced data. For this model the proportional changes in prices predicted by the regression model in column (3) are identical to the actual changes in column (1)—essentially because the regression passes through the sample mean. Column (4) shows the proportional change in prices attributable to changes in knowledge stocks, and column (5) expresses this amount as a percentage of the total change predicted by the model. In every case, the proportional change in price attributable to the change in the knowledge stock is larger—occasionally very much larger—than the actual proportional change in prices, such that growth in agricultural knowledge stocks accounted for more than 100 percent of the actual price change. In all these cases, the implication is that, in the absence of increases in agricultural knowledge stocks, the prices would have risen as a result of other factors (such as increases in demand, or increases in costs of energy or marketing inputs). Indeed, in several cases including fish, vegetables, fruit and tree nuts (i.e., all the "healthy" categories of commodities) and meat animals, growth in agricultural knowledge stocks accounted for more than 300 percent of the actual price change. A similar pattern can be seen in the last rows of the table, in which more than 100 percent of the decline in aggregate price index price is attributable to growth in the knowledge stock (105 percent in the models that includes both SAES and USDA intramural research without extension and 314 percent in the model that also includes extension). Such large impacts are plausible in view of the very large changes in primal measures of farm productivity that are largely attributed to agricultural R&D.[12]

Columns (6)–(8) in Table 3 show the corresponding results from the regression model using the undifferenced data, and columns (9)–(11) for that model augmented with a time trend. Using the undifferenced data, the elasticity of prices with respect to the knowledge stocks is much smaller compared with the corresponding estimates in columns (3)–(5), and in columns (7) and (8) of Table 3 the changes in prices attributed to the changes in the knowledge stocks are therefore much smaller. When the time trend variable is included its coefficient is generally not statistically significant, the significance of some other variables is reduced, and the elasticity of

[12] For example, figures presented by Alston et al. (2010, p. 425–426) suggest that returning to 1949 productivity in 2002, holding all inputs constant, would reduce U.S. agricultural production by 61 percent. Such a large reduction in total quantity would have very large price impacts, given inelastic demand for aggregate farm production.

prices with respect to knowledge stocks increases. Consequently, in columns (10) and (11) of Table 3, the changes in prices attributed to the changes in the knowledge stocks are larger than their counterparts on columns (7) and (8) but they are nevertheless still generally smaller than their counterparts in columns (4) and (5) from the model in first-differences. The first-difference model is preferred on statistical grounds.

In the next section we examine the implications for food consumption and obesity if knowledge stocks had not grown since 1980, and farm commodity prices had therefore not fallen as much as they did—and in some cases would have risen, according to the estimates in column (4) of Table 3. We can also use the results in Table 2 to infer the changes in commodity prices that would be implied by alternative counterfactual scenarios for agricultural research expenditures. The next section describes the simulation model that is used to translate those changes in commodity prices into changes in food consumption and obesity, and the section after that presents the simulation results for various changes in knowledge stocks in 2002.

3. Elements of the Policy Simulation Model

Our analysis is undertaken using a model that was developed specifically to simulate the effects of agricultural policies that affect farm commodity prices on U.S. food prices and consumption patterns, and from there to impacts on obesity and its social costs. The model is described in detail by Okrent (2010) and in summary form by Okrent and Alston (2012) and by Rickard, Okrent and Alston (2012) who used it to analyze the economic consequences of various actual and hypothetical taxes and subsidies on food and farm commodities through their impacts on U.S. caloric consumption, obesity, and its social costs. The interested reader is referred to those studies for the more complete details of the model and its parameterization. Here we provide a brief sketch of the main elements; further details are available in Appendix B.

Equilibrium Displacement Model

At the core of the analysis is an equilibrium displacement model in which the primary supply and demand relationships are represented by logarithmic differential approximations and elasticities, and we solve for proportional changes in prices and quantities induced by exogenous shocks. Such models have a rich tradition in agricultural economics. The equilibrium displacement model used here was developed by Okrent (2010) to be used to analyze the economic welfare consequences of farm commodity and food policies through their implications for food consumption and obesity. The model includes supply equations for ten U.S. farm commodities (oilseeds, food grains, fruits and tree nuts, vegetables and melons, sugar, other crops, meat animals, poultry and eggs, milk, and fish) and a composite marketing input that are linked through fixed proportions marketing margins relationships to the prices of nine retail food products (cereals and bakery products, meat, eggs, dairy products, fruits and vegetables, other foods, nonalcoholic beverages, food-away-from-home, and alcoholic beverages).

The model is solved jointly for proportional changes in prices and quantities of both the retail food products and the farm commodities used to produce them, as a result of policy changes introduced as exogenous shocks. In the present application, the exogenous shock is a change in equilibrium prices of farm commodities, reflecting a shift to a counterfactual scenario of public agricultural research spending. The basis for the shift in farm commodity prices, which are treated as exogenous in this analysis, is the regression analysis reported in Section 2.

Implied Changes in Body Weight

Once the proportional changes in quantities of retail products have been calculated for an exogenous shift in farm commodity prices using the model, the changes in quantities can be translated into measures of changes in calorie consumption and changes in body weight. First, we used the 24-hour dietary recall data collected by the 2001-2002 National Health and Nutrition Examination Survey (NHANES) to translate changes in food consumption into changes in calorie consumption (Centers for Disease Control, National Center for Health Statistics 2003). The NHANES collects daily quantities of food and calorie intake for a nationally representative sample of individuals and categorizes foods based on the USDA food classification system, which includes the following food categories: dairy, meats, eggs, beans, seeds and nuts, cereals and bakery products, fruits, vegetables, fats, sweets, nonalcoholic beverages and alcoholic beverages. We aggregated the food categories so they closely match the food products included in our simulation model. Using the sample weights, we calculated average daily quantities of (and calories from) each of the food categories consumed by individuals aged 18 and older.

Second, the simulated changes in daily calorie consumption are converted to changes in body weight for the average individual. Tracking changes from agricultural knowledge stocks to food consumption and then to caloric intake is complex. The dynamic relationship between calorie intake and body weight is even more complex, and we make some simplifications in this aspect of our analysis. An individual who loses weight will need fewer calories to maintain the lower body weight. Consequently, given a fixed reduction in daily energy intake, an individual's weight will decrease but eventually will settle at a new steady state, which can take several years to achieve. The models by Christiansen et al. (2005) and Hall et al. (2009) suggest that, starting from a steady state with body weight and caloric consumption in equilibrium, a reduction in food consumption resulting in a deficit of 100 kilocalories per day would cause a 4.7 to 7.7 pound decrease in weight over one year and a 12.8 pound decrease in steady-state weight.[13]

[13] Hall et al. (2009) suggest the formula $\Delta B_{lb} = 0.047 \times \Delta kcal$ where ΔB_{lb} denotes the change in weight measured in pounds, and $\Delta kcal$ denotes the change in daily calorie surplus (energy intake less energy expenditure) measured in kilocalories. Similar models by Christiansen et al. (2005) suggest that

Welfare Measures

In this analysis we are dealing with exogenous changes in equilibrium farm commodity prices. The underlying commodity supply functions might well be upward sloping but we are not measuring the supply shifts or associated changes in producer surplus in this analysis. Rather, we are focusing on the consumer side of the problem for which it is appropriate to take these equilibrium price changes as exogenous. In this sense, the welfare measures are partial, since a more complete analysis would also quantify the changes in producer welfare associated with the research-induced supply shifts leading to the observed changes in equilibrium prices.

We use compensating variation (CV) measures of consumer surplus (CS) to represent the costs (benefits) from the policy borne by consumers. We augment this measure of consumer welfare to include costs related to changes in public health-care expenditures induced by changes in public agricultural knowledge stocks through their effects on commodity prices and consumption. Following Okrent and Alston (2012), using the expenditure function e(.), a compensating variation measure of the change in welfare for a representative consumer is:

$$(4) \qquad \Delta CS = -\left[\mathrm{e}(\mathbf{P}^{(1)}, u^{(0)}) - \mathrm{e}(\mathbf{P}^{(0)}, u^{(0)}) \right],$$

which represents the amount of income that must be taken away from consumers, after prices change from $\mathbf{P}^{(0)}$ to $\mathbf{P}^{(1)}$, to restore the representative consumer's original utility at $u^{(0)}$ (i.e., CV). A second-order Taylor series expansion of $\mathrm{e}(\cdot)$ around $\mathbf{P}^{(0)}$ holding utility constant at $u^{(0)}$ can be used to approximate equation (4) as:

$$(5) \qquad \Delta CS \approx -\mathrm{E}\,\mathbf{P}^{\mathrm{T}}\mathbf{D}^{P}\mathbf{Q} - \frac{1}{2}\mathrm{E}\,\mathbf{P}^{\mathrm{T}}\mathbf{D}^{PQ}[\boldsymbol{\eta}^{N} + \boldsymbol{\eta}^{NM}\mathbf{w}^{\mathrm{T}}]\mathrm{E}\,\mathbf{P},$$

$\Delta B_{1yr} = \dfrac{\Delta kcal}{1.5\alpha}[1 - \exp\{-1.5\alpha\rho(365)\}]$, and $\Delta B_{ss} = \dfrac{\Delta kcal}{1.5\alpha}$, where $\alpha = 5.21$ and $\rho = 0.00032$.

where E**P** denotes a vector of proportional changes in commodity prices, $\boldsymbol{\eta}^N$ is an $N \times N$ matrix of price elasticities of demand, $\boldsymbol{\eta}^{NM}$ is an $N \times 1$ vector of elasticities of demand with respect to total expenditure, **w** is an $N \times 1$ vector of expenditure shares, $\mathbf{D}^{PQ}$ and $\mathbf{D}^{P}$ are $N \times N$ diagonal matrices with expenditures on and prices of the *n*th retail food product as a diagonal element (i.e., $P^{n(0)}Q^{n(0)}, \forall n = 1,..., N$ and $P^{n(0)}, \forall n = 1,..., N$), respectively, and superscript T denotes the transpose of a matrix.

