The Effects of Farm Commodity and Retail Food Policies on Obesity and Economic Welfare in the United States

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Abstract

Many commentators have claimed that farm subsidies have contributed significantly to the "obesity epidemic" by making fattening foods relatively cheap and abundant and, symmetrically, that taxing "unhealthy" commodities or subsidizing "healthy" commodities would contribute to reducing obesity rates. In this paper we estimate and compare the economic welfare effects from hypothetical farm commodity and retail food policies as alternative mechanisms for encouraging consumption of healthy food or discouraging consumption of unhealthy food, or both. To do this, we develop an equilibrium displacement model that characterizes the linkages among multiple commodities that are vertically linked to multiple retail products, where the commodities and retail products are related in production and consumption. We simulate the likely effects on food and commodity consumption of several policies that have been proposed in as ways of addressing obesity: (a) eliminating current farm programs including farm subsidies and trade barriers on agriculture, (b) a subsidy on fruit and vegetable retail products, (c) a subsidy on fruit and vegetable farm commodities, (d) a tax on the fat content of food products, (e) a tax on the calorie content of food products, (f) a tax on the sugar content of food products, or (g) a uniform tax on food. We then translate the changes in food consumption into changes in calorie consumption, adult body weight, and public health-care expenditures, and compare the changes in social welfare for each policy. We find that among all these policies, a tax on calories would be the most efficient as obesity policy, having the lowest deadweight loss per pound of fat reduction in average adult weight, and yielding a net social gain once the impact on public health care expenditures is considered, whereas the other policies typically would involve significant net social costs.

JEL Codes: Q18, I18, H2
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1. Introduction

Obesity is an escalating problem around the world that has received much attention recently, particularly in the United States. In less than thirty years, the prevalence of obese Americans more than doubled (Flegal et al. 2002). In 1960–62, 13.4 percent of U.S. adults were obese and by 2003–04, 32.2 percent were obese. This upward trend in the adult obesity rate has received a lot of press, with public health advocates demanding immediate action to reduce obesity rates. Indeed, First Lady Michelle Obama launched the 'Let's Move' campaign to address childhood obesity, so children born today will reach adulthood at a healthy weight (White House Task Force on Childhood Obesity 2010).

Obesity has become a public health issue because the consequences of obesity in terms of higher risk of morbidity and mortality for an individual translate into increased medical care costs not only for the individual but also for society, and these costs are large and growing. Finkelstein et al. (2009) estimated that 37% of the rise in inflation-adjusted per capita health care expenditures between 1998 and 2006 was attributable to increases in the proportion of Americans who were obese. Indeed, the increased prevalence of obesity was found to be responsible for almost $40 billion of increased medical spending between 1998 and 2006. Across all insured individuals, per capita medical spending for the obese was $1,429 higher in 2006, or roughly 42 percent higher, than for someone of normal weight, and more than half of the expenditures attributable to obesity were financed by Medicare and Medicaid.

The recent upward trend in the adult obesity rate is attributable to an energy imbalance, whereby calories consumed are greater than calories expended, given a genetic predisposition. Arguably, the genetic composition of the United States has not changed significantly in the past 20 years; thus, increases in the rate of obesity imply that many individuals have increased their consumption of calories or decreased their physical activity or both. Over the past two decades, median body weight increased 10–12 lbs for adult men and women. This rate of gain required a net calorie imbalance of 100 to 150 calories per day (Cutler, Glaeser, and Shapiro 2003). Because the daily energy imbalance is relatively small, many economic factors such as price and income changes coupled with changes in individual preferences could have contributed to the observed gain in body weight.

Policymakers have suggested a variety of policies to address obesity in the United States. Regulatory and fiscal instruments have been suggested by policymakers as ways to change the eating habits of individuals: for instance, taxing foods with high fat or high sugar content, or subsidizing healthier foods such as fresh fruits and vegetables. However, economists disagree about the extent to which changes in food prices have contributed to the increased rate of obesity in the United States. Some studies suggest that taxation or subsidization of certain foods would be effective as means of reducing average body weight in the United States (O'Donoghue and Rabin 2006; Cash, Sunding, and Zilberman 2005). A tax on foods that are energy dense and fattening (e.g., soda and chips) would make fattening foods more expensive relative to nonfattening foods such that consumers would substitute away from consumption of fattening foods and into consumption of nonfattening foods. Others argue that such pricing policies would have little effect on food consumption, and hence obesity (Schroeter, Lusk, and Tyner 2007; Kuchler, Tegene and Harris 2004; Chouinard et al. 2007; Gelbach, Klick, and Strattman 2007) and would be regressive, falling disproportionately heavily on the poor (e.g., Chouinard et al. 2007).

Related to the issue of whether food prices have been a major contributor to obesity in the United States is the question of whether agricultural policies made farm commodities cheaper and more abundant, especially those that are primary ingredients in fattening foods. The idea that farm subsidies have contributed significantly to the problem of obesity in the United States has been reported frequently in the press, and has assumed the character of a stylized fact. It is conceptually possible that farm policies have contributed to lower relative prices and increased consumption of fattening foods by making certain farm commodities more abundant and therefore cheaper. However, several economic studies have found these effects to be small or nonexistent (Alston, Sumner, and Vosti, 2006, Alston, Sumner, and Vosti 2008, Beghin and Jensen 2008, Miller and Coble 2007, Schmidhuber 2004, Senauer and Gemma 2006).

To date, most evaluations of food taxes and subsidies as obesity policies have primarily focused on consumer responses, largely ignoring the potential role that producers play in food production and consumption. In this paper we model and quantify the potential impacts on food consumption, body weight, and social welfare that would result from subsidies and taxes on food products or on farm commodities used to produce food. To do so, we develop a framework that is a generalization of models of commodity-retail product price transmission discussed in the marketing margins literature. Based on this general framework, we also establish formulas for approximating policy-induced changes in social welfare that do not rely on a particular choice of functional form for the consumer expenditure function or for producer profit function. We apply these methods to simulate various policies and their impacts on prices, consumption, and welfare. To do this, we use new estimates of demand elasticities for food and other goods, estimated specifically with this application in mind, combined with estimates of commodity supply elasticities from the literature along with detailed data on farm-to-retail marketing costs and the nutrient content of different foods.

2. A Model of *N* Inter-related Food Products and *L* Inter-related Commodities

To determine the implications of agricultural policies for obesity and its economic consequences, we develop an equilibrium displacement model that can be used to examine the transmission of policy-induced changes in commodity prices to changes in consumption and prices of food products. Gardner (1975) developed a one-output, two-input model of a competitive industry to analyze how the retail-farm price ratio responds to shifts in the supply of farm commodities or marketing inputs, or in the demand for retail products. He derived formulas for elasticities of price transmission that nest the fixed proportions model of Tomek and Robinson (2003) as a special case. Wohlgenant (1989) and Wohlgenant and Haidacher (1989) developed a different one-output, two-input model for which they did not assume constant returns to scale at the industry level. For each of eight food products they estimated the elasticities of price transmission between the retail price and the prices of a corresponding farm commodity and a composite marketing input.

The linkages between markets for farm commodities and retail products are generally modeled assuming that one farm commodity and one or more marketing factor are inputs into the production of a particular food at home (FAH) (i.e., food purchased at a retail outlet and prepared at home). For example, the farm commodity beef is the primary ingredient for the retail food product beef. However, food away from home (FAFH) (e.g., food purchased at restaurants) and combination FAH products (e.g., soups, frozen dinners) incorporate multiple farm commodities. Under the assumption of fixed proportions, the price transmission between farm commodities and both combination FAH products and FAFH would certainly be less than the price transmission between farm commodities and non-combination FAH products because the farm commodity cost represents a smaller share of the retail value of FAH and combination food products. FAFH and combination foods now constitute more than half of personal consumption expenditures on food—41 and 14 percent, respectively in 2009 (U.S. Department of Commerce, Bureau of Economic Analysis 2010) and the majority of average daily calories consumed are from these two categories of food—33 percent and 18 percent, respectively, in 2005–06 (Centers for Disease Control and Prevention, National Center for Health Statistics 2010). Consequently it is important to include these categories of food in the analysis of food policies and obesity.

Here, we extend a system compromising one output product with *L* inputs, as presented by Wohlgenant (1982), to *N* output products with *L-1* farm commodities used as inputs along with one composite marketing input.[1] The market equilibrium for this system can be 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:

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

(2) $$C^n = \mathrm{c}^n(\mathbf{W})Q^n, \forall n = 1,..,N,$$

(3) $$X_l^n = \left(\partial \mathrm{c}^n(\mathbf{W}) / \partial W_l\right) Q^n = \mathrm{g}_l^n(\mathbf{W})Q^n, \forall n = 1,...,N; \forall l = 1,...,L,$$

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

The superscripts on variables denote food products, and the subscripts denote the farm commodities and the composite marketing input. Equation (1) represents the demand for *n*th retail food product in which the quantity demanded, Q^n, is a function of an $N \times 1$ vector of retail prices, **P**, and an exogenous demand shifter, A^n, which subsumes the effects of changes in total consumer expenditure and other exogenous shifters on retail demand. In equation(2), the

[1] For the rest of this analysis, "commodities" will include farm commodities and the composite marketing input.

technology for the industry producing good n is expressed as a total cost function in which the total cost of producing the nth retail product C^n is a function of an $L \times 1$ vector of prices of farm commodities and the marketing input, $\mathbf{W}$ and the quantity of the product, Q^n. Under the assumption of constant returns to scale at the industry level, the average cost per unit of product n is equivalent to its marginal cost (i.e., $C^n / Q^n = \mathrm{c}^n(\mathbf{W})$), and, under the further assumption of competitive market equilibrium with no price distortions, marginal cost and average cost are equal to the retail price, P^n:

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

The Hicksian demand for commodity l by industry n in equation (3) is derived by applying Shephard's lemma to the total cost function in (2). The $L \times N$ Hicksian demand equations can be reduced to L equations because total demand for commodity l, X_l , is the sum of the Hicksian demands for commodity l across all retail industries, i.e.

