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Effects of U.S. Public Agricultural R&D on U.S. Obesity and its Social Costs

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ABSTRACT.

How much has food abundance, attributable to U.S. public agricultural R&D, contributed to 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 consumer welfare. 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 public health-care expenditures related to obesity. On the other hand, such an increase in spending would have generated very substantial consumer benefits, and net national benefits, given the very large benefit-cost ratios for agricultural R&D. Consequently, a policy of revising agricultural R&D priorities to pursue obesity objectives is likely to be comparatively unproductive and socially wasteful.

Key Words: obesity, public health expenditures, social costs, agricultural R&D

JEL Codes: Q16, Q18, I18, I13, Q11, H4

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. 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 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, MacEwan, Alston, and Okrent (2014) estimated that $166.2 billion or 15.2 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 (e.g., see Alston, Okrent and Parks 2012). 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. For example, 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. 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 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.[1]

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; Mazzochi, Traill and Shogren 2009). The primary purpose of this paper is to investigate this scenario, which is plausible given the large 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.[2]

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.[3] Some such policies

[1] 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).

[2] Some authors have argued that this is because productivity gains for fruit 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.

[3] Whether the R&D portfolio should be rebalanced 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.

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 Task Force on Childhood Obesity Report to the President 2010).

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. 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.[4] 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 toward enhancing the supply of ingredients of a healthier diet could enhance national welfare.

[4] 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.

In this paper we examine the effects of U.S. public investments in agricultural R&D on obesity and consumer 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 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 briefly describes the equilibrium displacement model (from Okrent and Alston 2012) we use 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. We also compute the corresponding changes in consumer welfare, associated with the simulated food price changes, and changes in public health-care expenditures associated with the predicted changes in food consumption and their consequences for obesity. 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. Panels a and b of Figure 1 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). Over the 50 years between 1960 and 2010 among specialty crops the real prices declined by approximately 20 percent for fruit and tree nuts, but only 10 percent for vegetables and melons. Over the same period, the real prices of food grains (primarily wheat and rice) declined by close to 50 percent and the real prices of meat animals, poultry and eggs and dairy commodities, commodities that use feed grains as inputs to production, declined by 40–60 percent. Associated with these price changes were substantial increases in quantities produced and consumed and shifts in the balance of consumption. The increases 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 (represented by peanuts), 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.[5]

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. Commodity 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, all resulting from three types of factors. First, is a set of factors that shift the U.S. supply of a commodity (including prices of inputs used in farming, farm production technology, and seasonal conditions as they affect that commodity and other commodities that compete for farming resources). Second, is a set of factors that shift the U.S. demand for a commodity (including changes in population, per capita income, tastes and preferences, and household technology that affect final consumer demand and thus derived demand, as well as the technology and the prices of inputs used in processing, transporting, and marketing farm and food products as they influence the marketing margin). Third, is a set of factors that affect the

[5] As documented by Pardey, Alston and Chan-Kang (2013), 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 much larger impact on reducing farm costs.

supply of imports to the United States and demand for exports from the United States. These include foreign counterparts of all of the same variables that affect U.S. domestic supply and domestic demand for the same commodities, as well as international transportation costs and technology and trade restricting policies, which influence the international transmission of price signals, and currency exchange rates that affect the terms of trade.

Clearly a great many influences are involved. While we cannot explicitly include every such variable, some introspection suggests a set of variables to include that will serve as a proxy for the full set. First, are variables that shift final U.S. demand for food, including total population, wages, and income per capita. Second, are the prices of the primary factors of production, some of which work through multiple pathways. Movements in global energy prices, can have a pervasive influence both through their direct effects on costs at every stage of production, but also indirectly from their effects on commodity prices through the biofuels economy, on general wage rates, and on currency exchange rates. Likewise, labor wage rates are implicated directly in every stage of production and also have some influence on final demand through both income effects and the opportunity cost of time as it affects food preparation costs and thus food choices. In the same spirit, interest rates and the general level of prices in the economy are relevant variables that have roles to play throughout the entire food chain. Third, although only a small fraction of U.S. production and consumption of agricultural commodities is traded, international trade has important influences on prices both at home and abroad. While it is not possible to include all the relevant variables for every country, the key influences may be captured by the inclusion of variables to represent U.S. currency exchange rates (trade-weighted), and global population and income measures.

Fourth and finally, changes in the technology of production on farms, the focus of this work, are likely to have had important influences on food commodity prices, as may have changes in technology used in food processing, transportation, manufacturing and retailing, and in household production of food, as they influence the demand for food commodities. Such changes will have taken place both in the United States and in other countries. While we do not observe the "state of technology" directly, we can include as a proxy variable a measure of an agricultural "knowledge stock," which is based on past expenditures on agricultural R&D. A complete specification would include such knowledge stock variables both for foreign and domestic agricultural production (reflecting both public and private investments in research and extension pertaining to agriculture and food both in the United States and by the rest of the world, ROW). However, suitable data are not available to construct a measure of the foreign agricultural knowledge stock. In addition, studies that have attempted to model U.S. agricultural productivity using measures of private agricultural R&D have generally failed to find a significant relationship, either because of inadequate data or multicollinearity problems (e.g., Huffman and Evenson 2006, Wang et al. 2013). Data are available for measuring the U.S. public agricultural R&D knowledge stock. Since this stock is likely to be positively correlated with the other (private and foreign) excluded agricultural knowledge stocks, the associated regression coefficient should be interpreted with caution—it is likely to be an upwards biased measure of the effect of the U.S. public agricultural knowledge stock—since it will reflect to some extent the effects of other types of agricultural R&D.