Lastly, we augment the measure of changes in social welfare (i.e., consumer surplus) to include changes in public health-care expenditures resulting from changes in steady-state body weight. Parks, Alston and Okrent (2013) estimated that a one-unit increase in average adult BMI would increase annual public health-care expenditures by $32 per adult for a nationally representative sample, which is an increase of $5.07 per adult per year for a one-pound increase in adult body weight.[14] We apply the body-weight-to-health-care-expenditure multiplier to the change in steady-state body weight resulting from the exogenous shift in farm commodity prices, and incorporate this cost, along with consumer surplus, in our measure of the change in social welfare. The total change in public health-care expenditures (*H*) is given by:

$$(6) \qquad \Delta H = e \Delta B_{ss} \times pop$$

where *e* is the marginal increase in public health-care expenditures from a one-pound increase in steady-state body weight (from Parks, Alston and Okrent 2013), ΔB_{ss} is the change in steady-state body weight (see footnote 13) and *pop* is total adult population in the United States in 2002. The full measure of the annual change in social welfare from a policy shock that induces changes in public health-care spending, is therefore

$$(7) \qquad \Delta SW = \Delta CS - \Delta H,$$

[14] The average height for adults in the 2007-08 NHANES was 1.692 meters.

where ΔCS is the annual change in social welfare defined in (5) and ΔH is the increase in public health-care spending defined in (6).

4. Simulation Analysis and Results

As noted, the simulation model is parameterized based on data in 2002, so the simulations are best interpreted as applying in that base year, although they remain approximately valid for other years. In the simulations we consider counterfactual scenarios in which particular knowledge stocks are greater (or smaller) than the actual stocks by 10 percent—as would be consistent with a permanent 10 percent increase (or decrease) in the stream of annual research investments over the previous 50 years. We consider four counterfactual scenarios including (a) a 10 percent increase in all commodity-specific agricultural knowledge stocks, (b) a 10 percent increase in the agricultural knowledge stocks associated with specialty crops (i.e., vegetables and melons, and fruits and tree nuts), (c) a 10 percent decrease in all other agricultural knowledge stocks (i.e., including food grains and oilseeds, other crops, and the various categories of livestock products), and (d) a 10 percent increase in the agricultural knowledge stocks associated with specialty crops (i.e., vegetables and melons, and fruits and tree nuts), combined with a 10 percent decrease in all other agricultural knowledge stocks (i.e., including food grains and oilseeds, other crops, and the various categories of livestock products). Given the elasticity of –1.93, a 10 percent increase in a particular commodity-specific knowledge stock implies a 19.3 percent decrease in the price of the corresponding commodity. The simulation results are summarized in Tables 4 through 6. Appendix Tables D.1-1 through D.1-3 provide the corresponding results based on the regression results for the model estimated with undifferenced data (as reported in the upper half of Table 2), which are presented to illustrate the sensitivity of findings to the econometric specification.

Table 4 shows the proportional changes in prices and quantities consumed for each food category as a result of the simulated 10 percent changes in various commodity-specific knowledge stocks and associated 19.3 percent changes in prices of the farm commodities. All of the induced food-price changes in column (1), reflecting increases in all of the knowledge stocks, are comparatively small—well less than 10 percent (except for eggs, fruits and vegetables, and meats) reflecting the generally small shares of farm commodities in the food products they are used to produce. The consequent proportional changes in consumption are even smaller in magnitude, reflecting the generally inelastic demands for foods; but they are also of mixed signs reflecting the consequences of changes in relative prices and substitution responses as well as own-price effects. In particular, even though the prices of all food categories have fallen, consumption falls for cereals and bakery, FAFH, nonalcoholic beverages, and alcoholic beverages. The consumption changes in columns (2), (3) and (4) show even more mixed patterns reflecting the effects of changes in relative prices of farm commodities in addition to the types of changes in column (1). In column (4), in particular, with a 19.3 percent decrease in prices of specialty crops (fruits, tree nuts, vegetables and melons) and a 19.3 percent increase in prices of all other farm commodities, consumption falls for all food categories except eggs, fruits and vegetables, and alcoholic beverages.

[Table 4. *Projected Commodity Prices and Consumption under Alternative R&D Scenarios*]

The corresponding changes in daily caloric intake are generally small, reflecting the net effect of small percentage increases or decreases in consumption of individual food categories. A 10 percent increase in all of the knowledge stocks (column 1 of Table 5) would give rise to a 13.70 kcal per day increase in average caloric intake per adult, which translates to an increase in steady-state body weight by 1.75 lb (1.05 lb after one year). A 10 percent increase in the knowledge stock just for specialty crops (column 2 of Table 5) would give rise to an increase in steady-state body weight by 0.50 lb (0.30 lb after one year) while a 10 percent decrease in the knowledge stock for all other farm products (column 3 of Table 5) would give rise to a decrease in steady-state body weight by 1.25 lb (0.75 lb after one year). Combining the 10 percent increase in the knowledge stock just for specialty crops with a 10 percent decrease in the knowledge stock for all other farm commodities (column 4 of Table 5) would give rise to a decrease in steady-state body weight by 0.75 lb (0.45 lb after one year). All of these effects are comparatively modest.

[Table 5. *Projected Changes in Daily Calorie Consumption and Steady-State Body Weight*]

The net welfare effects in row (3) of Table 6 are dominated by the impacts on consumer surplus in row (2), which are almost an order of magnitude larger than the partially offsetting impacts on public health-care expenditures in row (1). Consequently the consumer benefits from lower prices, associated with an increase in the agricultural knowledge stocks, much more than outweigh the taxpayer costs resulting from the small induced increases in food consumption and obesity.

[Table 6. *Changes in Social Welfare and Obesity-Related Health-Care Expenditures*]

The last two rows of Table 6 show the changes in social welfare associated with the simulated changes in the agricultural knowledge stocks expressed per pound of induced change in steady-state U.S. average adult body weight. These ratios are all positive, reflecting the fact that policies that would induce an increase in welfare also would induce an increase in body weight. The entries can be interpreted as a measure of the marginal social cost per pound to induce a decrease in body weight by *reducing* agricultural knowledge stocks by 10 percent for all commodities (column 1), for just specialty crops (column 2), for all commodities except specialty crops (column 3), and for all commodities except specialty crops while increasing knowledge stocks for specialty crops (column 4). It is only a partial measure of marginal cost because it does not count the consequences for producers, who would forego substantial benefits if agricultural knowledge stocks were reduced, and does not count the associated saving in costs of public research expenditures. Even so, the measures here are interesting, and indicate that to reduce body weight using this approach would cost consumers in the range of $60 to $100 per pound, which would be only partially offset by savings in public health-care costs of about $5 per pound. This is a comparatively expensive way to reduce obesity. For comparison, Okrent and Alston (2012) estimated that taxes on the caloric content of food would cost consumers $0.86 per pound reduction in body weight.

An alternative counterfactual experiment is to consider the consequences if agricultural knowledge stocks were to revert to their values in 1980. To analyze this case we conduct a simulation using the proportional changes in prices shown in column (5) of Table 3. This analysis entails much larger shifts and a bigger extrapolation compared with the 10 percent shifts just considered. The results are reported in column (5) in Tables 4 through 6.

In Table 4, column (5), reverting to the 1980 public commodity-specific knowledge stocks in 2004 would imply wide-ranging increases in food prices. Modest price increases (less than 10 percent) would be implied for alcoholic and nonalcoholic beverages, cereals and bakery, and food away from home; more substantial increases (around 15 to 25 percent) would be implied for dairy and other foods; and quite large increases (around 70 percent) would be implied for meats, eggs, and fruits and vegetables. The corresponding simulated changes in consumption include 8–15 percent increases for three categories (cereals and bakery, food away from home, and alcoholic beverages) and decreases for the other six categories (especially meats, fruits and vegetables, and other foods). A reversion to 1980 knowledge stocks would thus imply a relative increase in consumption of less-healthy categories of food, in addition to changes in total consumption, discussed next.

In Table 5, column (5), reverting to the 1980 public commodity-specific knowledge stocks in 2004 would imply wide-ranging changes in caloric intake from different categories of food in response to the simulated changes in food prices, reflecting both differences in percentage changes in quantities consumed and differences in energy density. The largest increases in caloric consumption are for cereals and bakery, food away from home, and alcoholic beverages, and the largest decreases are for meats, fruits and vegetables, and other foods. The net impact would imply a decrease in adult daily caloric intake by 85 kcal, and a reduction in steady-state body weight of 10.9 lb per adult American (6.5 lb in one year after the change).