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

Equation (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 (1), (4), (5), and (6), and expressing these equations in relative change terms (i.e., using $dX_i / X_i = \mathrm{E}X_i$) yields

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

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

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

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

where

(11) $$\eta^{nk} = \frac{\partial \mathrm{Q}^n\left(\mathbf{P}, A^n\right)}{\partial P^k}\frac{P^k}{Q^n}$$ is the Marshallian elasticity of demand for retail product *i* with respect to retail price *k*

(12) $$SC_l^n = \frac{X_l^n W_l}{X_l W_l}$$ is the share of the total cost of commodity *l* across all industries used by retail product *n* (farm-commodity share)

(13) $$\eta_{lm}^{n*} = \left(\frac{\partial\, \mathrm{g}_l^n\left(\mathbf{W}\right)Q^n}{\partial W_m}\right)\frac{W_m}{X_l^n}$$ is the Hicksian elasticity of demand for commodity *l* in industry *n* with respect to commodity price *m*,

(14) $$\varepsilon_{lj} = \frac{\partial\, \mathrm{f}_l\left(\mathbf{W}, B_l\right)}{\partial W_j}\frac{W_j}{X_l}$$ is the elasticity of supply of commodity *l* with respect to commodity price *j*

(15) $$\alpha^n = \frac{\partial \mathrm{Q}^n\left(\mathbf{P}, A^n\right)}{\partial A^n}\frac{A^n}{Q^n}\mathrm{E}\, A^n$$ is the proportional shift of demand for retail product *n* in the quantity direction

(16) $$\beta_l = \frac{\partial\, \mathrm{f}_l\left(W_l, B_l\right)}{\partial B_l}\frac{B_l}{X_l}\mathrm{E}\, B_l$$ is the proportional shift of supply of commodity *l* in the quantity direction

Several simplifications can be made to the system. We know that $\partial\, \mathrm{c}^n\left(\cdot\right)/\partial W_l = X_l^n / Q^n$, so equation (8) can be rewritten as

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

where the share of total cost for retail product *n* attributable to commodity *l* (farm-product share) is:

(18) $$SR_l^n = X_l^n W_l / P^n Q^n.$$

Second, the share-weighted Hicksian elasticity of demand for commodity *l* with respect to the price of commodity *m* is

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

Equation (9) can be rewritten using (19):

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

This system can be modified to accommodate policy shocks such as the introduction of taxes and subsidies on food products or taxes and subsidies on farm commodities The subsidy and taxation policies cause wedges between consumer (or buyer) and producer (or seller) prices of retail products or commodities. Let t^n be the tax rate on food product n, and $P^{D,n}$ and $P^{S,n}$ be the consumer and producer prices of retail product n, respectively, so that

(21) $$P^{D,n} = (1+t^n)P^{S,n}.$$

The introduction of t^n implies that the total differential of (21) expressed in terms of proportionate changes is

(22) $$\mathrm{E}\,P^{D,n} = t^n + \mathrm{E}\,P^{S,n}.$$

Substituting (22) into (7) yields

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

Likewise, the proportionate change in the seller price of commodity l, $\mathrm{E}W_{Sl}$, can be written as the sum of its subsidy rate, s_l, and the proportionate change in its buyer price.

(24) $$\mathrm{E}W_{S,l} = s_l + \mathrm{E}W_{D,l}.$$

Substituting (24) into (10) yields

(25) $$\mathrm{E}\,X_l = \sum_{j=1}^{L} \varepsilon_{lj}\,\mathrm{E}\,W_{D,l} + \sum_{j=1}^{L} \varepsilon_{lj} s_l + \beta_l.$$

To simplify the notation, we present equations (17), (20), (23)and (25) in matrix notation. Letting **EQ**, and $\mathbf{EP}^S$ be $N \times 1$ vectors of proportionate changes in quantities and producer prices of retail products, respectively, and **EX**, and $\mathbf{EW}_D$ be $L \times 1$ vectors of proportionate changes in quantities and buyer prices of commodities, respectively, the system is

$$(26)\quad \begin{bmatrix} \mathbf{I}^N & \textbf{-}\boldsymbol{\eta}^N & \mathbf{0} & \mathbf{0} \\ \mathbf{0}^N & \mathbf{I}^N & \mathbf{0} & \textbf{-SR} \\ \textbf{-SC} & \mathbf{0}^{\mathrm{T}} & \mathbf{I}_L & \textbf{-}\boldsymbol{\eta}_L^* \\ \mathbf{0}^{\mathrm{T}} & \mathbf{0}^{\mathrm{T}} & \mathbf{I}_L & \textbf{-}\boldsymbol{\varepsilon}_L \end{bmatrix} \begin{bmatrix} \mathbf{EQ} \\ \mathbf{EP}^S \\ \mathbf{EX} \\ \mathbf{EW}_D \end{bmatrix} = \begin{bmatrix} \boldsymbol{\alpha}+\boldsymbol{\eta}^N\mathbf{t}^N \\ \mathbf{0} \\ \mathbf{0} \\ \boldsymbol{\beta}+\boldsymbol{\varepsilon}_L\mathbf{s}_L \end{bmatrix},$$

where $\mathbf{I}^N$ and $\mathbf{I}_L$ are $N \times N$ and $L \times L$ identity matrices, $\mathbf{0}^N$ and $\mathbf{0}$ are $N \times N$ and $N \times L$ matrices of all zeros, $\boldsymbol{\eta}^N$ is an $N \times N$ matrix of Marshallian elasticities of demand for retail products (equation (11)), $\boldsymbol{\eta}_L^*$ is an $L \times L$ matrix of Hicksian elasticities of demand for commodities (equation (13)), $\mathbf{SR}$ is an $N \times L$ matrix of farm-product shares (equation (18)), $\mathbf{SC}$ is an $L \times N$ matrix of farm-commodity shares (equation (12)), $\boldsymbol{\varepsilon}_L$ is an $L \times L$ matrix of elasticities of supply of commodities (equation (14)), and $\boldsymbol{\alpha}+\boldsymbol{\eta}^N\mathbf{t}^N$ and $\boldsymbol{\beta}+\boldsymbol{\varepsilon}_L\mathbf{s}_L$ be $N \times 1$ and $L \times 1$ vectors of exogenous factors affecting the demand for retail products and the supply of commodities, respectively. Using matrix block inversion, the solutions for $\mathbf{EQ}$, $\mathbf{EP}^S$, $\mathbf{EX}$ and $\mathbf{EW}_D$ are:

$$(27)\quad \begin{bmatrix} \mathbf{EQ} \\ \mathbf{EP}^S \\ \mathbf{EX} \\ \mathbf{EW}_D \end{bmatrix} = \begin{bmatrix} \mathbf{I}^N - \boldsymbol{\eta}^N\mathbf{SRf}^{-1}\mathbf{SC} & \boldsymbol{\eta}^N\mathbf{SRf}^{-1} \\ -\mathbf{SRf}^{-1}\mathbf{SC} & \mathbf{SRf}^{-1} \\ \left(\mathbf{I}_L - (\boldsymbol{\eta}_L^* + \mathbf{SC}\boldsymbol{\eta}^N\mathbf{SR})\mathbf{f}^{\mathbf{-1}}\right)\mathbf{SC} & \left(\boldsymbol{\eta}_L^* + \mathbf{SC}\boldsymbol{\eta}^N\mathbf{SR}\right)\mathbf{f}^{-1} \\ -\mathbf{f}^{-1}\mathbf{SC} & \mathbf{f}^{-1} \end{bmatrix} \begin{bmatrix} \boldsymbol{\alpha}+\boldsymbol{\eta}^N\mathbf{t}^N \\ \boldsymbol{\beta}+\boldsymbol{\varepsilon}_L\mathbf{s}_L \end{bmatrix},$$

where $\mathbf{f}^{\mathbf{-1}} = (\textbf{-}\boldsymbol{\varepsilon}_L + \boldsymbol{\eta}_L^* + \mathbf{SC}\boldsymbol{\eta}^N\mathbf{SR})^{-1}$. The vectors of proportionate changes in consumer prices of retail products and seller prices of commodities, $\mathbf{EP}^D$ and $\mathbf{EW}_S$, respectively, can be recovered using (22) and (24).

Simplifying assumptions can be used to reduce the general model to a more-manageable form, such as (a) exogenous commodity prices $(\varepsilon_{ll} = \infty)$, (b) exogenous commodity quantities $(\varepsilon_{ll} = 0)$, or (c) fixed input proportions $(\sigma_{lj} = 0)$. Under the assumption of exogenous commodity prices, equation (25) becomes

(28) $-d\ln W_l = \bar{\beta}_l + s_l, \forall l = 1,...,L,$

where $\bar{\beta}_l$ is a proportionate shift in supply of commodity *l* in the price direction. Under this assumption, the solution in (27) reduces to the first column in Table 1. Wohlgenant and Haidacher (1989) and Wohlgenant (1989) assumed that farm commodity supply is predetermined with respect to the farm commodity price in current period, which implies that $\varepsilon_{lj} = 0, \forall j, l = 1,..., L$, such that (10) becomes

(29) $EX_l = \beta_l, \forall l = 1,..., L.$

This implies that the general model reduces to the second column in Table 1. Lastly, under an assumption of fixed proportions, the Hicksian elasticity of demand between two factor inputs *l* and *j* in output *n* is zero (i.e., η_{lj}^{n*} = 0, ∀ *l*,*j* = 1, ..., *L*, ∀ *n* = 1, ..., *N*).[2] Hence, the solution with fixed input proportions is that from the general model with $\boldsymbol{\eta}_L^* = \mathbf{0}_L$, or the last column in Table 1.

INSERT Table 1 HERE

3. Measures of Changes in Social Welfare

Based on the general price transmission model, we formulate equations for estimating the change in social welfare from a subsidy or tax policy. Changes in social welfare are measured as the sum of costs (benefits) that accrue to consumers, producers, and taxpayers from a policy shock. Measures of compensating variation (CV) and changes in profit and taxpayer expenditure

[2] To show the implications of this assumption for the general model, note the elasticity of substitution can be written as

$$\sigma_{lj}^n = \left(\frac{\partial^2 \mathrm{C}^n(\mathbf{W}, Q^n)}{\partial P^i \partial P^j}\right) \mathrm{C}^n(\mathbf{W}, Q^n) / \left(\frac{\partial \mathrm{C}^n(\mathbf{W}, Q^n)}{\partial P^i}\right)\left(\frac{\partial \mathrm{C}^n(\mathbf{W}, Q^n)}{\partial P^j}\right)$$

(Sato and Koizumi 1975). Conveniently, this definition of the elasticity of substitution relates directly to the Hicksian elasticity of demand for the inputs:

$$\eta_{lj}^{n*} = \sigma_{lj}^n SR_l^n, \forall l, j = 1,..., L, \forall n = 1,..., N.$$

Substituting this into (19), the farm-product-share-weighted Hicksian elasticity of demand for commodity *l* with respect to price of commodity *m* becomes

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

(revenue) are used to represent these costs (benefits). This measure of social welfare is then adjusted to account for externalities that are borne by taxpayers who bear some of the costs of payment for health care services of obese individuals who use government-funded insurance.