Decisions about the model specification are complicated by the fact that many of the supply and demand shift variables mentioned above are dominated by similar trends, and are thus, highly correlated with one another, such that it will be challenging econometrically to obtain robust estimates of their effects on prices. Rather than include a comprehensively long list of such variables, we opted for a more parsimonious approach in which we include a few shift variables and try some alternative specifications to develop a sense of the sensitivity of the key parameter—on the knowledge stock variable—to the inclusion of additional covariates.

Against this background, 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 vector of other variables representing shifters of supply and demand for U.S. farm commodities, $\mathbf{Z}_t$, and a random error term, $\varepsilon_{l,t}$, as follows:

(1) $$\Delta\ln W_{l,t} = \alpha_0 + \alpha_{Kl}\Delta\ln K_{l,t} + \sum_{j=1}^{J}\beta_{jl}\Delta\ln Z_{j,t} + \mathcal{E}_{l,t}, \forall l = 1, \ldots, L.$$

In this model all of the economic variables are defined in real U.S. dollar terms in that nominal values of $W_{l,t}$ and elements of $\mathbf{Z}_t$ are deflated by the implicit price deflator for GDP, and the knowledge stock variable, $K_{l,t}$, 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. The vector of supply and demand shift variables includes an index of range and pasture conditions, indexes of the prices of energy and agricultural marketing inputs, measures of gross domestic income (reflecting effects of growth in per capita income and population) in the United States and in the rest-of–the world, and a trade-weighted index of the exchange rate. In early work we tried models with variables in levels and logarithms, but we did not find any interesting differences so we opted to use the models with variables in logarithms, which is convenient for our purposes. Also, as shown in equation (1), we first-differenced all of the variables because we detected unit roots in half of the price and knowledge stock series using the augmented Dickey-Fuller test. Thus, all the economic variables are expressed in proportional growth-rate form and the estimated coefficients are elasticities.

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

We computed the knowledge stock variables 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. Here we report results from models estimated using data for a shorter 25-year period, 1980–2004, which excludes the influence of both the 1970s price spike and the more-recent price spike in 2008.

Estimation Results

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. Thus the ten equations were estimated as a system using a seemingly unrelated regressions (SUR) model, with a cross-equation restriction on the elasticities associated with the knowledge stocks. The results of the preferred model are reported in Table 2. In this model, the elasticity of commodity prices with respect to their commodity-specific knowledge stocks is –2.385, and statistically significantly different from zero at the 1 percent level of significance.

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

As noted, in the preferred model, the vector of supply and demand shift variables includes an index of range and pasture conditions, indexes of the prices of energy and agricultural marketing inputs, measures of income in the United States and in the rest-of–the world, and a trade-weighted index of the exchange rate. Every one of these variables has a significant regression coefficient in at least one of the 10 equations. We tried other specifications including additional variables such as interest rates and time trends. Generally the inclusion of additional variables of this nature resulted in a loss of statistical significance of individual parameters with no improvement in explanatory power of the model, consistent with multicollinearity, and the model was somewhat fragile with respect to this aspect of the specification.

The coefficient on the knowledge stock variable, α_{Kl}, is of the greatest interest here. The inclusion of additional regressors tended to result in a larger but less precisely estimated value for α_{Kl} —estimates ranged between –2 and –4 for most of the models but more often between –1 and –2 for the models including only a few shift variables. For example, the estimate of α_{Kl} was –1.95 for an iteration of the model that included just three of these variables—the index of range and pasture conditions, and indexes of the prices of energy and agricultural marketing inputs. The extended model in Table 2 has better explanatory power and for that reason is preferred for and used in the analysis that follows.

Growth Accounting

Using the elasticity estimates from the commodity price model we 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) $$\Delta\ln\widehat{W}_{l,1980-04} = \hat{\alpha}_0 + \hat{\alpha}_{Kl}\Delta\ln K_{l,1980-04} + \sum_{j=1}^{J}\hat{\beta}_{jl}\Delta\ln Z_{j,1980-04}\ \forall l = 1, \ldots, L,$$

where, for each variable, the $\Delta\ln X_{1980\text{-}04}$, $X = K, Z, W$ refers to proportional change in K, Z and W between 1980 and 2004. The proportional changes in prices attributable to changes in agricultural knowledge over the same time period are given by

(3) $$\Delta\ln\widehat{W}_{l|\Delta\mathbf{Z}=0,1980-04} = \hat{\alpha}_{Kl}\Delta\ln K_{l,1980-04}\ \forall l = 1, \ldots, L,$$

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*]

Table 3, column (1) shows the actual percentage changes in prices over the interval 1980–2004, with real decreases ranging from 19 percent for fruit and tree nuts up to more than 84 percent for sugar, food grain, and "other." 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. Columns (3)–(5) refer to results from our model. The proportional changes in prices predicted by the regression model in column (3) are identical to the actual changes in column (1) 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 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. The implication is that, as one would expect, in the absence of increases in agricultural knowledge stocks, prices would have risen as a result of other factors (such as increases in demand, or increases in costs of energy). 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. 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.[6]

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—indeed, according to the estimates in column (4) of Table 3, they would have risen. 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.