The welfare implications are summarized in column (5) of Table 6. Reverting to the 1980 public commodity-specific knowledge stocks in 2004 would have resulted in a loss to consumers of $223.9 billion, which would be partially offset by a saving to taxpayers of $12.4 billion in public health-care costs. The reduction in average U.S. adult body weight by 10.9 lb would cost consumers $92 per pound and would cost the nation $87 per pound after the savings in public health-care costs are taken into account. Recall, these are only partial measure of the total economic impact because they do not take into account either the taxpayer costs of funding public agricultural R&D or the producer benefits from adopting the innovations that gave rise to the equilibrium commodity price changes modeled here.

5. Conclusion

Various studies have made one or both of two claims about agricultural R&D and obesity: first, that public agricultural R&D has contributed to the obesity epidemic by making food commodities cheaper; second, that the balance of public agricultural R&D spending shouild be tilted to favor healthier foods, such as fruits and vegetables. The analysis in this paper confirms the first claim but questions the second.

Our regression models of commodity prices indicate that public agricultural R&D contributed significantly to the large real decline in commodity prices between 1980 and 2004. Indeed, in our preferred model growth in the agricultural knowledge stock accounted for well more than 100 percent of the decline in prices for most commodity groups and for the index of aggregate farm output, which means that, in the absence of the increases in the knowledge stocks, prices would have risen rather than falling as they did.

Even so, the implications for obesity are relatively modest. Using a multimarket simulation model we found that the large commodity price increases implied by reverting in 2004 to the 1980 knowledge stock would imply a decrease in caloric intake (85 kcal per adult per day) and in steady-state body weight (10.9 lb per adult American). This would be a costly reversion. It would cost consumers $224 billion of which only $12.4 billion would be offset by savings in public health-care costs to reduce average U.S. adult body weight by 10.9 lb. This translates to $87 per pound after the savings in public health-care costs are taken into account. The costs per pound are very similar for an alternative experiment in which we simulate a 10 percent increase in knowledge stocks for specialty crops (consistent with a 10 percent increase in research spending over the previous 50 years combined with a 10 percent decrease in all other knowledge stocks) but the total effects on obesity are very small (0.74 lb per adult reduction in body weight). The estimated impacts would be even smaller if we had used elasticities from our alternative regression results based on undifferenced data.

These results may seem surprising. They follow from two basic facts about the food market complex. First, farm commodities represent a variable but generally small fraction of the cost of retail food. A price increase of 100 percent for a farm commodity implies a much smaller increase in retail food cost—typically in the range of 20 percent, but in many cases much less. Second, the demand for individual food categories is typically inelastic. Compounding the role of inelastic demand, consumption responses will be damped further if prices of subsitututes rise together, as happens when the prices of ingredients increase.

The implication is that agricultural R&D policy is unlikely to be an effective policy instrument for reducing obesity, both because the effects are small and because it takes a very long time, measured in decades, for changes in research spending to have their main effects on commodity prices. Moreover, as our results and others have shown, the opportunity cost of reducing agricultural research spending, in the hope of eventually reducing the social costs of obesity, would be very high because agricultural research yields a very large social payoff.

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Appendix A
Data for the Analysis

A.1 Backcasting Public Agricultural Research Expenditure

We estimated commodity-specific total agricultural R&D expenditures using linear predictions based on the following basic model:

$$\text{(A.1-1)}\quad \frac{AgRD_{l,t}}{AgRD_t} = \beta_0 + \beta_1 AgRD_t + \beta_2 FED_t + \beta_3 SL_t + \beta_4 GDP_t + \beta_5 AgVal_{l,t} + \varepsilon_{l,t}\,,$$

where, in year *t*, $AgRD_{l,t}$ is public agricultural research expenditures for commodity *l*, $AgRD_t$ total public agricultural research expenditures, FED_t is federal spending on nondefense, SL_t is state and local spending, GDP_t is real gross domestic product per capita, and $AgVal_{l,t}$ is the value of production of commodity *l*, with all of the monetary values in 2009 dollars.

Data on the R&D variables are from two data sources. The commodity-specific R&D expenditures are based on the Current Research Information System (CRIS), which compiles expenditure data by U.S. Department of Agriculture (USDA) research agencies, State Agricultural Experiment Stations (SAES), Forestry Schools, 1890 Universities and Tuskegee University, Colleges of Veterinary Medicine, and other cooperating institutions. These data are available from 1970 to 2009 but we use the data from 1975 forward because of data integrity issues. The data are organized into 10 commodity-specific categories (oilseeds, fruits and tree nuts, vegetables and melons, meat animals, poultry and eggs, other crops including peanuts, milk, fish and grains) and 2 non-commodity-specific categories (farm-related expenditures, which includes soil, land, rangeland, insects, fertilizer and pesticide, drainage and irrigation, remote sensing equipment, seed research, and non-farm expenditures). The total public agricultural research expenditure data are from AAJP (2010) and are available from 1889 to 2009. The nominal values are expressed in 2009 dollars using a deflator for public agricultural research expenditures, developed by Pardey, Chan-Kang and Anderson (in preparation).

We use the National Income and Product Accounts (USDC-BEA 2012) for the *FED*, *SL* and *GDP* variables (see Table A-1 for more details), and these data are available from 1929 to the present. The US and State Farm Income and Wealth Statistics (USDA-ERS 2012c) reports cash receipts received by farmers for commodities between 1924 and 2011 which we use as a proxy for the $AgVal_l$ variables. The share of total public research expenditure on non-commodity-specific R&D expenditures is modeled as

$$\text{(A.1-2)}\ \frac{AgRD_{ncs,t}}{AgRD_t} = \beta_0 + \beta_1 AgRD_t + \beta_2 FED_t + \beta_3 SL_t + \beta_4 GDP_t + \beta_5 AgVal_t + \varepsilon_{ncs,t}\,,$$

where $AgRD_{ncs}$ is public non-commodity-specific agricultural research expenditures and $AgVal_t$ is the total value of all agricultural output at time t reported in the National Income and Product Accounts. The nominal values are expressed in 2009 dollars using the GDP implicit price deflator.

We estimate the coefficients in (A.1-1) and (A.1-2) using the data summarized in Table 1 from 1975 to 2009 and ordinary least squares (OLS). Across these OLS regressions, the adjusted R^2 values range between 0.47 for sugar and 0.98 for fish. We then use the explanatory variables between 1929 and 2009 and the estimated coefficients in (A.1-1) and (A.1-2) to predict the share of total public research expenditure on each of the 12 commodity-specific and non-commodity-specific categories:

$$\text{(A.1-3)}\quad \hat{w}_{l,t} = \hat{\beta}_0 + \hat{\beta}_1 AgRD_t + \hat{\beta}_2 FED_t + \hat{\beta}_3 SL_t + \hat{\beta}_4 GDP_t + \hat{\beta}_5 AgVal_{l,t}\,,$$

where $\hat{w}_{l,t}$ is the predicted share of total public agricultural research spending on category i in year t = 1929,…, 2009 and $\hat{\beta}_0 - \hat{\beta}_5$ are OLS coefficients from (A.1-1) and (A.1-2). Since the predicted shares do not sum to one in a given year, we rescale the shares to enforce additivity:

$$\text{(A.1-4)}\quad \hat{w}^R_{l,t} = \frac{\hat{w}_{l,t}}{\sum_i \hat{w}_{l,t}}\,.$$

Applying the predicted and rescaled shares in (A.1-4) to $AgRD$, we first estimate commodity- and non-commodity-specific expenditures for the period 1929–2009. We then partition the non-commodity-specific farm-related expenditures among the commodity categories based on the their predicted shares of total public research expenditure:

$$\text{(A.1-5)}\quad Ag\hat{R}D_{l,t} = \hat{w}^R_{l,t} AgRD + \hat{w}^R_{l,t} Ag\hat{R}D_{ncs,t}\,,$$

where l denotes the commodity-specific categories and $Ag\hat{R}D_{ncs,t}$ is predicted total expenditures for non-commodity-specific farm-related public research spending.

Figure A.1-1 panels a–j compares the actual (dashed line) with the predicted (solid line) commodity- and non-commodity specific public agricultural R&D spending. Each panel also includes the mean absolute percentage error (MAPE) for out-of-sample forecasts based on data excluded from estimation, e.g., years 1970 and 1974, and in-sample forecasts. The in-sample mean absolute percentage errors between the predicted and actual expenditures are between 4 and 12 percent. The out-of-sample percentage errors are higher, ranging between 5 and 31 percent.

A. 2 Estimation of Knowledge Stocks

Following AAJP (2010, 2011) we characterized the relationship between the commodity-specific annual knowledge stock, $K_{l,t}$, as a function of (a) the overall lag length, L_R, (b) a set of lag weights from a gamma lag distribution, b_j, (c) commodity specific R&D expenditures, $AgRD_{l,t}$, and (d) parameters that determine the shape of the gamma distribution, δ and λ. That is,

(A.2-5) $$K_{l,t} = \sum_{j=0}^{L_R} b_j AgRD_{l,t-j},$$

(A.2-6) $$b_j = \begin{cases} \dfrac{(k+1)^{\frac{\delta}{1-\delta}} \lambda^{k-g}}{\sum_{j=0}^{L_R} \left[(k+1)^{\frac{\delta}{1-\delta}} \lambda^{k-g} \right]}, & \text{if } L_R \geq k > 0, \\ 0, & \text{otherwise.} \end{cases}$$

Appendix A.1 describes our procedure for backcasting the agricultural R&D expenditure data which we used in equation (A.2-5) with L_R = 50 years, along with specific values of δ and λ that represent the preferred lag distribution shape.