Following Martin and Alston (1992, 1993) and Just, Hueth and Schmitz (2004), we define social welfare (*SW*) as

$$SW = \sum_{n=1}^{N}\left[\pi\left(P^{n}, \mathbf{W}\right)\right] + \sum_{l=1}^{L}\left[\pi\left(W_{l}\right)\right] + \mathrm{g}(\mathbf{P}, \mathbf{W}) - \sum_{i=1}^{I}\mathrm{e}\left(\mathbf{P}, u_{i}\right), \tag{30}$$

where $\mathrm{e}(\mathbf{P}, u_i)$ is the minimum expenditure necessary to obtain a given level of utility, u_i for individual consumer *i* at product prices, $\mathbf{P}$; $\pi(P^n, \mathbf{W})$ is profit for retail product producer *n*, where $\mathbf{W}$ is an $L \times 1$ vector of commodity prices; $\pi(W_l)$ is profit for commodity producer *l*; and $\mathrm{g}(\mathbf{P},\mathbf{W})$ is change in government revenue generated by the introduction of the policy being analyzed.[3] A compensating variation measure of the change in social welfare for a representative consumer, retail product producer, and commodity producer is

$$\begin{aligned} \Delta SW &= \left[\pi\left(\mathbf{P}^{(1)}, \mathbf{W}^{(1)}\right) - \pi\left(\mathbf{P}^{(0)}, \mathbf{W}^{(0)}\right)\right] \\ &+ \left[\pi\left(\mathbf{W}^{(1)}\right) - \pi\left(\mathbf{W}^{(0)}\right)\right] \\ &+ \left[\mathrm{g}\left(\mathbf{P}^{(1)}, \mathbf{W}^{(1)}\right) - \mathrm{g}\left(\mathbf{P}^{(0)}, \mathbf{W}^{(0)}\right)\right] \\ &- \left[\mathrm{e}\left(\mathbf{P}^{(1)}, u^{(0)}\right) - \mathrm{e}\left(\mathbf{P}^{(0)}, u^{(0)}\right)\right], \end{aligned} \tag{31}$$

where the last term in square brackets on the RHS is 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 consumer's original utility at $u^{(0)}$ (i.e., compensating variation, CV).[4]

[3] This treatment assumes a dollar of government revenue is worth one dollar. It would be a straightforward extension to allow for a marginal social opportunity cost of government revenue greater than one dollar. Doing so would shift the balance of the equation in favor of the tax policies.

[4] Since retail producers are assumed to make zero profit (i.e., equation (8)), then

$$\left[\pi\left(\mathbf{P}^{(1)}, \mathbf{W}^{(1)}\right) - \pi\left(\mathbf{P}^{(0)}, \mathbf{W}^{(0)}\right)\right] = 0.$$

Martin and Alston (1992) demonstrated how a second-order Taylor series expansion of (30) of around ($\mathbf{P}^{(0)}$, $\mathbf{W}^{(0)}$), holding utility constant at $u^{(0)}$, can be used to approximate (31) without specifying functional forms for the consumer expenditure and profit functions:

$$
(32)\qquad
\begin{aligned}
\mathrm{SW}\left(\mathbf{P},\mathbf{W},u^{(0)}\right) \;&\approx\; \mathrm{SW}\left(\mathbf{P}^{(0)},\mathbf{W}^{(0)},u^{(0)}\right) \\
&+\; \mathbf{\Delta}^{\mathrm{T}}\nabla\,\mathrm{SW}\left(\mathbf{P}^{(0)},\mathbf{W}^{(0)},u^{(0)}\right) \\
&+\; 0.5\mathbf{\Delta}^{\mathrm{T}}\nabla^{2}\,\mathrm{SW}\left(\mathbf{P}^{(0)},\mathbf{W}^{(0)},u^{(0)}\right)\mathbf{\Delta},
\end{aligned}
$$

where ∇ and ∇^2 denote the gradient and Hessian of the social welfare function, respectively, the T superscript denotes the transpose of a matrix, and

$$\mathbf{\Delta}^{\mathrm{T}} = \left[\mathbf{\Delta P}^{D} \quad \mathbf{\Delta P}^{S} \quad \mathbf{\Delta W}_{D} \quad \mathbf{\Delta W}_{S}\right],$$

is a $2(N + 1)$ vector of changes in producer and consumer prices of products and commodities, respectively.

Evaluating (32) at $\left(\mathbf{P}^{D(1)},\mathbf{P}^{S(1)},\mathbf{W}_{D}^{(1)},\mathbf{W}_{S}^{(1)}\right)$ and then subtracting $\mathrm{SW}\left(\mathbf{P}^{(0)},\mathbf{W}^{(0)},u^{(0)}\right)$ from both sides yields an approximation to the change in social welfare implied by a change in prices from $\mathbf{P}^{(0)}$, $\mathbf{W}^{(0)}$ to $\mathbf{P}^{(1)}$, $\mathbf{W}^{(1)}$ as would be implied by a policy simulation using the price transmission model:

$$
(33)\qquad
\begin{aligned}
\Delta SW \;&= \mathrm{SW}\left(\mathbf{P}^{(1)},\mathbf{W}^{(1)},u^{(0)}\right) - \mathrm{SW}\left(\mathbf{P}^{(0)},\mathbf{W}^{(0)},u^{(0)}\right) \\
&\approx \mathbf{\Delta}^{(1)\mathrm{T}}\nabla\,\mathrm{SW}\left(\mathbf{P}^{(0)},\mathbf{W}^{(0)},u^{(0)}\right) + 0.5\mathbf{\Delta}^{(1)\mathrm{T}}\nabla^{2}\,\mathrm{SW}\left(\mathbf{P}^{(0)},\mathbf{W}^{(0)},u^{(0)}\right)\mathbf{\Delta}^{(1)},
\end{aligned}
$$

where

$$\mathbf{\Delta}^{(1)\mathrm{T}} = \left[\mathbf{P}^{D(1)} - \mathbf{P}^{(0)} \quad \mathbf{P}^{S(1)} - \mathbf{P}^{(0)} \quad \mathbf{W}_{D}^{(1)} - \mathbf{W}^{(0)} \quad \mathbf{W}_{S}^{(1)} - \mathbf{W}^{(0)}\right].$$

The approximation in (33) reduces to

$$
(34) \quad \begin{aligned}
\Delta SW \approx & \left(\mathbf{EW}_S\right)^{\mathrm{T}} \mathbf{D}_W \mathbf{X}^{(0)} + 0.5\left(\mathbf{EW}_S\right)^{\mathrm{T}} \mathbf{D}_{WX} \boldsymbol{\varepsilon}_L \mathbf{EW}_S && \text{(a)} \\
& - \left[\left(\mathbf{EP}^D\right)^{\mathrm{T}} \mathbf{D}^P \mathbf{Q}^{(0)} + 0.5\left(\mathbf{EP}^D\right)^{\mathrm{T}} \mathbf{D}^{PQ}\left(\boldsymbol{\eta}^N + \boldsymbol{\eta}^{N,M}\mathbf{w}^T\right)\mathbf{EP}^D\right] && \text{(b)} \\
& + \left(\mathbf{t}^N\right)^{\mathrm{T}} \mathbf{D}_P \mathbf{Q} + \left(\mathbf{t}^N\right)^{\mathrm{T}} \mathbf{D}_{PQ} \mathbf{EQ} && \text{(c)} \\
& - \left(\mathbf{s}_L\right)^{\mathrm{T}} \mathbf{D}_W \mathbf{X} - \left(\mathbf{s}_L\right)^{\mathrm{T}} \mathbf{D}_{WX} \mathbf{EX} && \text{(d)}
\end{aligned}
$$

(see Technical Appendix 1A).

In this equation the measure of social welfare change depends on the initial prices and quantities of food products and of commodities used as inputs to produce them, the elasticities of commodity supply and product demand, the exogenous rates of tax and subsidy, and the proportional changes in prices of commodities and products that would result from the introduction of those taxes and subsidies. The approximation of social welfare in (34) is graphically intuitive. To see this, note that line (a) and line (b) in equation (34) are the change in profits across all commodity markets and the compensating variation across all retail product markets, respectively. Line (c) comprises the change in government revenue from introducing a set of retail taxes, and line (d) comprises the change in government revenue from introducing a set of commodity taxes.

We augment the measures of change in social welfare to reflect changes in public health-care expenditures related to changes in obesity status. To quantify the change in government health-care expenditures associated with policy-induced changes in food consumption and obesity status, we use multipliers defined in terms of the body mass index (BMI). BMI is defined as weight (W) in kilograms divided by height (H) in meters squared:

$$
(35) \quad BMI = \mathrm{W}\left(\mathbf{Q}, \bar{E}, \bar{g}\right) / \bar{H}^2,
$$

where W(·) is a function of **Q**, an N × 1 vector of quantities of food and nonfood, $\bar{E}$, energy expenditure that is held constant, and $\bar{g}$, genetic predisposition. Taking the derivative of (35) and expressing it in logarithmic differentials yields

$$\mathrm{E}\,BMI = \sum_{n=1}^{N} \eta^{W,Q^n}\,\mathrm{E}\,Q^n,$$

where η^{W,Q^n} is the elasticity of weight with respect to the quantity of food *n* consumed. Assuming that public health-care expenditures will increase by an amount *e* per unit increase of BMI, the change in social welfare from a policy shock that induces changes in public health care spending, is

$$\text{(36)} \qquad \Delta SW^* = \Delta SW + \left(\boldsymbol{\eta}^{WQ}\right)^{\mathrm{T}} e\mathbf{EQ}\sum_{i=1}^{I}\left(BMI_i\right),$$

where the ΔSW is the change in social welfare defined in (34), $\boldsymbol{\eta}^{WQ}$ is an $N \times 1$vector of elasticities of weight with respect to quantities consumed of different foods, and **EQ** is defined in (37) for the general model and in Table 1 for the nested cases.