[6] 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 be expected to have very significant price impacts.

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. In this application, since the prices of farm commodities and marketing inputs are exogenous, so too are the retail food prices, given fixed input proportions in food processing and manufacturing. The simulated proportional change in price of an individual food is computed as a weighted average of proportional changes in farm commodity prices, where the weights are the shares of the commodities in the retail cost of the food product.

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.[7]

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

[7] 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. We use a similar model to that of Christiansen et al. (2005), who suggest that $\Delta B_{1yr} = \frac{\Delta kcal}{1.5\alpha}[1 - \exp\{-1.5\alpha\rho(365)\}]$, and $\Delta B_{ss} = \frac{\Delta kcal}{1.5\alpha}$, where $\alpha = 5.21$ and $\rho = 0.00032$.

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. Following Okrent and Alston (2012), using the expenditure function e(.), a compensating variation measure of the change in welfare for a representative consumer is:

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

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:

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

where E$\mathbf{P}$ denotes a vector of proportional changes in food 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, $\mathbf{w}$ 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.

We also measure the implied changes in public health-care expenditures resulting from simulated changes in steady-state body weight. MacEwan, Alston and Okrent (2014) estimated that a one-unit increase in average adult BMI would increase annual public health-care expenditures by $27 per adult for a nationally representative sample, which is an increase of $4.35 per adult per year for a one-pound increase in adult body weight.[8] 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 compare this cost with corresponding changes in consumer surplus. 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 MacEwan, Alston and Okrent 2014), ΔB_{ss} is the change in steady-state body weight and *pop* is total adult population in the United States in 2002.

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 first set of 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. Next, we estimate the effects of reverting the 2002 knowledge stocks back to their 1980 values, which effectively increases prices of all farm commodities. Lastly, to gauge the plausibility of our results based on econometric estimates of the links from knowledge stocks to prices, our third set of simulations considers the effects of reverting the 2002 farm commodity prices back to their 1980 values.

Marginal (10 percent) Changes in Particular Knowledge Stocks

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

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 –2.385, a 10 percent increase in a particular commodity-specific knowledge stock implies a 23.85 percent decrease in the price of the corresponding commodity. The simulation results are summarized in Tables 4 through 6.

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 23.85 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) 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, food away from home, 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 23.85 percent decrease in prices of specialty crops (fruits, tree nuts, vegetables and melons) and a 23.85 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 14.54 kcal per day increase in average caloric intake per adult, which translates to an increase in steady-state body weight by 1.86 lb (1.11 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 0.54 lb (0.32 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 1.33 lb (0.79 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 0.79 lb (0.47 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 effects in row (3) of Table 6 are dominated by the impacts on consumer surplus (ΔCS) in row (2), which are almost an order of magnitude larger than the partially offsetting impacts on public health-care expenditures (ΔH) 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. The last two rows of Table 6 show the same measures (ΔCS and $\Delta CS - \Delta H$) 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 $90 per pound, which would be only partially offset by savings in public health-care costs of about $4.35 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.

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

Revert to 1980 Knowledge Stocks

An alternative counterfactual experiment is to consider the consequences if agricultural knowledge stocks were to revert to their values in 1980. This analysis entails much larger shifts and a bigger extrapolation compared with the 10 percent shifts just considered. In particular, reverting back 1980 values of commodity-specific knowledge stocks in 2004 would imply increases in commodity prices ranging from 65 percent (for dairy) to over 500 percent (for fish and seafood), as shown in Table 3. Consequently, 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 15 percent) would be implied for alcoholic and nonalcoholic beverages, cereals and bakery, and food away from home; more substantial increases would be implied for dairy and other foods (18 and 33 percent, respectively); and quite large increases (around 90 percent) would be implied for meats, eggs, and fruits and vegetables. The corresponding simulated changes in consumption include 10–20 percent increases for three categories (cereals and bakery, food away from home, and alcoholic beverages) and decreases for the other six categories (especially 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 105 kcal, and a reduction in steady-state body weight of 13.48 lb per adult American (8.07 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 \$276.67 billion, which would be partially offset by a saving to taxpayers of \$13.11 billion in public health-care costs. The reduction in average U.S. adult body weight by 13.48 lb would cost consumers \$91.8 per pound and would cost the nation \$87.5 per pound after the savings in public health-care costs are taken into account.

Revert to 1980 Commodity Prices

The results reported above refer to simulations of particular sets of price changes, which are consistent with particular changes in agricultural knowledge stocks to the extent that the elasticity (α_{Kl} = –2.385) was estimated accurately. But even if the elasticity is not estimated accurately, the results are meaningful as measures of the consequences of the simulated price changes and hence of the consequences of a change in knowledge stocks sufficient to cause the simulated price change. Thus, for instance, if the elasticity were overestimated by 50 percent (i.e., α_{Kl} = –1.20) then the implication is that the estimates overstate the true effects of the given changes in knowledge stocks by 100 percent, or, equivalently, the measured effects would require double the simulated change in knowledge stocks.