Table A.1-1. *Summary Statistics of Explanatory Variables and Sources of Data*

	Mean	Standard Deviation	Min	Max	Source
	Millions of Dollars (2009 real values)				
Federal nondefense expenses (*FED*)	132,514	95,570	8,255	367,600	Government consumption expenditures, 1929-2009 (table 3.9.5, USDC-BEA 2012b)
State and local expenditures (*SL*)	623,980	523,883	78,427	1,823,600	Government consumption expenditures, 1929-2009 (table 3.9.5, USDC-BEA 2012b)
GDP per capita (*GDP*)	24,392	12,281	6,237	47,945	Gross domestic product, 1929-2009 (table 1.1.5, USDC-BEA 2012b)
Total public spending on agricultural R&D (*AgRD*)	2,928	1,548	704	5,249	Total public agricultural R&D and extension (excl. forestry), 1929-2009 (appendix table 6.1, Alston et al. 2010)
Total agricultural output (*AgVal*)	233,731	63,915	79,810	355,417	Farm sector output, 1929-2009 (table 7.3.5, USDC-BEA 2012b)
Cash receipts ($AgVal_l$)					Cash receipts by commodity groups and selected commodities, 1929-2009 (table 5, USDA-ERS 2012c)
Dairy	27,947	5,634	13,338	37,918	
Fish[a]	442	434	77	1,258	
Fruit/tree nuts	11,783	3,804	4,472	19,407	
Food grains	13,162	5,602	2,961	30,624	
Meat animals	63,989	20,707	15,665	117,777	
Oilseeds (excl. peanuts)	13,412	9,708	213	34,784	
Other crops (incl. peanuts)	1,288	566	201	2,419	
Poultry/eggs	21,130	6,450	7,019	37,111	
Sugar cane/beets	2,222	1,105	717	7,255	
Vegetables/melons	14,153	4,303	4,844	20,389	

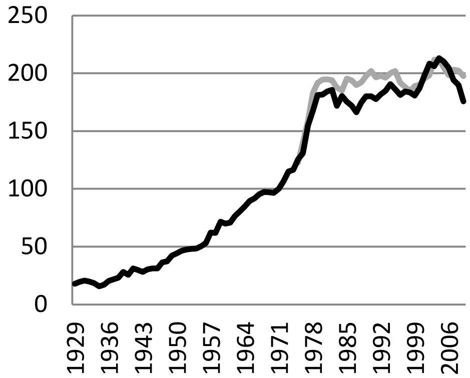
Notes: Cash receipts, total agricultural output, GDP per capita, federal nondefense and state and local expenditures are deflated by implicit price deflator for GDP (USDC-BEA 2012b). Total public spending on agricultural R&D is deflated by index for agricultural R&D developed by Pardey, Chan-Kang and Andersen (in preparation).

[a] Cash receipts for the fish commodity group are only available from 1950 onward.

Figure A.1-1. *Comparison of Predicted and Actual Public Investments in Agricultural R&D, 1929–2009*

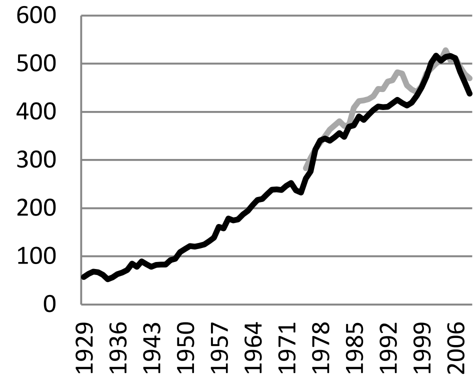
Million dollar (2009=100)

Panel a. *Oilseeds*



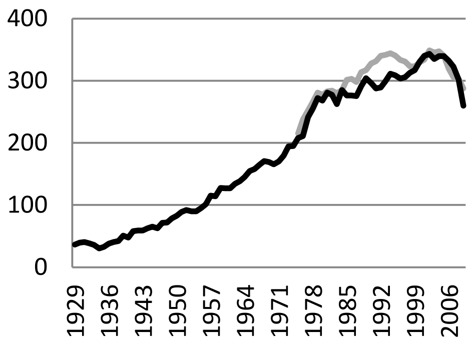
MAPE (in sample) = 5.7
MAPE (out of sample) = 26.6

Panel b. *Food grains*



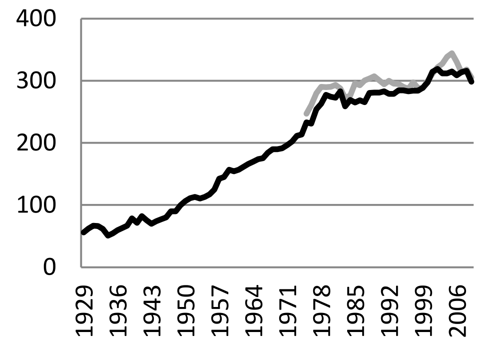
MAPE (in sample) = 5.6
MAPE (out of sample) = 17.6

Panel c. *Vegetables and melons*



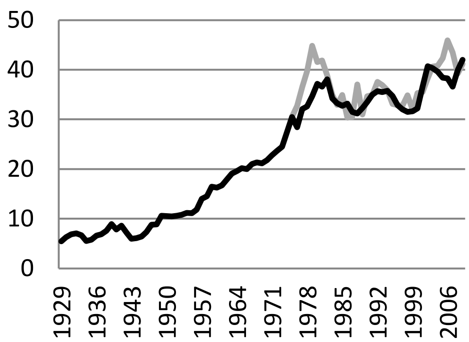
MAPE (in sample) = 5.6
MAPE (out of sample) = 9.0

Panel d. *Fruits and tree nuts*



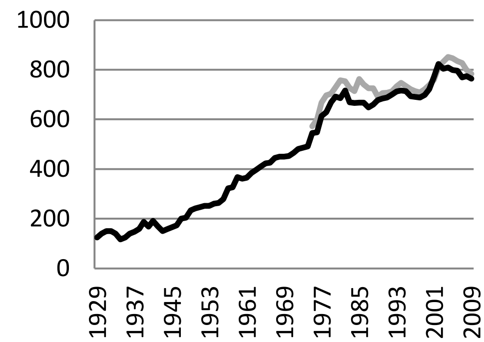
MAPE (in sample) = 5.5
MAPE (out of sample) = 16.2

Panel e. *Sugar*



MAPE (in sample) = 6.6
MAPE (out of sample) = 26.5

Panel f. *Other crops*



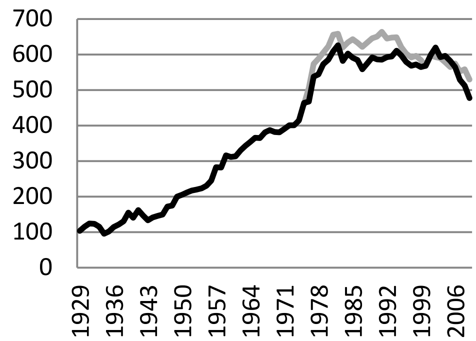
MAPE (in sample) = 5.3
MAPE (out of sample) = 16.3

Predicted Actual

Figure A.1-1. *Comparison of Predicted and Actual Public Investments in Agricultural R&D, 1929–2009 (continued)*

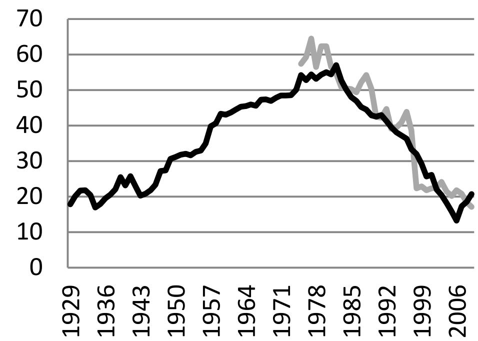
Million dollar (2009=100)

Panel g. *Meat animals*



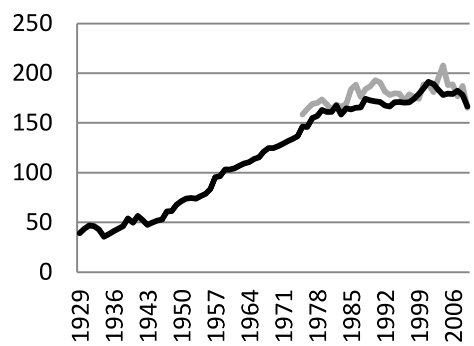
MAPE (in sample) = 4.8
MAPE (out of sample) = 5.5

Panel h. *Milk*



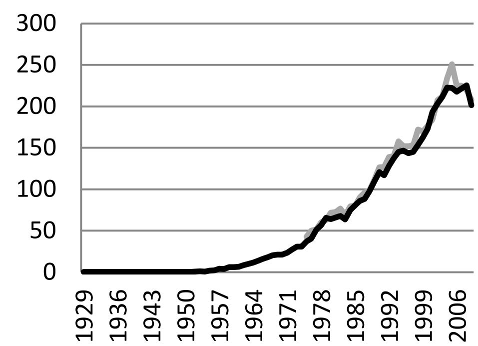
MAPE (in sample) = 12.0
MAPE (out of sample) = 31.1

Panel i. *Poultry and eggs*



MAPE (in sample) = 5.9
MAPE (out of sample) = 15.4

Panel j. *Fish*



MAPE (in sample) = 6.0
MAPE (out of sample) = 13.4

Predicted   Actual

Source: Authors' calculations.