4. Data

The data necessary to parameterize the model include (a) Marshallian elasticities of demand for food products, (b) farm-retail product shares (i.e., the cost of each individual farm commodity as a share of the value of each retail food product) and farm-commodity shares (i.e., the share of each commodity used in the production of each retail food product), (c) elasticities of supply of farm commodities and the composite marketing input, (d) elasticities of substitution between farm commodities and the composite marketing input (i.e., Hicksian elasticities of demand for commodities), (e) food-to-calorie multipliers, (f) calorie-to-weight multipliers, and (g) weight-to-health expenditure multipliers. In all of the simulations, we assumed fixed proportions technology in the food industry, such that all Hicksian elasticities of demand for commodities are zero (i.e., $\boldsymbol{\eta}_L^* = \mathbf{0}$).

First, we use elasticities of demand for eight FAH products (i.e., cereals and bakery products, red meat, poultry and eggs, seafood and fish, dairy, fruits and vegetables, other foods, nonalcoholic beverages), a FAFH composite, and alcoholic beverages, from Okrent and Alston (2011) to parameterize $\boldsymbol{\eta}^N$. The Marshallian elasticities of demand for these products are listed in Table 2.[5]

INSERT Table 2 HERE

For the elasticities of supply of farm commodities ($\boldsymbol{\varepsilon}_L$), we look at two cases. First, we assume commodity prices are exogenous. The assumption of exogenous commodity prices is implicitly an extreme assumption about the elasticities of supply. In this case, the elasticities of supply of the commodities are all effectively infinity, and the solutions to the general model collapse to the nested solutions in Table 1. The assumption of exogenous prices may be extreme but it has been applied widely in models of food policy and obesity. As a more complicated but also more realistic alternative, we also analyzed a case with endogenous prices of food and farm commodities. For this case we used own-price elasticities of supply of farm commodities based on the lower bound estimates of Chavas and Cox (1995). Because the farm commodities in Chavas and Cox do not exactly correspond to the farm commodities being analyzed in this study, we assumed that each of the disaggregated commodities has the same own-price elasticities as their corresponding aggregate commodity group (Table 3). Lastly, we assumed that the elasticity of supply for the marketing input is large and close to being perfectly elastic.

[5] Okrent and Alston (2011) estimated these elasticities specifically with the present application in mind. 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.

INSERT Table 3 HERE

We estimated the farm-retail product (**SR**), farm-commodity (**SC**) shares and values for the total output for retail products and commodities ($\mathbf{D}_{WX}$ and $\mathbf{D}^{PQ}$, respectively) 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). The estimated shares and retail product and commodity values for 2002 are presented in Table 4, Table 5, and Table 6.

INSERT Table 4 HERE

INSERT Table 5 HERE

INSERT Table 6 HERE

Once the proportionate changes in quantities of retail products have been calculated for a given policy using the model as represented in (38), the changes in quantities consumed can be translated into measures of changes in calorie consumption and changes in weight ($\boldsymbol{\eta}^{WQ}$). First, we used one day of 24-hour dietary recall data collected in the 2003–04 National Health and Nutrition Examination Survey (NHANES) to estimate average daily grams of the nine foods consumed as well as the associated average daily calories, and grams of fat and added sugar for individuals 18 years and older (Table 7). Second, we converted the changes in calorie consumption resulting from a policy to changes in weight for the average individual adult. One frequently used relationship in textbooks (e.g., Whitney, Cataldo, and Rolfes 1994) and academic articles that address the potential impacts of fiscal policies on weight (e.g., Chouinard et al. 2007; Smith, Lin and Lee 2010) is that a pound of fat tissue has about 3,500 calories. We use this relationship to convert changes in calorie consumption into changes in body weight.

INSERT Table 7 HERE

Lastly, we used estimates from the public health literature to quantify how the changes in weight translate into changes in public health-care expenditures (Centers for Disease Control and Prevention, National Center for Health Statistics 2008). We based our estimate of the weight-to-health care multiplier (e) on Pronk et al. (1999). Pronk et al. (1999) estimated that a one-unit increase in BMI would yield an $11 increase in billed charges for health care services over 18 months for a random sample drawn from population of individuals 40 years and older enrolled in a Minnesota health plan. In the health economics literature, the actual cost of services provided by a health care provider is less than the amount billed for these services by the provider. To account for this discrepancy, billed charges are multiplied by a cost-to-charge ratio. For Minnesota in 1994, the cost-to-charge ratio for urban areas was 0.597 (Haddix and Schaffer 1996). Hence, $e = \$11 \times 0.597 = \$6.57$.

5. Simulations

We simulated the price, quantity, calorie, weight and social welfare effects for various policies that have been suggested by policymakers as ways to reduce the costs of obesity in the United States. The first set of policy simulations addresses the notion that subsidies to farmers are a key driver of obesity patterns in the United States (e.g., Pollan 2003, 2007; Tillotson 2004; Muller, Schoonover, and Wallinga 2007). Agricultural economists have argued that farm subsidies have had minimal impacts on obesity (e.g., Alston, Sumner, and Vosti 2006; Alston, Sumner, and Vosti 2008; Beghin and Jensen 2008), but none of the previous studies quantified the impacts. The second set of policy simulations quantifies the effects of subsidizing fruit and vegetable commodities and fruit and vegetable retail products; both policies have been suggested by nutritionists (Tohill 2005; Guthrie 2004) and mentioned in the Farm Bill debate (Guenther 2007; Bittman 2011) as ways of addressing obesity. The third and final set of policies are taxes on the nutrient content of foods—i.e., taxes on food products based on their content of calories, sugar or fat. If the goal of a policy is to reduce the weight and hence BMI status of a population, then a calorie tax would intuitively be the most efficient tax, but proponents typically favor taxes on particular energy-dense foods (such as sodas) or sources of calories (such as sugar or fat).

Removal of Farm Subsidies

We computed the effects of eliminating farm subsidies using estimates of their price impacts from several sources and treating commodity prices as exogenous in our model for this purpose. Sumner (2005) estimated that elimination of subsidies for corn, wheat and rice would increase the world prices of these crops by 9–10%, 6–8% and 4–6%, respectively, based on market prices and policies in the early 21st century. Using the value of U.S. production of each crop relative to their sum as weights, we calculated the value-share-weighted effect of the elimination of grain subsidies on the composite food grain price to be an 8.4 percent increase. The elimination of the corn subsidy would also affect the price of feed grains, and hence, the cost of production and prices of livestock commodities. The effect of the removal of corn subsidies on the price of a livestock commodity is computed as the percentage change in the world market price of corn from the elimination of the subsidy, multiplied by the cost share of corn in production of that commodity. Applying these implied price changes in the simulation model, eliminating farm subsidies on grain commodities would result in a decrease in consumption of 819 calories per adult per year, which corresponds to a decrease in body weight of 0.11 kilograms per year for an average adult individual in the United States (Table 8). The removal of the U.S. grain subsidy would increase social welfare, but the actual magnitude of the net gain cannot be determined using the social welfare measure presented in this paper because this measure does not reflect the government revenue effects of changes in border measures or other details of the actual subsidies that are represented in our analysis as fully coupled equivalent rates.

INSERT Table 8 HERE

Some agricultural policies entail benefits or costs to consumers in addition to those implied by changes in world market prices, including trade barriers for sugar, dairy, and some fruit and vegetable commodities. To capture the effects of these policies on commodity prices paid by buyers, we used the commodity-specific consumer support estimates (CSEs) calculated by the Organization for Economic Co-operation and Development (2010) for three periods: 1989–2009, 2000–2009, and 2006 (Table 9).

INSERT Table 9 HERE

The removal of border measures would result in lower prices and increases in consumption of some commodities. We represented this policy in the model as the introduction of an equivalent set of subsidies in conjunction with the removal of the other farm subsidies already discussed. The net effect would be to increase calorie consumption. Not surprisingly, calories from consumption of dairy and fruit and vegetable food products would increase (by 1,720 kcal and 827 kcal, respectively) if subsidies were introduced that would have effects equivalent to eliminating the 2006 CSEs. Compared to eliminating just grain subsidies, eliminating all farm subsidies would result in a larger reduction in consumption of calories of cereals and bakery products (–1,451 kcal versus –218 kcal). This result is driven by greater substitution out of cereals and bakery products into fruits and vegetables and dairy because the increase in the price of grain commodities is now accompanied by a reduction in the price of milk, fruit, and vegetable commodities.

Elimination of all subsidies including trade barriers would lead to an increase in annual per capita consumption in the range of 165 to 1,435 calories (equivalent to an increase in body weight of 0.03% to 0.23%), depending on the size of the policy-induced price wedges to be removed, as represented by the CSEs. Even though individuals would consume less calories from cereals and bakery products and FAFH, they would consume more calories from dairy and fruits and vegetables. These results indicate that U.S. farm policy, for the most part, has not made food commodities significantly cheaper and has not had a significant effect on caloric consumption.

Subsidies Applied to Fruits and Vegetables

We estimated the likely effects from two types of subsidies applied to fruits and vegetables: (a) subsidies applied to fruit and vegetable retail products at a rate of 10%, and (b) subsidies applied to fruit and vegetable farm commodities at a rate of approximately 16.24 % (Table 10). Both policies would cost the government roughly $5,846 million per year.

INSERT Table 10 HERE

In the case of exogenous commodity prices, a 10% subsidy on fruit and vegetable retail products would cause the consumption of fruit and vegetables to increase. However, because fruits and vegetables are substitutes for cereals and bakery products, meat, nonalcoholic beverages and FAFH, consumption of these foods, and hence, calories from them would decrease (by 1,712 kcal per year, 961 kcal per year, 849 kcal per year, and 1,625 kcal per year, respectively). Hence, a policy of subsidizing fruit and vegetable retail products at 10% would potentially increase calorie consumption by 254 per year for an average adult in the United

States. This policy would yield benefits to consumers of $5,680 million per year (Table 11). The net change in social welfare would be a loss of $166 million per year. This measure excludes the additional cost to government from increases in the body weight of the Medicare and Medicaid populations. The increase of 0.03 kilograms in body weight per year for the average adult would potentially cost $19 million in public health care expenditures, increasing the deadweight loss to $186 million per year.