As one way of addressing uncertainty about the accuracy of our estimate of this elasticity, we simulated the implications of reverting to 1980 commodity prices in 2004, using the proportional changes in prices in column (1) of Table 3. Given rapid growth in demand, we would expect prices to have risen in the absence of research-induced increases in supply rather than stay constant. On this view, the simulation of a reversion to 1980 prices can be interpreted as yielding a lower-bound estimate of the effect of reverting to 1980 knowledge stocks.

Reverting to the 1980 commodity prices in 2004 would imply generally smaller and less disparate increases in food prices (between 5 and 21 percent for all categories of food at home except for nonalcoholic beverages in Table 4, column 6) compared with reverting to 1980 knowledge stocks (between 12 and 90 percent for all categories of food at home except for nonalcoholic beverages in Table 4, column 5). The corresponding simulated changes in consumption include 0–4 percent increases for five categories (cereals and bakery, food away from home, nonalcoholic beverages, alcoholic beverages, and eggs) and 4–8 percent decreases for the other four categories (meats, dairy, fruits and vegetables, and other foods). A reversion to 1980 prices 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 (6), reverting to the 1980 commodity-specific prices in 2004 would imply increases in caloric consumption from cereals and bakery, as well as food away from home and beverages, which are more than offset by decreases in caloric consumption especially from other foods and dairy, but also meats and fruits and vegetables. The net impact would imply a decrease in adult daily caloric intake by 38 kcal, and a reduction in steady-state body weight of 4.85 lb per adult American (2.90 lb in one year after the change).

The consumer and taxpayer welfare implications are summarized in Table 6, column (6). Reverting to the 1980 commodity prices in 2004 would have resulted in a loss to consumers of $65.00 billion, which would be partially offset by a saving to taxpayers of $4.72 billion in public health-care costs. The reduction in average U.S. adult body weight by 4.85 lb would cost consumers $60.0 per pound and would cost the nation $55.6 per pound after the savings in public health-care costs are taken into account. Recall, as with the simulated changes in knowledge stocks, these are only partial measures of the total economic impact because they do not take into account the taxpayer costs of funding public agricultural R&D nor the producer benefits from adopting the innovations that gave rise to the equilibrium commodity price changes modeled here. Given benefit-cost ratios on the order of 20:1 or 30:1, as reported by Alston et al. (2010), the omission of the taxpayer cost of financing agricultural R&D would be unimportant, compared with the omission of producer benefits from the resulting innovations. Therefore, the reported measures of economic impact almost surely understate the net social cost of foregoing research-induced innovations, and the consequent reductions in food prices since 1980, as a way of reducing obesity.

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; and second, that the balance of public agricultural R&D spending should 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, which means that, in the absence of the increases in the knowledge stocks, prices would have risen rather than fall, as they did. Even so, the implications for obesity are relatively modest. Using a multimarket simulation model we found reverting commodity prices back to 1980 values in 2004—a lower-bound estimate of the effects of agricultural productivity on commodity prices—would imply small decreases in caloric intake (37.88 kcal per adult per day) and steady-state body weight (4.85 lb per adult American). This would be a costly reversion. It would cost consumers $65.01 billion, of which only $4.72 billion would be offset by savings in public health-care costs, to reduce average U.S. adult body weight by 4.85 lb. This translates to $55.6 per pound after the savings in public health-care costs are taken into account. The costs per pound are similar for various alternative experiments in which we simulate changes in knowledge stocks for particular commodities or all commodities.

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:

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

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

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

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 equations (A.1-1) and (A.1-2) using the data summarized in Table A.1-1 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 equations (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 equations (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 equation (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.

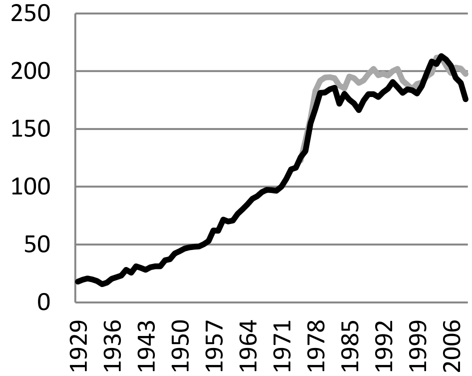
Table A.1-1. *Summary Statistics of Explanatory Variables and Sources of Data*

	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 ($AgVal_l$)					
Dairy	27,947	5,634	13,338	37,918	Cash receipts by commodity groups and selected commodities, 1929–2009 (table 5, USDA-ERS 2012c)
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.

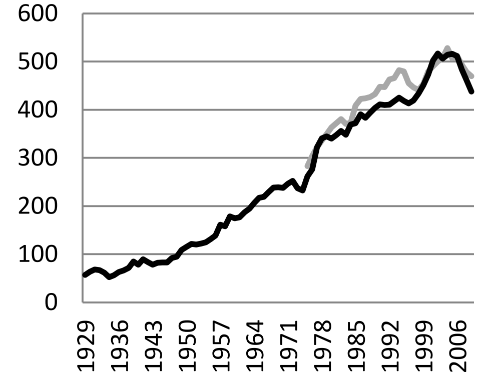
Figure A.1-1. *Comparison of Predicted and Actual Public Investments in Agricultural R&D, 1929–2009*