Appendix B

Models Linking Commodity and Retail Food Markets, Obesity and Welfare Measures

B.1 The Market Equilibrium Model

In the equilibrium displacement model developed by Okrent (2010) the market equilibrium is expressed in terms of N demand equations for food products, N total cost equations for food product supply, L supply equations for input commodities and $L \times N$ equations for competitive market clearing:

(B.1-1) $$Q^n = \mathrm{Q}^n(\mathbf{P}, A^n), \forall n = 1,.., N,$$

(B.1-2) $$P^n = \mathrm{c}^n(\mathbf{W}), \forall n = 1,.., N,$$

(B.1-3) $$X_l = \sum_{n=1}^{N} \mathrm{g}_l^n(\mathbf{W})Q^n, \forall l = 1,..., L,$$

(B.1-4) $$X_l = \mathrm{f}_l(\mathbf{W}, B_l), \forall l = 1,.., L.$$

Equation (B.1-1) represents the demand for nth food product in which the quantity demanded, Q^n, is a function of an $N \times 1$ vector of product prices, $\mathbf{P}$, and an exogenous demand shifter, A^n. Equation (B.1-2) is based on the assumption of constant returns to scale at the product industry level and competitive market equilibrium, where the price of the nth product is set equal to the marginal cost of producing product n, $\mathrm{c}^n(\mathbf{W})$, which is a function of an $L \times 1$ vector of commodity prices, $\mathbf{W}$. Equation (B.1-3) is the Hicksian demand for commodity l, X_l, which is derived from applying Shephard's lemma to the total cost functions of the N products (i.e., $\partial C^n / \partial W_l = \mathrm{g}_l^n(\mathbf{W})Q^n$), and then summing across the N product industry demands for commodity l. Equation (B.1-4) is the supply function for commodity l, which is a function of all of the commodity prices and an exogenous supply shifter, B_l.

Totally differentiating equations (B.1-1) to (B.1-4), and converting to elasticity form yields equations for proportionate changes in quantities and prices of retail products (i.e., $\mathrm{E}Q^n = \mathrm{d}Q^n/Q^n$ and $\mathrm{E}P^n = \mathrm{d}P^n/P^n$ where d is the total differential operator) and farm commodities (i.e., $\mathrm{E}X_l = \mathrm{d}X_l/X_l$ and $\mathrm{E}W_l = \mathrm{d}W_l/W_l$) in equations (B.1-5) to (B.1-8):

(B.1-5) $\quad \mathrm{E}\,Q^n = \sum_{k=1}^{N} \eta^{nk}\,\mathrm{E}\,P^k + \alpha^n, \forall n = 1,..,N,$

(B.1-6) $\quad \mathrm{E}\,P^n = \sum_{l=1}^{L} \frac{\partial \mathrm{c}^n(\mathbf{W})}{\partial W_l} \frac{W_l}{P^n} \mathrm{E}\,W_l, \forall n = 1,..,N,$

(B.1-7) $\quad \mathrm{E}\,X_l = \sum_{n=1}^{N} SC_l^n \sum_{m=1}^{L} \left(\eta_{lm}^{n*}\,\mathrm{E}\,W_m + \mathrm{E}\,Q^n \right), \forall l = 1,...,L,$

(B.1-8) $\quad \mathrm{E}\,X_l = \sum_{j=1}^{L} \varepsilon_{lj}\,\mathrm{E}\,W_j + \beta_l, \forall l = 1,...,L,$

where $\boldsymbol{\eta}^{nk}$ is the Marshallian elasticity of demand for retail product *i* with respect to retail price *k*, SC_l^n is the share of the total cost of commodity *l* used in the production of retail product *n* (farm commodity use share), $\boldsymbol{\eta}_{lm}^{n*}$ is the Hicksian elasticity of demand for commodity *l* in industry *n* with respect to commodity price *m*, $\boldsymbol{\varepsilon}_{ij}$ is the elasticity of supply of commodity *l* with respect to commodity price *j*, $\boldsymbol{\alpha}^n$ is the proportional shift of demand for retail product *n* in the quantity direction, and $\boldsymbol{\beta}_l$ is the proportional shift of supply of commodity *l* in the quantity direction. Since $\partial\, \mathrm{c}^n(\cdot) / \partial W_l = X_l^n / Q^n$, equation (B.1-6) can be rewritten as

(B.1-9) $\quad \mathrm{E}\,P^n = \sum_{l=1}^{L} SR_l^n\,\mathrm{E}\,W_l, \forall n = 1,..,N,$

where $SR_l^n = X_l^n W_l / P^n Q^n$ and is the share of total cost for retail product *n* attributable to commodity *l* (farm-retail cost share). Second, the share-weighted Hicksian elasticity of demand for commodity *l* with respect to the price of commodity *m* is

(B.1-10) $\quad \eta_{lm}^{*} = \sum_{n=1}^{N} SC_l^n \eta_{lm}^{n*}.$

Equation (B.1-7) can be rewritten using (B.1-16):

(B.1-11) $\quad \mathrm{E}\,X_l = \sum_{m=1}^{L} \eta_{lm}^{*}\,\mathrm{E}\,W_m + \sum_{n=1}^{N} SC_l^n\,\mathrm{E}\,Q^n, \forall l = 1,...,L.$

Furthermore, assuming fixed factor proportions, the Hicksian elasticity of demand between two factor inputs *l* and *j* in product *n* is zero (i.e., $\eta_{lj}^{n*} = 0$, $\forall\ l,j = 1, ..., L$, $\forall\ n = 1, ..., N$), which implies:

(B.1-12) $\quad \mathrm{E}\,X_l = \sum_{n=1}^{N} SC_l^n\,\mathrm{E}\,Q^n, \forall l = 1,...,L.$

Lastly, under the assumption of exogenous commodity prices (i.e., $\varepsilon_{ll} \rightarrow \infty$), B, B, (B.1-8) becomes (B.1-8) becomes

(B.1-13) $\quad -\mathrm{E}W_l = \beta_l, \forall l = 1,...,L$,

where β_l is a proportionate shift in supply of commodity *l* in the price direction. This model is parameterized using data as described in the next section, and solved using linear algebra methods to evaluate the effects of various exogenous price change scenarios as discussed in the text.

B.2 Parameterization of the Market Equilibrium Model

Since we are primarily concerned with the effects of a farm commodity policy on prices and consumption of retail food products ($\boldsymbol{\beta} > 0$, $\boldsymbol{\alpha} = 0$) we only need data to parameterize (a) a matrix of elasticities of demand for retail products, $\boldsymbol{\eta}^N$, and (b) farm-retail cost shares, **SR**. The elasticities of demand for food products are from Okrent and Alston (2011). They estimated the National Bureau of Research (NBR) model (Neves 1987) with annual Personal Consumption Expenditures and Fisher-Ideal price indexes from 1960 to 2009 (U.S. Department of Commerce, Bureau of Economic Analysis 2010). They evaluated these elasticities and preferred them compared with those from other models they estimated (that were dominated statistically by the NBR model) and compared with others from the literature.

The farm-retail product shares are from Okrent and Alston (2012) who estimated **SR** using the Detailed Use Table (after redefinitions) from the 2002 Benchmark Input-Output (I-O) Accounts (U.S. Department of Commerce, Bureau of Economic Analysis 2007). The Detailed Use Table shows the use of farm commodities, retail products, and services by different industries (intermediate input use) and final users (personal consumption, net imports, private fixed investment, inventories, and government).

Appendix C

Models Linking Total Agricultural Product Prices and Knowledge Stocks

We implemented the model in equation (1) at the national level by using a national public agricultural knowledge stock in place of the commodity specific knowledge stocks but otherwise keeping the model the same. The knowledge stock variable, K_t, is based on research source-specific (e.g., state SAEA or USDA intramural) spending data deflated by a research deflator series from AAJP (2010).

We computed the knowledge stock variable by applying the gamma lag distribution weights from the preferred model of AAJP (2011) to data on source-specific public research spending. With this lag distribution, a total of 50 years of lagged research affect current productivity and prices, although the effects are small after 40 years, with a peak impact after 24 years. To estimate such a model requires long time-series. The United States Department of Agriculture (USDA) compiles detailed data on public research spending by the 50 State Agricultural Experiment Stations (SAESs) and by the USDA itself in its intramural research.

Useful data were available to us for the years 1949 through 2009 (AAJP 2010 Appendix Tables 4-3 and 6-1). We used source-specific public research spending to construct knowledge stocks for the 38-year period 1969–2004. This period includes the volatile 1970s, with a large spike in commodity prices in 1973 and 1974 that was not related to U.S. farm productivity. We tried models that included the early years, with dummy variables for 1973 and 1974, and for a shorter 25-year period, 1980–2004, that did not include the influence of either the 1970s price spike or the more-recent price spike in 2008.