INSERT Table 11 HERE

A slightly different story unfolds when we allow for upward-sloping supply of farm commodities. In this case the subsidy on fruit and vegetable retail products has a negative effect on overall calorie consumption (254 kcal per year compared with –79 kcal per year). When the supply of farm commodities is less than perfectly elastic, the effect of the fruit and vegetable product subsidy on food prices, and thus on consumption, is smaller across all food products, but especially so for food products that have relatively large farm-retail product shares. The food products with the biggest farm-retail product shares include eggs, dairy and fruits and vegetables. Hence, when we allow for upward-sloping supply, the effect of the subsidy policy on consumption on these food products is dampened to a much greater degree compared with FAFH and cereals and bakery products, which have relatively small farm-retail product shares. The result is a larger decrease in calories consumed per year for foods that are substitutes for fruits and vegetables relative to the increase in calories consumed per year for fruits and vegetables and its complements. Ultimately, average body weight would decrease by 0.01 kilograms per adult per year under the assumption of upward-sloping supply. It should be noted that under both assumptions about commodity supply, the 10 % fruit and vegetable product policy has very little impact on calorie consumption.

Suppose the government were to spend the same amount of money but chose to subsidize fruit and vegetable farm commodities rather than fruit and vegetable food products. This would translate into a 16.24% subsidy on fruit and vegetable commodities, depending on the assumptions made about the supply of commodities. Subsidies on fruit and vegetable commodities would cause consumption of calories to increase to a much greater extent than subsidies on fruit and vegetable products. The difference arises largely because fruit and vegetable commodities are used as inputs in the production of FAFH, and consequently subsidies on fruit and vegetable commodities reduce the cost of production of FAFH as well as fruit and vegetable retail products. Consumers would still substitute away from FAFH and towards now relatively cheaper fruits and vegetables, but this effect is dampened by the implicit subsidy to FAFH from the fruit and vegetable commodity subsidies. Hence, the reduction in calories consumed from FAFH is smaller under the fruit and vegetable commodity subsidies compared with the fruit and vegetable product subsidy, and the net effect is an increase in calories consumed. Assuming that the supply of commodities is perfectly elastic, calories consumed from FAFH would decrease by 1,083 kcal per adult per year in response to the subsidy on fruit and vegetable commodities, which is substantially less than the decrease in calories consumed from FAFH caused by the subsidy on fruit and vegetable products (1,625 kcal per adult per year). The same rationale holds for the scenario of upward-sloping supply of commodities.

Under the exogenous price assumption, the fruit and vegetable farm commodity subsidies are less distortionary than the fruit and vegetable product subsidy (i.e., $166 million compared with $109 million) because the fruit and vegetable product subsidy induces the most substitution in the highest value markets (i.e., FAFH and meat). For the case of upward-sloping supply, the fruit and vegetable product subsidy is still less distortionary ($106 million compared with $68 million) but to a much lesser extent. However, under both commodity supply scenarios, the fruit and vegetable commodity subsidy would result in an increase in consumption of calories and body weight (between 0.06 kg and 0.11 kg per adult per year). If the objective is to reduce consumption of calories and body weight, these results imply that a tax, not a subsidy, should be applied to fruit and vegetable farm commodities. Given that the model is approximately linear over the small changes being analyzed, the effects of a tax can be seen by multiplying all the results for a subsidy by minus one.

Food Taxes

We derived ad valorem taxes for foods that would correspond to per unit taxes on their nutrient content in fat, calories, and sugar (see Technical Appendix 3A). We arbitrarily chose a tax of half a cent per gram of fat (i.e., $5 per kilogram). Subsequently, we chose the sugar tax ($0.002637 per gram) and the calorie tax ($0.0001632 per calorie) such that the resulting annual reduction in calories consumed per adult would be approximately the same under each tax policy. We also analyzed the policy of a uniform tax on all foods (roughly 5%) that would achieve approximately the same reduction in calories per day.

Fat Tax. A fat tax would cause total annual consumption of calories to decrease by 18,531 kcal per adult with upward-sloping supply of commodities and 19,302 kcal per adult with exogenous commodity prices. More than half of the reduction in calories consumed would come from decreased consumption of FAFH. FAFH is a gross substitute for meat, and fruits and vegetables, and these foods are taxed at lower rates than FAFH (5.66% tax on FAFH compared with a 1.92% tax on fruits and vegetables, a 4.95% tax on meat). In addition, FAFH is a gross complement for cereals and bakery products and dairy, two of the most heavily taxed foods. Hence, consumption of FAFH decreases not only because of an increase in its own price, but also because of strong cross-price effects from increases in other prices. Not surprisingly, the reduction in calories consumed under the fat tax also reflects a decrease in calories from both dairy and cereals and bakery products.

The magnitude of the deadweight loss under the two supply scenarios is approximately equivalent: $1,854 million when commodity supply is perfectly elastic and $1,669 million when commodity supply is upward sloping. When supply is upward sloping, both consumers and producers would be negatively affected by the policy, with the burden falling mainly on consumers. Public health-care expenditures attributable to obesity would decline by approximately $1,477 million in the case of exogenous commodity prices and $1,418 million in the case of upward-sloping supply. The fat tax would ultimately cost between $0.20 and $1.44 per pound of weight lost by adult Americans.

Calorie Tax. Suppose, the U.S. government taxed food products at a rate of approximately $0.00016 per calorie to achieve approximately the same reduction in calories as the fat tax of $5 per kilogram. Again, more than half of the calorie reduction would be the result of a decrease in calories consumed from FAFH. However, unlike the fat tax, under a calorie tax about a quarter of the total decrease in calories consumed per adult per year would result from reduced consumption of cereals and bakery products. Again, changes in the consumption of dairy products would contribute importantly to the reduction in consumption of calories (a reduction of 1,893 kcal per year with upward-sloping commodity supply, or 1,490 kcal per year with perfectly elastic commodity supply), although the magnitude of the change is smaller compared with the fat tax.

Compared with the fat tax, the calorie tax would distort relative prices and consumption less, which implies a smaller deadweight loss. The deadweight loss from the calorie tax ranges between $1,212 million and $1,105 million per year. Because the tax rates under the different tax policies were constructed to achieve approximately the same reduction in calorie consumption per adult per year, the change in public health care expenditures is approximately the same under the calorie tax as under the fat tax. The change in social welfare, including changes in public health care expenditures, from the calorie tax is positive (between $265 million and $313 million per year), which reflects the smaller deadweight loss associated with the calorie tax compared with the fat tax. A calorie tax would cost $0.89 per pound lost for an American adult if we do not account for the resulting reduction in health care expenditures associated with decreases in obesity. Including these savings implies a benefit of $0.25 per pound lost under a calorie tax.

Sugar Tax. Suppose, alternatively, the U.S. government taxed food products at a rate of $0.0026 per gram of sugar to achieve approximately the same reduction in calories as the fat and calorie tax. Like the fat and calorie taxes, more than half of the reduction in calories consumed would reflect a decrease in calories consumed from FAFH. However, unlike taxes on fat or calories, a reduction in calories consumed from nonalcoholic beverages would account for about a quarter of the total decrease in calories consumed per adult per year. Similar to the fat and calorie taxes, changes in the consumption of dairy products are an important source of calorie reduction (reductions of 2,101 kcal per adult per year under upward-sloping commodity supply scenario compared with 2,817 kcal per adult per year under perfectly elastic commodity supply). Compared with the fat and calorie taxes, the sugar tax would be associated with a deadweight loss of $1,270 million under exogenous commodity prices and $1,145 million under upward-sloping commodity supply. When the reduction in public health care expenditures associated with the calorie reduction is included, the change in social welfare becomes a net gain (between

$207 and $274 million). Including the changes in health care costs from the sugar policy, the benefit would be between $0.16 and $0.22 per adult pound lost, which is smaller than the benefit from an equivalent calorie tax but still better than the fat tax, which would involve a deadweight loss.

Uniform Food Tax. The last tax policy we analyze is a uniform tax on all foods of about 5%. The uniform tax rate was chosen to achieve approximately the same reduction in calories as the taxes in fat, calorie, or sugar tax would, around 18–19,000 kcal per adult per year. The uniform tax is more distortionary than the sugar and calorie taxes but less so than the fat tax. The deadweight loss excluding changes in health care costs induced by the uniform tax would be between $1,367 million and $1,495 per year. Like the calorie tax and sugar tax, the uniform tax could potentially result in a net gain if changes in public health care costs are considered. For the case of upward-sloping supply, the uniform tax would benefit the United States at $0.04 per pound lost while for the case of perfectly elastic supply, the uniform tax would cost $0.01 per pound lost.

6. Summary and Conclusion

Previous studies of the potential impacts of food and farm policies on obesity have imposed restrictive assumptions on their analysis. For example, studies of the potential impacts of food policies on obesity have all assumed that 100 percent of the incidence of a tax or subsidy would be borne by final consumers. A related issue is the determination of the relevant counterfactual alternative in policy analysis. Many of these studies evaluated the effect of a tax or subsidy on one group of foods (e.g., beverages or snack foods) without considering substitution effects on consumption of foods not included in their analysis.

We set out to analyze and evaluate the effects of food and farm policies on food consumption, body weight of adults, and social welfare in the United States. To address this goal, we developed an equilibrium displacement model that allows for multiple inter-related food products to be vertically linked to multiple inter-related farm commodities and marketing inputs. We established the structure of the equilibrium displacement model to make it possible to obtain corresponding approximations to exact money metric measures of welfare changes associated with policy changes. We showed how the solutions of the equilibrium displacement model could be used to estimate the effects of any of the policies on social welfare and its distribution between consumers and producers.

The first set of policy experiments showed that eliminating farm subsidies—including direct subsidies on grains and indirect subsidies from trade barriers on dairy, sugar, and fruit and vegetable commodities—would have very limited impact on calorie consumption, and hence, obesity. Second, we found that for both supply scenarios, the most efficient policy would be a tax on food based on its caloric content, which would yield a benefit to national welfare between \$0.21 \$0.25 per pound of fat lost. An equivalent sugar tax would also yield a benefit under both supply scenarios, although less than the calorie tax. A comparable fat tax or uniform food tax would be more expensive, respectively costing approximately \$0.01 or \$0.29 per pound of body fat lost in the case of exogenous prices.

In contrast to the tax policies, the fruit and vegetable subsidies would be very inefficient. A 10% subsidy on fruit and vegetable retail products would cost \$20.14 per pound lost under the assumption of inelastic supply of commodities. Because the fruit and vegetable commodity subsidy would actually increase consumption of calories under both supply scenarios, for comparison, we calculated the cost per pound of fat reduction for a 17% tax on fruit and vegetable commodities. A tax on fruit and vegetable commodities would be slightly more efficient than a subsidy on fruit and vegetable retail products, costing \$2.30 per pound of fat lost compared with \$2.34 in the case of exogenous prices.