Panel a. *Oilseeds*



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

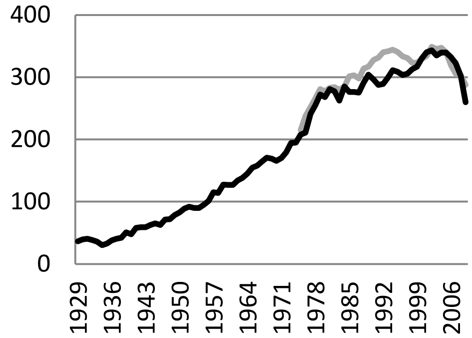
Panel b. *Food grains*



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

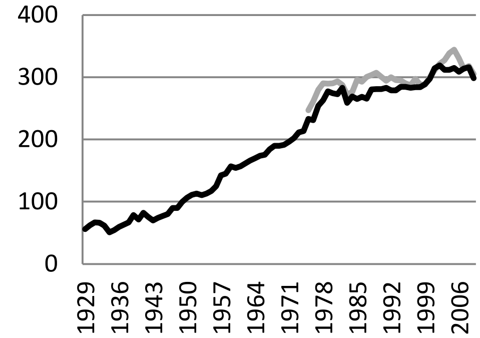
Million dollar (2009=100)

Panel c. *Vegetables and melons*



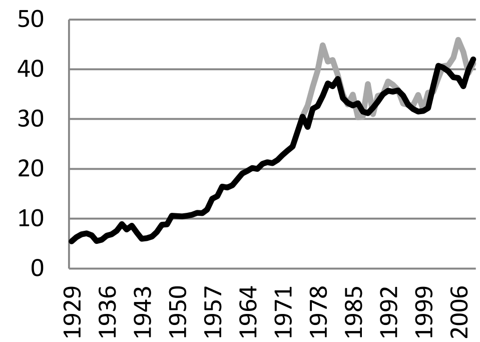
MAPE (in sample) = 5.6
MAPE (out of sample) = 9.0

Panel d. *Fruits and tree nuts*



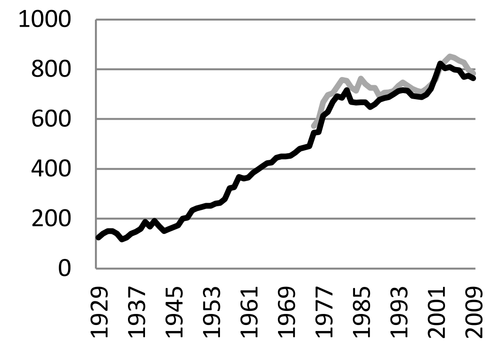
MAPE (in sample) = 5.5
MAPE (out of sample) = 16.2

Panel e. *Sugar*



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

Panel f. *Other crops*



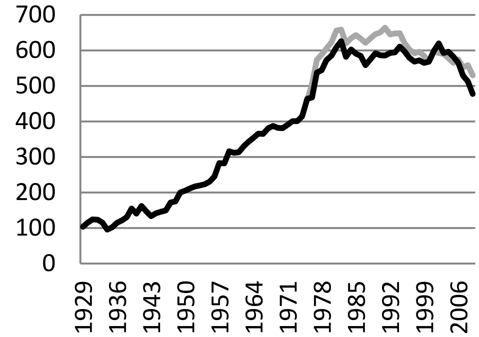
MAPE (in sample) = 5.3
MAPE (out of sample) = 16.3

Predicted   Actual

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

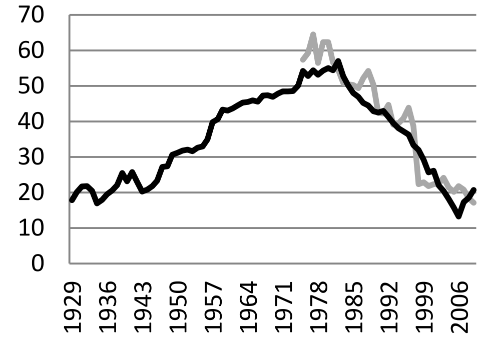
Million dollar (2009=100)

Panel g. *Meat animals*



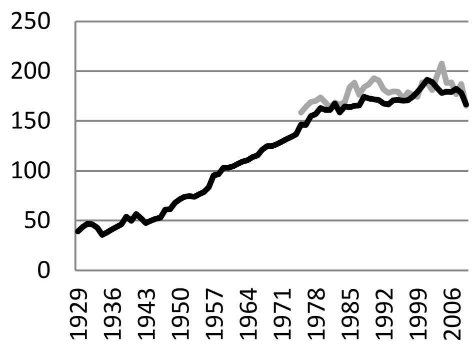
MAPE (in sample) = 4.8
MAPE (out of sample) = 5.5

Panel h. *Milk*



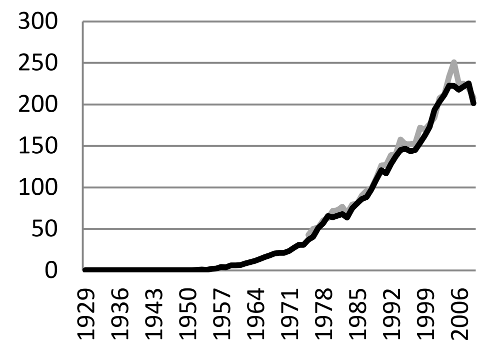
MAPE (in sample) = 12.0
MAPE (out of sample) = 31.1

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

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

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

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

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*, $\boldsymbol{\varepsilon}_{lj}$ 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) $\mathrm{E}\,P^n = \sum_{l=1}^{L} SR_l^n\,\mathrm{E}\,W_l, \forall n = 1,..,N,$

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) $\eta_{lm}^{*} = \sum_{n=1}^{N} SC_l^n \eta_{lm}^{n*}.$

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

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

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

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

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.