The results using data for 1980–2004, excluding the time-trend variable, are reported in Table C.1-1 and the results for the first-difference model are reported in Table C.1-2. In the model with undifferenced data, the elasticity of the agricultural output price with respect to the source-specific knowledge stocks ranges from –2.17 to –0.91, depending on the source of R&D funds and knowledge stock, and is statistically different from zero at the 1 percent level of significance. In the first-difference double-log model the elasticity of agricultural output price with respect to the source-specific knowledge stocks ranges from –5.76 to –1.60, depending on the source of R&D funds and knowledge stock, but is not statistically different from zero at the 10 percent level of significance.

Table C.1-1. *Double-Log Model of Agricultural Output Price Index*

Regressors	(1)	(2)	(3)	(4)	(5)
Knowledge Stock					
State SAES	-1.39**				
	(0.17)				
Total SAES (excluding forestry)		-0.91**			
		(0.14)			
USDA IM			-2.17**		
			(0.30)		
Total public agricultural R&D[a]				-1.19**	
				(0.16)	
Total public agricultural R&D and extension[a]					-1.27**
					(0.18)
Other Regressors					
Crude oil price	0.15*	0.17*	0.05	0.16*	0.16*
	(0.06)	(0.07)	(0.06)	(0.06)	(0.07)
Range and pasture index	-0.00	-0.00	-0.00	-0.00	-0.00
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Marketing index	-1.96*	-1.16	-2.59*	-1.60	-1.56
	(0.78)	(0.82)	(0.92)	(0.81)	(0.84)
Constant	19.34**	12.95*	26.90**	17.50**	18.47**
	(4.88)	(4.91)	(6.28)	(5.13)	(5.44)
Observations	25	25	25	25	25
R^2	0.93	0.91	0.92	0.92	0.92

[a] Excludes forestry.
Standard errors in parentheses. ** p<0.01, * p<0.05

Table C.1-2. *First-Difference Double-Log Model of Agricultural Output Price Index*

Regressors	(1)	(2)	(3)	(4)	(5)
Knowledge Stock					
State SAES	-2.70				
	(1.40)				
Total SAES (excluding forestry)		-5.76			
		(3.32)			
USDA IM			-1.60		
			(0.94)		
Total public agricultural R&D[a]				-3.25	
				(1.83)	
Total public agricultural R&D and extension[a]					-3.58
					(2.18)
Other Regressors					
Crude oil price	0.06	0.05	0.06	0.05	0.06
	(0.05)	(0.05)	(0.05)	(0.05)	(0.05)
Range and pasture index	-0.00	-0.00	-0.00	-0.00	-0.00
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Marketing index	-1.15	-0.77	-1.22	-1.09	-1.19
	(1.16)	(1.15)	(1.20)	(1.17)	(1.21)
Constant	0.03	0.15	-0.00	0.05	0.05
	(0.04)	(0.10)	(0.02)	(0.05)	(0.05)
Observations	24	24	24	24	24
R^2	0.28	0.26	0.26	0.27	0.25
Durbin-Watson d-stat	1.93	1.87	1.90	1.91	1.88

[a] Excludes forestry.

Standard errors in parentheses. ** p<0.01, * p<0.05

Appendix D:
Fragility Analysis—Welfare Measures for the Undifferenced Model

Table D.1-1. *Projected Changes in Prices and Consumption under Alternative R&D Scenarios*

	Change in Selected Commodity Knowledge Stock				
	10% increase for all commodities (1)	10% increase for specialty crops (2)	10 % decrease for all except specialty crops (3)	10% increase for specialty crops, 10% decrease for all others (4)	Revert to 1980 Knowledge Stock (5)
Percentage Change in Price			*percentage*		
FAH					
Cereals and bakery	-0.38	-0.01	0.37	0.35	2.81
Meats	-2.31	0.00	2.31	2.31	21.10
Eggs	-3.77	0.00	3.77	3.77	20.57
Dairy	-1.53	-0.01	1.52	1.51	4.25
Fruits and vegetables	-2.67	-2.63	0.04	-2.59	19.73
Other foods	-0.95	-0.19	0.76	0.57	7.59
Nonalcoholic beverages	-0.18	-0.16	0.02	-0.14	1.15
FAFH	-0.26	-0.02	0.24	0.22	2.26
Alcoholic beverages	-0.22	-0.12	0.10	-0.01	1.51
Percentage Change in Consumption			*percentage*		
FAH					
Cereals and bakery	-0.70	-0.40	0.30	-0.10	4.35
Meats	0.30	-0.42	-0.71	-1.13	-4.21
Eggs	1.05	1.31	0.26	1.57	-3.33
Dairy	1.01	0.15	-0.86	-0.71	-1.67
Fruits and vegetables	1.15	1.54	0.39	1.94	-6.34
Other foods	1.04	0.40	-0.64	-0.24	-9.43
Nonalcoholic beverages	-0.22	-0.25	-0.04	-0.29	-0.87
FAFH	-0.20	-0.13	0.07	-0.06	2.26
Alcoholic beverages	-0.41	0.11	0.52	0.63	3.38

Notes: "Knowledge stocks" here refers to public agricultural knowledge stocks for farm commodities. "Specialty crops" here include fruits, tree nuts, vegetables and melons. Analysis based on logarithmic model of commodity prices and knowledge stocks.

Table D.1-2. *Changes in Daily Calorie Consumption and Steady-State Body Weight under Alternative R&D Scenarios*

	Change in Selected Commodity Knowledge Stock				Revert to 1980 Knowledge Stock
	10% increase for all commodities	10% increase for specialty crops	10 % decrease for all except specialty crops	10% increase for specialty crops, 10% decrease for all others	
	(1)	(2)	(3)	(4)	(5)
Daily Change in Per Capita Caloric Intake (kcal) by Food Category					
FAH					
Cereals and bakery	-2.48	-1.42	1.06	-0.36	15.32
Meats	0.45	-0.63	-1.07	-1.70	-6.34
Eggs	0.29	0.36	0.07	0.43	-0.92
Dairy	1.97	0.29	-1.68	-1.38	-3.26
Fruits and vegetables	1.61	2.17	0.56	2.72	-8.91
Other foods	4.16	1.61	-2.55	-0.94	-37.74
Nonalcoholic beverages	-0.35	-0.42	-0.06	-0.48	-1.43
FAFH	-1.43	-0.92	0.51	-0.41	16.56
Alcoholic beverages	-0.29	0.08	0.38	0.46	2.44
Daily Change in Total Per Capita Caloric Consumption and Body Weight					
Consumption (kcal)	3.92	1.13	-2.79	-1.67	-24.29
Body weight (lb)					
One year	0.30	0.09	-0.21	-0.13	-1.86
Steady-state	0.50	0.14	-0.36	-0.21	-3.11

Notes: "Knowledge stocks" here refers to public agricultural knowledge stocks for farm commodities. "Specialty crops" here include fruits, tree nuts, vegetables and melons. Analysis based on logarithmic model of commodity prices and knowledge stocks.

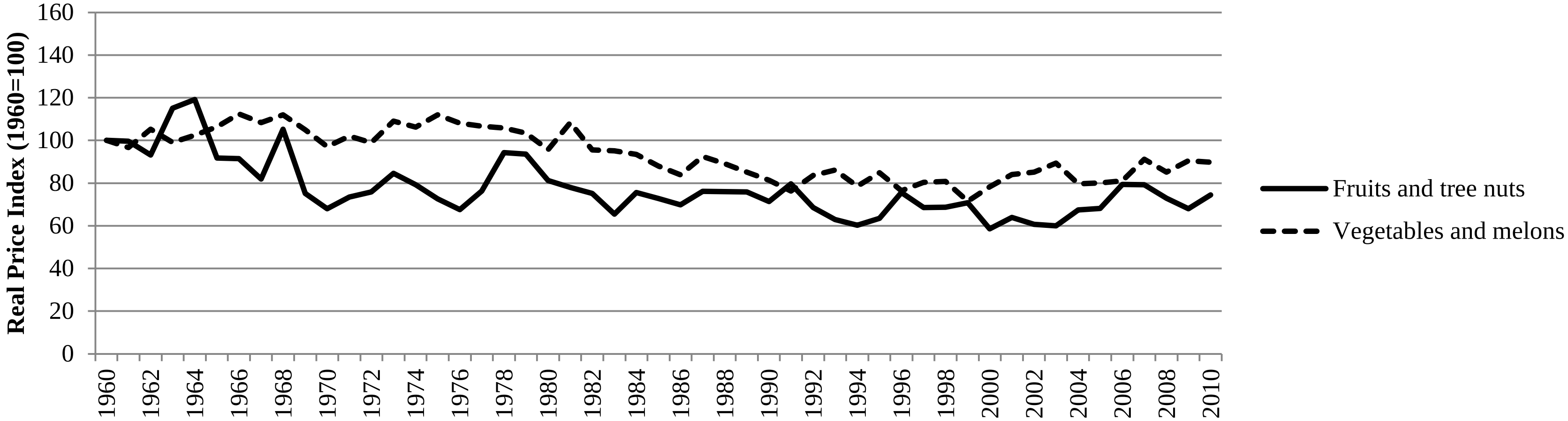
Table D.1-3. *Changes in Social Welfare and Obesity-Related Health-Care Expenditures*