Ultimately, if the goal of policymakers is simply to reduce obesity in the United States, among those considered here, the most efficient policy would be to tax calories. If other objectives also matter, a more complex policy may be called for. For instance, particular foods might involve externalities other than through their impacts on obesity (e.g., the consumption of saturated fats may be implicated in cancers or coronary heart disease in ways that mean calories consumed as saturated fats should be taxed more heavily than calories generally). Conversely, the overall nutritional composition of an individual's diet, and not just the caloric content may have health implications that matter (a diet of only grapefruit, which is low in calories, would be nutritionally poor), but would not be addressed by a calorie tax. Finally, a calorie tax would be regressive, falling disproportionately heavily on the poor. Consideration of these complications need not rule out a calorie tax, and do not seem likely to change the efficiency ranking of a calorie tax relative to the other taxes and subsidies considered here, but do imply that a calorie tax might have to be implemented as part of a package, jointly with other instruments, such as education programs, product information, and food assistance programs, and possibly combined with other taxes, subsidies, and regulations. The design of such policies might also need to account for the potential role of induced innovation in the food industry, which would make endogenous the nutrient content of particular food groups that has been treated as fixed in our analysis, and is a dimension with significant potential for change.

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1A. Technical Appendix of Derivations of Social Welfare Formula

The formula for social welfare (equation (34)) is derived by first solving the gradient of the social welfare function and then the Hessian of the social welfare function in (33). We first rewrite the $2(N+L)\times 1$ gradient of the social welfare function as

$$\nabla \mathrm{SW}\left(\mathbf{P},\mathbf{W},u\right)=\begin{bmatrix}\nabla_{P^D}\,\mathrm{SW}(\cdot)\\ \nabla_{P^S}\,\mathrm{SW}(\cdot)\\ \nabla_{W_D}\,\mathrm{SW}(\cdot)\\ \nabla_{W_S}\,\mathrm{SW}(\cdot)\end{bmatrix},$$

where ∇_{P^D} and ∇_{P^S} denote the vector of $N \times 1$ first-order partial derivatives of the social welfare function with respect to consumer and producers retail prices, and ∇_{W_D} and ∇_{W_S} denote the vector of $L \times 1$ first-order partial derivatives of the social welfare function with respect to buyer and seller commodity prices. The gradient of the social welfare function at $\left(\mathbf{P}^{(0)},\mathbf{W}^{(0)}\right)$ is

$$\text{(1A-1)}\qquad \nabla \mathrm{SW}\left(\mathbf{P}^{(0)},\mathbf{W}^{(0)},u^{(0)}\right)=\begin{bmatrix}\nabla_{P^D}\,\mathrm{g}\left(\mathbf{P}^{(0)},\mathbf{W}^{(0)},u^{(0)}\right)-\nabla_{P^D}\,\mathrm{e}\left(\mathbf{P}^{(0)},\mathbf{W}^{(0)},u^{(0)}\right)\\ \nabla_{P^S}\,\mathrm{g}\left(\mathbf{P}^{(0)},\mathbf{W}^{(0)},u^{(0)}\right)-\nabla_{P^S}\,\mathrm{e}\left(\mathbf{P}^{(0)},\mathbf{W}^{(0)},u^{(0)}\right)\\ \nabla_{W_D}\pi\left(\mathbf{P}^{(0)},\mathbf{W}^{(0)},u^{(0)}\right)+\nabla_{W_D}\,\mathrm{g}\left(\mathbf{P}^{(0)},\mathbf{W}^{(0)},u^{(0)}\right)\\ \nabla_{W_S}\pi\left(\mathbf{P}^{(0)},\mathbf{W}^{(0)},u^{(0)}\right)+\nabla_{W_S}\,\mathrm{g}\left(\mathbf{P}^{(0)},\mathbf{W}^{(0)},u^{(0)}\right)\end{bmatrix},$$

where $\nabla_{P^D}\,\mathrm{e}\left(\cdot\right)$, $\nabla_{P^D}\,\mathrm{g}\left(\cdot\right)$, $\nabla_{P^S}\,\mathrm{e}\left(\cdot\right)$, and $\nabla_{P^S}\,\mathrm{g}\left(\cdot\right)$ are $N \times 1$ gradients of the consumer expenditure and the government revenue functions, respectively, and $\nabla_{W_D}\pi\left(\cdot\right)$, $\nabla_{W_D}\,\mathrm{g}\left(\cdot\right)$ $\nabla_{W_S}\pi\left(\cdot\right)$ and $\nabla_{W_S}\,\mathrm{g}\left(\cdot\right)$ are $L \times 1$ gradients of the profit and government revenue functions with respect to consumer and product prices of commodities, respectively.

Several substitutions can be made to simplify (1A-1). Since the producer prices of retail products have no effect on consumer expenditure on goods and the buyer prices of commodities have no effect on profits for commodity producers,

$$(1A\text{-}2)\qquad \nabla_{P^S}\,\mathrm{e}\left(\mathbf{P}^{(0)},\mathbf{W}^{(0)},u^{(0)}\right)=0,$$

$$(1A\text{-}3)\qquad \nabla_{W_D}\pi\left(\mathbf{P}^{(0)},\mathbf{W}^{(0)},u^{(0)}\right)=0,$$

Second, Shephard's lemma implies that the derivative of the consumer expenditure function with respect to price *n* is the Hicksian demand for good *n*. Hence, the gradient of the consumer expenditure function with respect to consumer prices of retail products is an *N*-vector of Hicksian demands for retail products, h(·):

$$\nabla_{P^D}\,\mathrm{e}\left(\mathbf{P}^{(0)},u^{(0)}\right)=\mathbf{h}\left(\mathbf{P}^{(0)},u^{(0)}\right).$$

At $\left(\mathbf{P}^{(0)},\mathbf{W}^{(0)}\right)$, Hicksian demands for retail products are equal to their Marshallian counterparts, so

$$(1A\text{-}4)\qquad \nabla_{P^D}\,\mathrm{e}\left(\mathbf{P}^{(0)},u^{(0)}\right)=\mathbf{Q}^{(0)}.$$

Third, Hotelling's lemma implies that the partial derivative of the profit function with respect to the producer price of commodity *l* is the supply of commodity *l*. Hence, stacking the *L* partial derivatives into an $L\times 1$vector yields the gradient of the profit function, which is equal to an $L\times 1$ vector of commodity supplies, which is equal to the corresponding vector of commodity demands at $\left(\mathbf{P}^{(0)},\mathbf{W}^{(0)}\right)$:

$$(1A\text{-}5)\qquad \nabla_{W_S}\pi\left(\mathbf{W}^{(0)}\right)=\mathbf{X}^{(0)}.$$

After substituting (1A-2)–(1A-4) into (1A-1), the gradient of the social welfare becomes

$$(1A\text{-}6)\qquad \nabla\,\mathrm{SW}\left(\mathbf{P}^{(0)},\mathbf{W}^{(0)},u^{(0)}\right)=\begin{bmatrix}\nabla_{P^D}\,\mathrm{g}\left(\mathbf{P}^{(0)},\mathbf{W}^{(0)},u^{(0)}\right)-\mathbf{Q}^{(0)}\\ \nabla_{P^S}\,\mathrm{g}\left(\mathbf{P}^{(0)},\mathbf{W}^{(0)},u^{(0)}\right)\\ \nabla_{W_D}\,\mathrm{g}\left(\mathbf{P}^{(0)},\mathbf{W}^{(0)},u^{(0)}\right)\\ \mathbf{X}^{(0)}+\nabla_{W_S}\,\mathrm{g}\left(\mathbf{P}^{(0)},\mathbf{W}^{(0)},u^{(0)}\right)\end{bmatrix}.$$

The $2(N+L)\times 2(N+L)$ Hessian of the social welfare function is

$$\nabla^2 \mathrm{SW}(\cdot) = \begin{bmatrix} \nabla^2_{P^D} \mathrm{SW}(\cdot) & \nabla_{P^D P^S} \mathrm{SW}(\cdot) & \mathbf{0} & \mathbf{0} \\ \nabla_{P^S P^D} \mathrm{SW}(\cdot) & \nabla^2_{P^S} \mathrm{SW}(\cdot) & \mathbf{0} & \mathbf{0} \\ \mathbf{0}^{\mathrm{T}} & \mathbf{0}^{\mathrm{T}} & \nabla^2_{W_D} \mathrm{SW}(\cdot) & \nabla_{W_D W_S} \mathrm{SW}(\cdot) \\ \mathbf{0}^{\mathrm{T}} & \mathbf{0}^{\mathrm{T}} & \nabla_{W_S W_D} \mathrm{SW}(\cdot) & \nabla^2_{W_S} \mathrm{SW}(\cdot) \end{bmatrix},$$

where $\mathbf{0}$ is a $N \times L$ matrix of zeros, $\nabla^2_{P^D}, \nabla^2_{P^S}$ $\nabla_{P^D P^S}$ and $\nabla_{P^S P^D}$ denote the $N \times N$ second-order partial derivatives of the social welfare function with respect to consumer and producer retail prices, and $\nabla^2_{W_D}, \nabla^2_{W_S}$ $\nabla_{W_D W_S}$ and $\nabla_{W_S W_D}$ denote the vector of $L \times L$ second-order partial derivatives of the social welfare function with respect to buyer and seller commodity prices. The Hessian of the social welfare function can be rewritten as

$$\text{(1A-7)} \qquad \nabla^2 \mathrm{SW}(\cdot) = \begin{bmatrix} \nabla^2_{P^D} \mathrm{g}(\cdot) - \nabla^2_{P^D} \mathrm{e}(\cdot) & \nabla_{P^D P^S} \mathrm{g}(\cdot) & \mathbf{0} & \mathbf{0} \\ \nabla_{P^S P^D} \mathrm{g}(\cdot) & \nabla^2_{P^S} \mathrm{g}(\cdot) & \mathbf{0} & \mathbf{0} \\ \mathbf{0}^{\mathrm{T}} & \mathbf{0}^{\mathrm{T}} & \nabla^2_{W_D} \mathrm{g}(\cdot) & \nabla_{W_D W_S} \mathrm{g}(\cdot) \\ \mathbf{0}^{\mathrm{T}} & \mathbf{0}^{\mathrm{T}} & \nabla_{W_S W_D} \mathrm{g}(\cdot) & \nabla^2_{W_S} \pi(\cdot) + \nabla^2_{W_S} \mathrm{g}(\cdot) \end{bmatrix}.$$