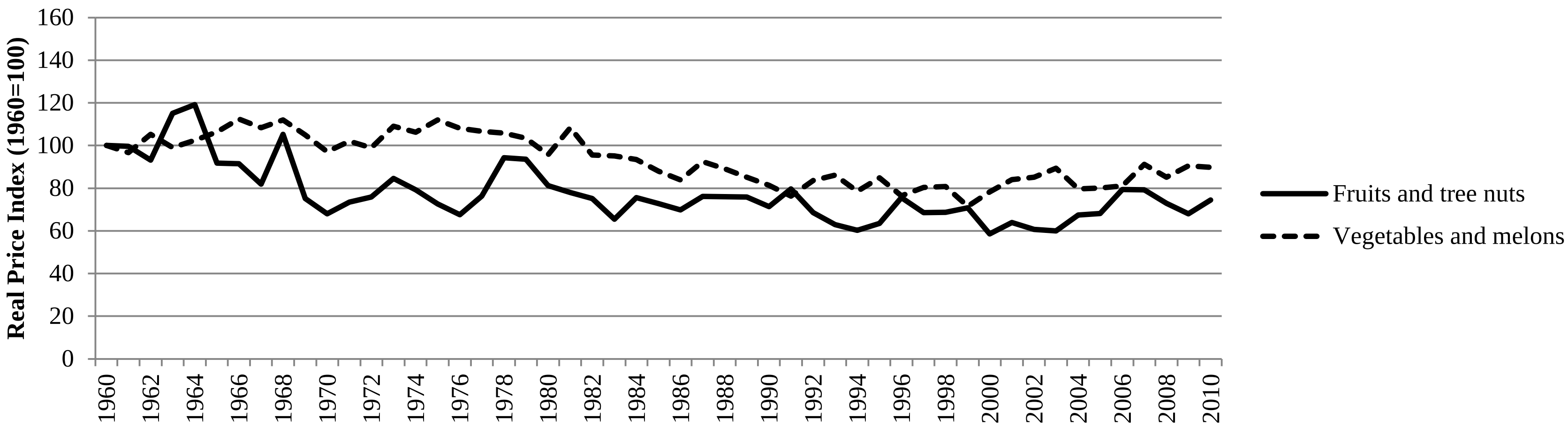
B.2 Parameterization of the Market Equilibrium Model

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.

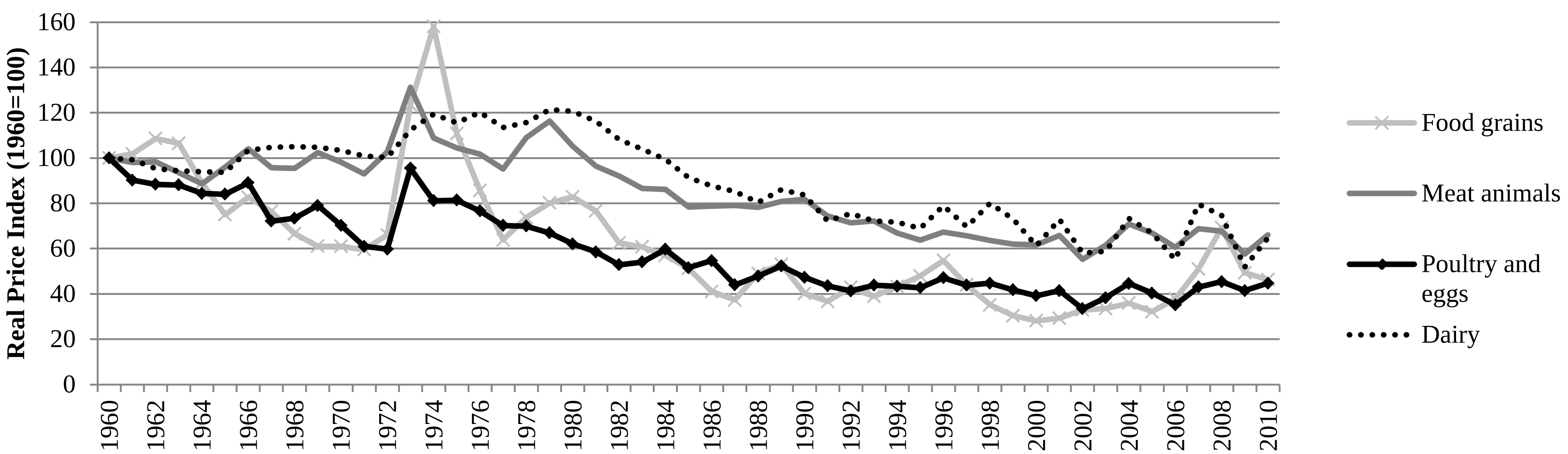
The farm-retail product shares are from Okrent and Alston (2012) who estimated **SR** using the Detailed Use Table (after redefinitions) from the 2002 Benchmark Input-Output (I-O) Accounts (U.S. Department of Commerce, Bureau of Economic Analysis 2007). The Detailed Use Table shows the use of farm commodities,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