	Change in Selected Commodity Knowledge Stock				Revert to 1980 Knowledge Stock
	10% increase for all commodities	10% increase for specialty crops	10 % decrease for all except specialty crops	10% increase for specialty crops, 10% decrease for all others	
	(1)	(2)	(3)	(4)	(5)
Change in Public Health-Care Costs (ΔH), millions of dollars per year					
	569	164	-405	-242	-3,523
Change in Social Welfare (ΔSW), millions of dollars per year					
Excluding ΔH	8,231	1,921	-6,317	-4,382	-63,716
Including ΔH	7,662	1,758	-5,912	-4,141	-60,192
Change in Steady-State Body Weight for U.S. Adults					
Millions of pounds	112	32	-80	-48	-695
Pounds per capita	0.50	0.14	-0.36	-0.21	-3.11
Cost per Pound Decrease in Body Weight, dollars per pound					
Excluding ΔH	73.32	59.48	79.00	91.95	91.67
Including ΔH	68.23	54.41	73.93	86.88	86.60

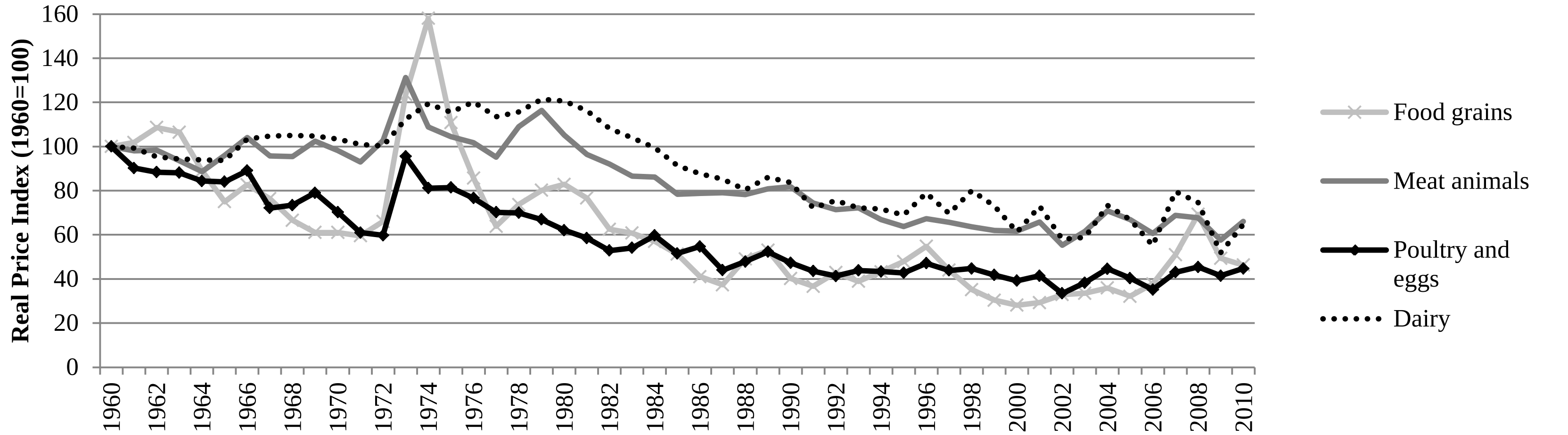
Notes: "Knowledge stocks" here refers to public agricultural knowledge stocks for farm commodities. "Specialty crops" here include fruits, tree nuts, vegetables and melons. Analysis based on logarithmic model of commodity prices and knowledge stocks. The total adult population in 2002 was 223,631,174 (USDC-Census 2013).

Figure 1: *Relative Prices of Selected Farm Commodities, 1960–2010*

Panel a. *Real Prices of Specialty Crops*



Panel b. *Real Prices of Food Grains and Livestock Commodities*



Source: See table 1.

Table 1. *Definitions of Variables used in the Regression Model of Commodity Prices*

	Source	Annual Average Growth			
		Nominal		Real[a]	
		1960–2010	1980–2006	1960–2010	1980–2006
		percent per year			
Prices (W_l)					
Food grains	Index of prices received by farmers for food grains (USDA-NASS various years)	3.96	1.37	0.26	-1.80
Oilseeds	Price index for prices received by farmers for oilseeds (USDA-NASS various years)	4.52	0.43	0.87	-2.68
Sugar	Duty-free price per pound paid in New York City (USDA-ERS 2012a)	6.58	2.72	2.68	-0.59
Other crops (incl. peanuts)	Average price per pound received by farmers for peanuts (USDA-NASS various years)	2.05	0.61	-1.56	-3.13
Fruits and tree nuts	Price index for prices received by farmers for fruits and tree nuts (USDA-NASS various years)	3.73	3.05	0.09	-0.15
Vegetables and melons	Price index for prices received by farmers for vegetables and melons (USDA-NASS various years)	3.66	2.58	0.00	-0.64
Meat animals	Price index for prices received by farmers for meat animals (USDA-NASS various years)	3.17	0.97	-0.46	-2.17
Poultry and eggs	Price index for prices received by farmers for poultry and eggs (USDA-NASS various years)	2.74	1.28	-0.88	-1.87
Dairy	Price index for prices received by farmers for dairy products (USDA-NASS various years)	3.48	0.83	-0.18	-2.32
Fish and seafood	Average price per ton of domestic landings (USDC-NOAA 2012)	4.72	1.14	1.03	-0.59
Range and pasture index (*R*)[b]	National pasture and range condition (USDA-WAOB 2012)	0.27	0.08	na	na
Crude oil price (*E*)	Crude oil production price, dollars per million Btu (US DOE-EIA 2012)	9.7	8.4	5.7	4.8
Food marketing price index (*M*)	Index of food marketing costs (USDA-ERS 2012b)	4.49	3.11	0.78	-0.14

[a] Prices of farm commodities, crude oil and food marketing costs deflated by GDP implicit price deflator (BEA 2012).
[b] The range and pasture index is available only from 1949–2004, therefore the averages reported above are for 1960–2004 and 1980–2004.

[c] The price index for food marketing costs is only available from 1970 to 2010. The index between 1960 and 1970 is an extrapolation from 1970 using the growth rate for wages of nondurable workers.

USDL-BLS=US Department of Labor-Bureau of Labor Statistics; USDA-NASS=US Department of Agriculture (USDA)-National Agricultural Statistics Service; USDA-ERS=USDA-Economic Research Service; USDC-NOAA=US Department of Commerce-National Oceanic and Atmospheric Administration; USDA-WAOB=USDA-World Agricultural Outlook Board; DOE-EIA=Department of Energy-Energy Information Agency.

Table 2. *Regressions of Commodity Prices Against Public Agricultural Knowledge Stocks*

	Sugar	Oilseeds	Food grains	Vegetables	Dairy	Meat animals	Fruit and tree nuts	Poultry and eggs	Fish	Other
Double-log model										
Ln(Knowledge stock)	–0.55** (0.05)	–0.55** (0.05)	–0.55** (0.05)	–0.55** (0.05)	–0.55** (0.05)	–0.55** (0.05)	–0.55** (0.05)	–0.55** (0.05)	–0.55** (0.05)	–0.55** (0.05)
Ln(Crude oil)	–0.01 (0.09)	0.09 (0.13)	0.04 (0.15)	0.06 (0.08)	–0.13 (0.07)	0.19** (0.06)	0.05 (0.06)	–0.03 (0.06)	0.15 (0.11)	–0.30 (0.17)
Range index	–0.00 (0.00)	0.00 (0.00)	0.00 (0.01)	–0.00 (0.00)	0.01* (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	–0.01* (0.00)	0.01 (0.01)
Ln(Marketing cost)	0.78 (0.75)	–0.09 (1.02)	1.61 (1.15)	–0.95 (0.64)	2.85** (0.56)	–0.92 (0.53)	–1.26* (0.51)	0.79 (0.52)	–3.65** (1.11)	2.26 (1.33)
Constant	–1.60 (3.73)	3.37 (5.10)	–4.44 (5.73)	7.77* (3.23)	–11.79** (2.80)	8.04** (2.75)	9.13** (2.63)	–1.06 (2.66)	19.76** (5.57)	–8.40 (6.63)
Observations	25	25	25	25	25	25	25	25	25	25
R-squared	0.76	0.66	0.68	0.50	0.83	0.82	0.50	0.77	0.77	0.57
First-difference double-log model										
Ln(Knowledge stock)	-1.93** (0.56)	-1.93** (0.56)	-1.93** (0.56)	-1.93** (0.56)	-1.93** (0.56)	-1.93** (0.56)	-1.93** (0.56)	-1.93** (0.56)	-1.93** (0.56)	-1.93** (0.56)
Ln(Crude oil)	0.01 (0.08)	0.10 (0.12)	0.06 (0.12)	-0.08 (0.08)	-0.07 (0.09)	0.16** (0.06)	-0.01 (0.08)	-0.12 (0.08)	0.00 (0.08)	0.03 (0.21)
Range index	-0.00 (0.00)	-0.00 (0.00)	-0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.01)
Ln(Marketing cost)	-3.54 (1.88)	0.60 (2.72)	1.25 (2.71)	3.58* (1.75)	-0.45 (1.95)	-2.63* (1.28)	-1.29 (1.77)	0.94 (1.82)	-2.45 (1.97)	0.61 (4.70)
Constant	0.010 (0.03)	0.057 (0.04)	0.033 (0.04)	0.07* (0.03)	-0.002 (0.02)	0.027 (0.02)	0.036 (0.02)	0.033 (0.02)	0.158** (0.06)	0.021 (0.06)
Observations	24	24	24	24	24	24	24	24	24	24
R-squared	0.30	0.08	0.06	0.19	0.14	0.37	0.06	0.18	-0.07	0.00

Note: Standard errors in parentheses, ** p<0.01, * p<0.05.