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 and Summary Statistics of Variables used in the Regression Model of Commodity Prices*

Variable	Source	Mean	Standard Deviation	Min	Max
Commodity Prices (1960=100)					
Food grains	Index of prices received by farmers for food grains (USDA-NASS various years)	45.81	14.08	28.11	82.88
Oilseeds	Price index for prices received by farmers for oilseeds (USDA-NASS various years)	71.25	20.01	41.89	117.02
Sugar	Duty-free price per pound paid in New York City (USDA-ERS 2012a)	90.27	25.16	62.49	186.25
Other (incl. peanuts)	Average price per pound received by farmers for peanuts (USDA-NASS various years)	69.35	17.30	36.34	97.75
Fruits and tree nuts	Price index for prices received by farmers for fruits and tree nuts (USDA-NASS various years)	69.88	6.65	58.55	81.24
Vegetables and melons	Price index for prices received by farmers for vegetables and melons (USDA-NASS various years)	85.73	7.99	71.52	108.31
Meat animals	Price index for prices received by farmers for meat animals (USDA-NASS various years)	74.63	12.17	55.22	105.13
Poultry and eggs	Price index for prices received by farmers for poultry and eggs (USDA-NASS various years)	46.97	7.10	33.44	62.07
Dairy	Price index for prices received by farmers for dairy products (USDA-NASS various years)	81.96	16.75	57.99	120.59
Fish and seafood	Average price per ton of domestic landings (USDC-NOAA 2012)	143.90	35.59	99.28	206.65
Supply and Demand Shifters					
Crop range	National pasture and range condition (USDA-WAOB 2012)	71.2	7.40	57	84
Crude oil price	Crude oil production price, constant dollars per million BTU, (US DOE-EIA 2012)	0.043	0.026	0.019	0.132
Index of food marketing costs	Real index of food marketing costs, 1960=100 (USDA-ERS 2012b)	144.05	5.39	139.20	156.22
Exchange Rate	Real index of exchange rates using U.S. agricultural exports as weights (USDA-ERS 2014)	98.62	8.40	76.96	111.36

U.S. GDI	U.S. GDI, in U.S. constant dollars, millions (World Bank 2014)	7,575,492	1,744,592	5,101,600	10,629,000
ROW GDI[a]	ROW gross domestic income, in U.S. constant dollars, millions	60,907,047	16,008,251	40,474,172	93,244,885

[a] Calculated as World GDI (in constant U.S. dollars) (World Bank 2014) less U.S. GDI (in constant U.S. dollars).

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; BTU = British thermal unit.

Table 2. *Regressions of Logarithmic Differences 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
Δln(Knowledge stock)	-2.39**	-2.39**	-2.39**	-2.39**	-2.39**	-2.39**	-2.39**	-2.39**	-2.39**	-2.39**
	(0.70)	(0.70)	(0.70)	(0.70)	(0.70)	(0.70)	(0.70)	(0.70)	(0.70)	(0.70)
Δln(Crude oil)	-0.037	-0.06	-0.04	-0.10	-0.07	0.15**	0.03	-0.15*	-0.05	-0.02
	(0.08)	(0.09)	(0.10)	(0.07)	(0.09)	(0.06)	(0.08)	(0.07)	(0.08)	(0.19)
ΔRange index	-0.006*	-0.003	-0.003	0.006*	0.004	0.002	0.001	0.004	0.001	0.01
	(0.003)	(0.003)	(0.004)	(0.003)	(0.003)	(0.002)	(0.003)	(0.003)	(0.003)	(0.007)
Δln(Marketing cost)	-4.74*	3.19	3.00	6.08**	0.84	-1.56	-1.03	3.25	-1.95	4.58
	(1.92)	(2.11)	(2.50)	(1.68)	(2.20)	(1.36)	(1.95)	(1.80)	(1.96)	(4.71)
Δln(Exchange Rate)	-0.212	-2.47**	-1.87**	-0.76	-0.34	-0.42	0.30	-1.17*	-0.85	-1.07
	(0.51)	(0.56)	(0.66)	(0.45)	(0.58)	(0.36)	(0.52)	(0.48)	(0.51)	(1.25)
Δln(GDI-ROW)	-0.19	-1.29	-1.01	0.38	-0.27	0.32	1.16	-0.81	-2.12*	1.13
	(0.92)	(1.02)	(1.20)	(0.81)	(1.06)	(0.66)	(0.93)	(0.86)	(0.98)	(2.26)
Δln(GDI-US)	0.03	1.80	0.48	1.10	0.96	-0.68	-0.61	2.12	2.96*	3.93
	(1.18)	(1.29)	(1.53)	(1.03)	(1.35)	(0.83)	(1.19)	(1.10)	(1.20)	(2.88)
Constant	0.46*	0.15	0.27	-0.40*	-0.30	-0.10	-0.05	-0.24	0.14	-0.81
	(0.21)	(0.24)	(0.28)	(0.19)	(0.25)	(0.15)	(0.22)	(0.20)	(0.22)	(0.53)
Observations	24	24	24	24	24	24	24	24	24	24
R-squared	0.41	0.56	0.36	0.40	0.16	0.45	0.09	0.37	0.18	0.20

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

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

	Actual change in (log) price	Actual change in K stock	Predicted change in (log) price	Change attributable to change in stock	Share attributable to change in stock
	(1)	(2)	(3)	(4)	(5)
			percentages		
Commodity					
Sugar	-87.62	78.33	-87.62	-186.83	213.21
Oilseeds	-51.22	92.45	-51.22	-220.50	430.49
Food grains	-83.6	76.38	-83.61	-182.16	217.87
Vegetables	-32.97	80.17	-32.97	-191.21	579.95
Dairy	-49.66	27.43	-49.66	-65.42	131.73
Meat animals	-38.44	67.57	-38.44	-161.15	419.23
Fruit and tree nuts	-18.52	62.2	-18.52	-148.35	800.83
Poultry and eggs	-33.02	54.5	-33.02	-129.99	393.70
Fish	-57.11	240.54	-57.11	-573.69	1,004.56
Other (peanuts)	-86.23	67.27	-86.23	-160.44	186.05

Note: Analysis based on model parameters in table 2.

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

	Change in Selected Commodity Knowledge Stock				Revert to 1980	
	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	Knowledge Stocks	Commodity Prices
	(1)	(2)	(3)	(4)	(5)	(6)
			percentage			
Percentage Change in Price of						
Food at home						
Cereals and bakery	-1.41	-0.05	1.35	1.30	12.19	5.27
Meats	-8.56	0.00	8.56	8.56	91.34	16.56
Eggs	-13.97	0.00	13.97	13.97	89.06	20.57
Dairy	-5.65	-0.02	5.63	5.60	18.39	13.69
Fruits and vegetables	-9.90	-9.75	0.15	-9.61	85.47	13.26
Other foods	-3.54	-0.72	2.82	2.11	32.89	10.19
Nonalcoholic beverages	-0.68	-0.60	0.08	-0.52	4.98	0.87
Food away from home	-0.96	-0.08	0.89	0.81	9.79	2.25
Alcoholic beverages	-0.82	-0.43	0.38	-0.05	6.54	1.97
Percentage Change in Consumption						
Food at home						
Cereals and bakery	-2.61	-1.49	1.11	-0.38	18.79	3.47
Meats	1.10	-1.54	-2.64	-4.19	-18.23	-3.58
Eggs	3.90	4.86	0.96	5.82	-14.45	0.47
Dairy	3.74	0.55	-3.18	-2.63	-7.21	-8.55
Fruits and vegetables	4.25	5.71	1.46	7.18	-27.48	-4.79
Other foods	3.85	1.49	-2.36	-0.87	-40.85	-7.31
Nonalcoholic beverages	-0.80	-0.94	-0.15	-1.09	-3.78	1.64
Food away from home	-0.72	-0.47	0.26	-0.21	9.77	0.40
Alcoholic beverages	-1.51	0.42	1.93	2.35	14.62	3.00

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 Body Weight under Alternative Scenarios*

	Change in Selected Commodity Knowledge Stock				Revert to 1980	
	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	Knowledge Stocks	Commodity Prices
	(1)	(2)	(3)	(4)	(5)	(6)
Daily Change in Per Capita Caloric Intake (kcal) by Food Category						
Food at home						
Cereals and bakery	-9.19	-5.27	3.92	-1.35	66.23	12.23
Meats	1.66	-2.32	-3.98	-6.30	-27.43	-5.39
Eggs	1.08	1.35	0.27	1.61	-4.00	0.13
Dairy	7.29	1.08	-6.21	-5.13	-14.08	-16.68
Fruits and vegetables	5.98	8.03	2.06	10.09	-38.63	-6.73
Other foods	15.42	5.96	-9.46	-3.50	-163.40	-29.23
Nonalcoholic beverages	-1.30	-1.54	-0.24	-1.78	-6.18	2.69
Food away from home	-5.30	-3.41	1.89	-1.52	71.62	2.94
Alcoholic beverages	-1.09	0.30	1.39	1.69	10.56	2.17
Daily Change in Total Per Capita Caloric Consumption and Body Weight						
Consumption (kcal)	14.54	4.18	-10.36	-6.17	-105.31	-37.88
Body weight (lb)						
One year	1.11	0.32	-0.79	-0.47	-8.07	-2.90
Steady-state	1.86	0.54	-1.33	-0.79	-13.48	-4.85

Notes: See notes to table 4.

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

	Change in Selected Commodity Knowledge Stock				Revert to 1980	
	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	Knowledge Stocks	Commodity Prices
	(1)	(2)	(3)	(4)	(5)	(6)
Public Health-Care Costs (ΔH), $m/year						
(1) Δ*H*	1,810	521	-1,289	-768	-13,109	-4,715
Consumer Surplus (ΔCS), $m/year						
(2) Δ*CS*	30,513	7,228	-23,382	-15,971	-276,665	-65,007
Net Change, $m/year						
(3) Δ*CS* – Δ*H*	28,703	6,707	-22,093	-15,202	-263,556	-60,292
Change in Steady-State Body Weight for U.S. Adults						
Millions of pounds	416	120	-296	-177	-3,014	-1,084
Pounds per capita	1.86	0.54	-1.33	-0.79	-13.48	-4.85
Cost per Pound Decrease (Benefit per Pound Increase) in Body Weight, $/lb						
Δ*CS*	73.3	60.4	78.9	90.4	91.8	60.0
Δ*CS* – Δ*H*	69.0	56.0	74.5	86.1	87.5	55.6

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).