Table 3. *Actual and Predicted Percentage Changes in Commodity Prices, 1980–2004*

a. Individual Commodity Prices

			First-differenced double-log model			Double-log model			Double-log model with time trend		
	Actual change in price	Actual change in K stock	Predicted change in (log) price	Change attribute-able to change in stock	Share attribute-able to change in stock	Predicted change in (log) price	Change attribute-able to change in stock	Share attribute-able to change in stock	Predicted change in (log) price	Change attribute-able to change in stock	Share attribute-able to change in stock
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
Commodity[a]						*percentages*					
Sugar	-87.62	78.33	-87.62	-151.34	172.72	-52.36	-43.16	82.43	-65.25	-122.75	188.13
Oilseeds	-51.22	92.45	-51.22	-178.62	348.73	-51.22	-50.94	99.45	-58.63	-144.88	247.10
Food grains	-83.60	76.38	-83.61	-147.56	176.49	-60.37	-42.08	69.71	-71.63	-119.68	167.09
Vegetables	-32.97	80.17	-32.97	-154.89	469.80	-34.94	-44.18	126.43	-25.62	-125.63	490.34
Dairy	-49.66	27.43	-49.66	-52.99	106.71	-43.48	-15.11	34.76	-52.43	-42.98	81.97
Meat animals	-38.44	67.57	-38.44	-130.54	339.60	-29.20	-37.23	127.50	-38.64	-105.88	274.01
Fruit and tree nuts	-18.52	62.20	-18.52	-120.17	648.73	-20.95	-34.27	163.60	-20.33	-97.47	479.54
Poultry and eggs	-33.02	54.50	-33.02	-105.30	318.92	-37.57	-30.03	79.94	-37.05	-85.41	230.52
Fish	-57.11	240.54	-57.11	-464.72	813.76	-96.37	-132.54	137.53	-87.49	-376.93	430.84
Other (peanuts)	-86.23	67.27	-86.23	-129.96	150.71	-54.82	-37.07	67.62	-80.71	-105.41	130.60

[a] Based on model parameters in table 2.

Table 3. *Actual and Predicted Percentage Changes in Commodity Prices, 1980–2004*

b. Aggregate Agricultural Output Price[b]

			First-differenced double-log model			Double-log model			Double-log model with time trend		
	Actual change in price	Actual change in K stock	Predicted change in (log) price	Change attribute-able to change in stock	Share attribute-able to change in stock	Predicted change in (log) price	Change attribute-able to change in stock	Share attribute-able to change in stock	Predicted change in (log) price	Change attribute -able to change in stock	Share attribute -able to change in stock
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
Knowledge Stock (K)						*percentages*					
Total SAES[c]	-64.33	72.97	-64.33	-159.06	247.24	-57.53	-66.55	115.68	-57.02	-186.51	327.08
USDA IM	-64.33	42.40	-64.33	-420.29	653.32	-63.95	-91.93	143.76	-63.28	-60.85	96.15
Total public agricultural R&D[c]	-64.33	62.12	-64.33	-67.84	105.46	-59.84	-74.11	123.83	-61.41	-165.17	268.97
Total public agricultural R&D and extension[c]	-64.33	56.93	-64.33	-201.88	313.81	-58.45	-72.18	123.50	-58.67	-135.94	231.72

[b]Based on model parameters in appendix table C.1-1 and C-1-2.
[c] Excludes expenditures for forestry.

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Table 4. *Projected Changes in Prices and Consumption under Alternative R&D Scenarios*

	Change in Selected Commodity Knowledge Stock				
	10% increase for all commodities	10% increase for specialty crops	10 % decrease for all except specialty crops	10% increase for specialty crops, 10% decrease for all others	Revert to 1980 Knowledge Stock
	(1)	(2)	(3)	(4)	(5)
Percentage Change in Price			*percentage*		
FAH					
Cereals and bakery	-1.33	-0.05	1.28	1.23	9.84
Meats	-8.06	0.00	8.06	8.06	73.99
Eggs	-13.15	0.00	13.15	13.15	72.14
Dairy	-5.32	-0.02	5.30	5.28	14.89
Fruits and vegetables	-9.32	-9.19	0.14	-9.05	69.23
Other foods	-3.33	-0.67	2.66	1.98	26.62
Nonalcoholic beverages	-0.64	-0.57	0.07	-0.49	4.03
FAFH	-0.91	-0.07	0.84	0.76	7.93
Alcoholic beverages	-0.77	-0.41	0.36	-0.05	5.29
Percentage Change in Consumption			*percentage*		
FAH					
Cereals and bakery	-2.46	-1.41	1.05	-0.36	15.25
Meats	1.04	-1.45	-2.49	-3.94	-14.76
Eggs	3.67	4.58	0.90	5.48	-11.70
Dairy	3.52	0.52	-3.00	-2.48	-5.85
Fruits and vegetables	4.00	5.38	1.38	6.76	-22.26
Other foods	3.63	1.40	-2.23	-0.82	-33.09
Nonalcoholic beverages	-0.75	-0.89	-0.14	-1.03	-3.06
FAFH	-0.68	-0.44	0.24	-0.20	7.92
Alcoholic beverages	-1.42	0.39	1.82	2.21	11.85

Notes: "Knowledge stocks" here refers to public agricultural knowledge stocks for farm commodities. "Specialty crops" here include fruits, tree nuts, vegetables and melons. Analysis based on first-differenced logarithmic model of commodity prices and knowledge stocks.

Table 5. *Changes in Daily Calorie Consumption and Steady-State Body Weight under Alternative R&D Scenarios*

	Change in Selected Commodity Knowledge Stock				Revert to 1980 Knowledge Stock
	10% increase for all commodities	10% increase for specialty crops	10 % decrease for all except specialty crops	10% increase for specialty crops, 10% decrease for all others	
	(1)	(2)	(3)	(4)	(5)
Daily Change in Per Capita Caloric Intake (kcal) by Food Category					
FAH					
Cereals and bakery	-8.65	-4.96	3.69	-1.27	53.73
Meats	1.56	-2.19	-3.75	-5.93	-22.22
Eggs	1.02	1.27	0.25	1.52	-3.24
Dairy	6.87	1.02	-5.85	-4.83	-11.42
Fruits and vegetables	5.63	7.57	1.94	9.51	-31.29
Other foods	14.52	5.62	-8.91	-3.29	-132.36
Nonalcoholic beverages	-1.23	-1.45	-0.22	-1.68	-5.01
FAFH	-4.99	-3.21	1.78	-1.43	58.06
Alcoholic beverages	-1.03	0.28	1.31	1.60	8.56
Daily Change in Total Per Capita Caloric Consumption and Body Weight					
Consumption (kcal)	13.70	3.94	-9.76	-5.81	-85.19
Body weight (lb)					
One year	1.05	0.30	-0.75	-0.45	-6.53
Steady-state	1.75	0.50	-1.25	-0.74	-10.90

Notes: See notes to table 5.

Table 6. *Changes in Social Welfare and Obesity-Related Health-Care Expenditures*

	Change in Selected Commodity Knowledge Stock				Revert to 1980 Knowledge Stock
	10% increase for all commodities	10% increase for specialty crops	10 % decrease for all except specialty crops	10% increase for specialty crops, 10% decrease for all others	
	(1)	(2)	(3)	(4)	(5)
Change in Public Health-Care Costs (ΔH), millions of dollars per year					
(1)	1,987	572	-1,415	-844	-12,360
Change in Social Welfare (ΔSW), millions of dollars per year					
(2) Excluding ΔH	28,739	6,800	-22,025	-15,063	-223,890
(3) Including ΔH	26,751	6,228	-20610	-14,219	-211,530
Change in Steady-State Body Weight for U.S. Adults					
Millions of pounds	392	113	-279	-166	-2438
Pounds per capita	1.75	0.50	-1.25	-0.74	-10.90
Cost per Pound Decrease (Benefit per Pound Increase) in Body Weight, dollars per pound					
Excluding ΔH	73.33	60.30	78.90	90.53	91.84
Including ΔH	68.26	55.23	73.83	85.46	86.77

Notes: "Knowledge stocks" here refers to public agricultural knowledge stocks for farm commodities. "Specialty crops" here include fruits, tree nuts, vegetables and melons. Analysis based on first-differenced logarithmic model of commodity prices and knowledge stocks. The total adult population in 2002 was 223,631,174 (USDC-Census 2013).