Several substitutions can be made to simplify (1A-7). First, the Hessian of the expenditure function with respect to consumer prices is the $N \times N$ Slutsky matrix, $\mathbf{S}(\mathbf{P}^{(0)}, u^{(0)})$:

$$\text{(1A-8)} \qquad \nabla^2_{P^D} \mathrm{e}\left(\mathbf{P}^{(0)}, u^{(0)}\right) = \nabla_{P^D} \mathbf{h}\left(\mathbf{P}^{(0)}, u^{(0)}\right) = \mathbf{S}\left(\mathbf{P}^{(0)}, u^{(0)}\right).$$

Second, Hotelling's lemma implies

$$\text{(1A-9)} \qquad \nabla^2_{W^S} \pi\left(\mathbf{W}^{(0)}\right) = \nabla_{W^S} \mathbf{X}_S \left(\mathbf{W}^{(0)}, \boldsymbol{\beta}^{(0)}\right),$$

where $\nabla_{W^S} \mathbf{X}_S \left(\mathbf{W}^{(0)}, \boldsymbol{\beta}^{(0)}\right)$ is an $L \times L$ matrix of partial derivatives of commodity demands with respect to commodity prices. Substituting (1A-8) and (1A-9) into (1A-7), the Hessian of the social welfare function becomes

$$(1A\text{-}10)\qquad \nabla^2 \mathrm{SW}(\cdot)=\begin{bmatrix} \nabla^2_{P^D}\,\mathrm{g}(\cdot)-\mathbf{S}(\cdot) & \nabla_{P^DP^S}\,\mathrm{g}(\cdot) & \mathbf{0} & \mathbf{0} \\ \nabla_{P^SP^D}\,\mathrm{g}(\cdot) & \nabla^2_{P^S}\,\mathrm{g}(\cdot) & \mathbf{0} & \mathbf{0} \\ \mathbf{0}^{\mathrm{T}} & \mathbf{0}^{\mathrm{T}} & \nabla^2_{W_D}\,\mathrm{g}(\cdot) & \nabla_{W_DW_S}\,\mathrm{g}(\cdot) \\ \mathbf{0}^{\mathrm{T}} & \mathbf{0}^{\mathrm{T}} & \nabla_{W_SW_D}\,\mathrm{g}(\cdot) & \nabla_{W_S}\mathbf{X}(\cdot)+\nabla^2_{W_S}\,\mathrm{g}(\cdot) \end{bmatrix}.$$

The change in social welfare from a policy-induced price change is found by substituting (1A-6) and (1A-10) into (1A-1) and multiplying out the block matrices:

$$(1A\text{-}11)\qquad \begin{aligned} \Delta SW \approx\ & \left(\Delta\mathbf{P}^D\right)^{\mathrm{T}}\left[\nabla_{P^D}\,\mathrm{g}(\cdot)-\mathbf{Q}^{(0)}\right]+\left(\Delta\mathbf{P}^S\right)^{\mathrm{T}}\nabla_{P^S}\,\mathrm{g}(\cdot) \\ +\ & \left(\Delta\mathbf{W}_S\right)^{\mathrm{T}}\left[\mathbf{X}^{(0)}+\nabla_{W_S}\,\mathrm{g}(\cdot)\right]+\left(\Delta\mathbf{W}_D\right)^{\mathrm{T}}\nabla_{W_D}\,\mathrm{g}(\cdot) \\ +\ & 0.5\left[\left(\Delta\mathbf{P}^D\right)^{\mathrm{T}}\left(\nabla^2_{P^D}\,\mathrm{g}(\cdot)-\mathbf{S}(\cdot)\right)+\left(\Delta\mathbf{P}^S\right)^{\mathrm{T}}\nabla_{P^SP^D}\,\mathrm{g}(\cdot)\right]\Delta\mathbf{P}^D \\ +\ & 0.5\left[\left(\Delta\mathbf{P}^D\right)^{\mathrm{T}}\nabla_{P^DP^S}\,\mathrm{g}(\cdot)+\left(\Delta\mathbf{P}^S\right)^{\mathrm{T}}\nabla^2_{P^S}\,\mathrm{g}(\cdot)\right]\Delta\mathbf{P}^S \\ +\ & 0.5\left[\left(\Delta\mathbf{W}_S\right)^{\mathrm{T}}\nabla_{W_SW_D}\,\mathrm{g}(\cdot)+\left(\Delta\mathbf{W}_D\right)^{\mathrm{T}}\nabla^2_{W_D}\,\mathrm{g}(\cdot)\right]\Delta\mathbf{W}_D \\ +\ & 0.5\left[\left(\Delta\mathbf{W}_S\right)^{\mathrm{T}}\left(\nabla_{W_S}\mathbf{X}(\cdot)+\nabla^2_{W_S}\,\mathrm{g}(\cdot)\right)+\left(\Delta\mathbf{W}_D\right)^{\mathrm{T}}\nabla_{W_DW_S}\,\mathrm{g}(\cdot)\right]\Delta\mathbf{W}_S. \end{aligned}$$

Letting $\mathbf{I}^P$ and $\mathbf{I}^Q$ be N × N identity matrices with diagonal elements $P^{n(0)}/P^{n(0)},\forall n=1,\ldots,N$, and $Q^{n(0)}/Q^{n(0)},\forall n=1,\ldots,N$, respectively, and $\mathbf{I}_W$ and $\mathbf{I}_X$ be L × L identity matrices with diagonal elements, $W_l^{(0)}/W_l^{(0)},\forall l=1,\ldots,L$ and $X_l^{(0)}/X_l^{(0)},\forall l=1,\ldots,L$, respectively, (1A-11) can be rewritten as

$$(1A\text{-}12)\qquad \begin{aligned} \Delta SW \approx\ & \left(\Delta\mathbf{P}^D\right)^{\mathrm{T}}\mathbf{I}^P\left[\nabla_{P^D}(\cdot)-\mathbf{Q}^{(0)}\right]+\left(\Delta\mathbf{P}^S\right)^{\mathrm{T}}\mathbf{I}^P\nabla_{P^S}\,\mathrm{g}(\cdot) \\ & +\left(\Delta\mathbf{W}_S\right)^{\mathrm{T}}\mathbf{I}_W\left[\mathbf{X}^{(0)}+\nabla_{W_S}\,\mathrm{g}(\cdot)\right]+\left(\Delta\mathbf{W}_D\right)^{\mathrm{T}}\mathbf{I}_W\nabla_{W_D}\,\mathrm{g}(\cdot) \\ & +0.5\left[\left(\Delta\mathbf{P}^D\right)^{\mathrm{T}}\mathbf{I}^P\left(\nabla^2_{P^D}\,\mathrm{g}(\cdot)-\mathbf{I}^Q\mathbf{S}(\cdot)\right)+\left(\Delta\mathbf{P}^S\right)^{\mathrm{T}}\mathbf{I}^P\nabla_{P^SP^D}\,\mathrm{g}(\cdot)\right]\mathbf{I}^P\Delta\mathbf{P}^D \\ & +0.5\left[\left(\Delta\mathbf{P}^D\right)^{\mathrm{T}}\mathbf{I}^P\nabla_{P^DP^S}\,\mathrm{g}(\cdot)+\left(\Delta\mathbf{P}^S\right)^{\mathrm{T}}\mathbf{I}^P\nabla^2_{P^S}\,\mathrm{g}(\cdot)\right]\mathbf{I}^P\Delta\mathbf{P}^S \\ & +0.5\left[\left(\Delta\mathbf{W}_S\right)^{\mathrm{T}}\mathbf{I}_W\nabla_{W_SW_D}\,\mathrm{g}(\cdot)+\left(\Delta\mathbf{W}_D\right)^{\mathrm{T}}\mathbf{I}_W\nabla^2_{W_D}\,\mathrm{g}(\cdot)\right]\mathbf{I}_W\Delta\mathbf{W}_D \\ & +0.5\left[\left(\Delta\mathbf{W}_S\right)^{\mathrm{T}}\mathbf{I}_W\left(\mathbf{I}_X\nabla_{W_S}\mathbf{X}(\cdot)+\nabla^2_{W_S}\,\mathrm{g}(\cdot)\right)+\left(\Delta\mathbf{W}_D\right)^{\mathrm{T}}\mathbf{I}_W\nabla_{W_DW_S}\,\mathrm{g}(\cdot)\right]\mathbf{I}_W\Delta\mathbf{W}_S. \end{aligned}$$

When the identity matrices are multiplied through (1A-12), the vectors of price differences are transformed into proportionate changes in prices, $\mathbf{EP}^D$, $\mathbf{EP}^S$, $\mathbf{EW}_D$, and $\mathbf{EW}_S$ and $\nabla_{W_S}\mathbf{X}(\cdot)$ and $\mathbf{S}(\cdot)$ are transformed into matrices of elasticities:

$$
\begin{aligned}
\Delta SW \quad \approx \quad & \left(\mathbf{EP}^D\right)^{\mathrm{T}} \mathbf{D}^P \left[\nabla_{P^D}\, \mathrm{g}(\cdot) - \mathbf{Q}^{(0)}\right] + \left(\mathbf{EP}^S\right)^{\mathrm{T}} \mathbf{D}^P \nabla_{P^S}\, \mathrm{g}(\cdot) \\
+ \quad & \left(\mathbf{EW}_S\right)^{\mathrm{T}} \mathbf{D}_W \left[\mathbf{X}^{(0)} + \nabla_{W_S}\, \mathrm{g}(\cdot)\right] + \left(\mathbf{EW}_D\right)^{\mathrm{T}} \mathbf{D}_W \nabla_{W_D}\, \mathrm{g}(\cdot) \\
- \quad & 0.5\left[\left(\mathbf{EP}^D\right)^{\mathrm{T}} \mathbf{D}^{PQ} \boldsymbol{\eta}^{*N}\right]\mathbf{EP}^D \\
+ \quad & 0.5\left[\left(\mathbf{EP}^D\right)^{\mathrm{T}} \mathbf{D}^P \nabla^2_{P^D}\, \mathrm{g}(\cdot)\mathbf{D}^P + \left(\mathbf{EP}^S\right)^{\mathrm{T}} \mathbf{D}^P \nabla_{P^S P^D}\, \mathrm{g}(\cdot)\mathbf{D}^P\right]\mathbf{EP}^D \\
\text{(1A-13)} \qquad + \quad & 0.5\left[\left(\mathbf{EP}^D\right)^{\mathrm{T}} \mathbf{D}^P \nabla_{P^D P^S}\, \mathrm{g}(\cdot) + \left(\mathbf{EP}^S\right)^{\mathrm{T}} \mathbf{D}^P \nabla^2_{P^S}\, \mathrm{g}(\cdot)\right]\mathbf{D}^P\mathbf{EP}^S \\
+ \quad & 0.5\left[\left(\mathbf{EW}_S\right)^{\mathrm{T}} \mathbf{D}_W \nabla_{W_S W_D}\, \mathrm{g}(\cdot) + \left(\mathbf{EW}_D\right)^{\mathrm{T}} \mathbf{D}_W \nabla^2_{W_D}\, \mathrm{g}(\cdot)\right]\mathbf{D}_W\mathbf{EW}_D \\
+ \quad & 0.5\left[\left(\mathbf{EW}_S\right)^{\mathrm{T}} \mathbf{D}_{WX} \boldsymbol{\varepsilon}_L\right]\mathbf{EW}_S \\
+ \quad & 0.5\left[\left(\mathbf{EW}_S\right)^{\mathrm{T}} \mathbf{D}_W \nabla^2_{W_S}\, \mathrm{g}(\cdot)\mathbf{D}_W + \left(\mathbf{EW}_D\right)^{\mathrm{T}} \mathbf{D}_W \nabla_{W_D W_S}\, \mathrm{g}(\cdot)\mathbf{D}_W\right]\mathbf{EW}_S,
\end{aligned}
$$

where $\mathbf{D}^P$ and $\mathbf{D}^Q$ are $N \times N$ diagonal matrices where the diagonal elements are $P^{n(0)}, \forall n = 1,\ldots,N$ and $Q^{n(0)}, \forall n = 1,\ldots,N$, respectively, $\mathbf{D}_W$ and $\mathbf{D}_X$ are $L \times L$ diagonal matrices where the diagonal elements are $W_l^{(0)}, \forall l = 1,\ldots,L$ and $X_l^{(0)}, l = 1,\ldots,L$, respectively, $\boldsymbol{\eta}^{N*}$ is an $N \times N$ matrix of Hicksian elasticities of demand for retail products, respectively, and $\boldsymbol{\varepsilon}_L$ is an $L \times L$ matrix of elasticities of supply for commodities. By the Slutsky equation, (1A-13) can be modified as

$$
\begin{aligned}
\Delta SW \approx\ & \left(\mathbf{EW}_S\right)^{\mathrm{T}} \mathbf{D}_W \mathbf{X}^{(0)} + 0.5\left(\mathbf{EW}_S\right)^{\mathrm{T}} \mathbf{D}_{WX} \boldsymbol{\varepsilon}_L \mathbf{EW}_S && \text{(a)}\\
& -\left[\left(\mathbf{EP}^D\right)^{\mathrm{T}} \mathbf{D}^P \mathbf{Q}^{(0)} + 0.5\left(\mathbf{EP}^D\right)^{\mathrm{T}} \mathbf{D}^{PQ}\left(\boldsymbol{\eta}^N + \boldsymbol{\eta}^{N,M}\mathbf{w}^T\right)\mathbf{EP}^D\right] && \text{(b)}\\
& +\left(\mathbf{EP}^D\right)^{\mathrm{T}} \mathbf{D}^P \nabla_{P^D}\, \mathrm{g}(\cdot) + \left(\mathbf{EP}^S\right)^{\mathrm{T}} \mathbf{D}^P \nabla_{P^S}\, \mathrm{g}(\cdot) && \text{(c)}\\
& +0.5\left(\mathbf{EP}^D\right)^{\mathrm{T}} \mathbf{D}^P \nabla^2_{P^D}\, \mathrm{g}(\cdot)\mathbf{D}^P \mathbf{EP}^D && \text{(d)}\\
& +0.5\left(\mathbf{EP}^S\right)^{\mathrm{T}} \mathbf{D}^P \nabla^2_{P^S}\, \mathrm{g}(\cdot)\mathbf{D}^P \mathbf{EP}^S && \text{(e)}\\
\text{(1A-14)} \qquad & +0.5\left(\mathbf{EP}^D\right)^{\mathrm{T}} \mathbf{D}^P \nabla_{P^D P^S}\, \mathrm{g}(\cdot)\mathbf{D}^P \mathbf{EP}^S && \text{(f)}\\
& +0.5\left(\mathbf{EP}^S\right)^{\mathrm{T}} \mathbf{D}^P \nabla_{P^S P^D}\, \mathrm{g}(\cdot)\mathbf{D}^P \mathbf{EP}^D && \text{(g)}\\
& +\left(\mathbf{EW}_S\right)^{\mathrm{T}} \mathbf{D}_W \nabla_{W_S}\, \mathrm{g}(\cdot) + \left(\mathbf{EW}_D\right)^{\mathrm{T}} \mathbf{D}_W \nabla_{W_D}\, \mathrm{g}(\cdot) && \text{(h)}\\
& +0.5\left(\mathbf{EW}_D\right)^{\mathrm{T}} \mathbf{D}_W \nabla^2_{W_D}\, \mathrm{g}(\cdot)\mathbf{D}_W \mathbf{EW}_D && \text{(i)}\\
& +0.5\left(\mathbf{EW}_S\right)^{\mathrm{T}} \mathbf{D}_W \nabla^2_{W_S}\, \mathrm{g}(\cdot)\mathbf{D}_W \mathbf{EW}_S && \text{(j)}\\
& +0.5\left(\mathbf{EW}_D\right)^{\mathrm{T}} \mathbf{D}_W \nabla_{W_D W_S}\, \mathrm{g}(\cdot)\mathbf{D}_W \mathbf{EW}_S && \text{(k)}\\
& +0.5\left(\mathbf{EW}_S\right)^{\mathrm{T}} \mathbf{D}_W \nabla_{W_S W_D}\, \mathrm{g}(\cdot)\mathbf{D}_W \mathbf{EW}_D, && \text{(l)}
\end{aligned}
$$

where $\boldsymbol{\eta}^N$ is an $N \times N$ matrix of Marshallian elasticities of demand for retail products with respect to retail price, $\boldsymbol{\eta}^{N,M}$ is an $N \times 1$ vector of elasticities of demand with respect to total expenditure, and $\mathbf{w}$ is an $N \times 1$ vector of consumer budget shares.

Now we must find the first- and second-order partial derivatives of the government revenue function with respect to all of the prices. The government can generate revenue by taxing commodities, retail products, or both. The government revenue generated from taxing J (M) retail product (commodity) markets is the sum of the differences between the producer (seller) price, P^{Sj} (W_{Sj}), and the consumer (buyer) price, P^{Dj} (W_{Dj}) times the corresponding quantity sold in the taxed market, Q^j (X_j):

$$
\mathrm{g}(\mathbf{P}, \mathbf{W}) = \sum_{j=1}^{J} (P^{Dj} - P^{Sj}) Q^j + \sum_{m=1}^{M} (W_{Dm} - W_{Sm}) X_m .
$$

For brevity, we show the calculations for the case of a retail tax policy but the effects of a commodity tax policy on government revenue are symmetric to those of a retail tax policy. The first-order partial derivatives of the government revenue function with respect to all the prices are

$$\text{(1A-15)} \qquad \frac{\partial \,\mathrm{g}(\mathbf{P},\mathbf{W})}{\partial P^{Dj}} = Q^j + \sum_{l=1}^{J}\left(P^{Dl} - P^{Sl}\right)\frac{\partial \,\mathrm{Q}^l}{\partial P^{Dj}}, \forall j = 1,\ldots,J,$$

$$\text{(1A-16)} \qquad \frac{\partial \,\mathrm{g}(\mathbf{P},\mathbf{W})}{\partial P^{Sj}} = -Q^j + \sum_{l=1}^{J}\left(P^{Dl} - P^{Sl}\right)\frac{\partial \,\mathrm{Q}^l}{\partial P^{Sj}}, \forall j = 1,\ldots,J.$$

Note that when (1A-15)–(1A-16) are evaluated at $\mathbf{P}^{(0)}$, the second term on the RHS is zero in both equations. Hence, substituting $\nabla_{P^D}\,\mathrm{g}(\cdot)$ and $\nabla_{P^S}\,\mathrm{g}(\cdot)$ into (1A-14) and expressing the results in summation notation yields the following equations for the first-order effects of a retail tax policy on government revenue:

$$\text{(1A-17)} \qquad \left(\mathbf{EP}^D\right)^{\mathrm{T}}\mathbf{D}^P\nabla_{P^D}\,\mathrm{g}(\cdot) = \sum_n^N \delta^n\,\mathrm{E}\,P^{Dn}P^{n(0)}Q^{n(0)},$$

$$\text{(1A-18)} \qquad \left(\mathbf{EP}^S\right)^{\mathrm{T}}\mathbf{D}^P\nabla_{P^S}\,\mathrm{g}(\cdot) = -\sum_n^N \delta^n\,\mathrm{E}\,P^{Sn}P^{n(0)}Q^{n(0)},$$

where

$$\delta^j = \begin{cases} 1 \text{ if } t^j > 0 \\ 0 \text{ otherwise} \end{cases}, \forall j = 1,\ldots,N.$$

The second-order partial derivatives of the government revenue function are:

$$\text{(1A-19)} \qquad \frac{\partial^2 \,\mathrm{g}(\mathbf{P},\mathbf{W})}{\partial P^{Dj}\partial P^{Dk}} = \frac{\partial \,\mathrm{Q}^j(\cdot)}{\partial P^{Dk}} + \frac{\partial \,\mathrm{Q}^k(\cdot)}{\partial P^{Dj}} + \sum_{l=1}^{J}\left(P^{Dl} - P^{Sl}\right)\frac{\partial^2 \,\mathrm{Q}^l}{\partial P^{Dj}\partial P^{Dk}}, \forall k, j = 1,\ldots,J,$$

$$\text{(1A-20)} \qquad \frac{\partial^2 \,\mathrm{g}(\mathbf{P},\mathbf{W})}{\partial P^{Sj}\partial P^{Sk}} = -\left(\frac{\partial \,\mathrm{Q}^j(\cdot)}{\partial P^{Sk}} + \frac{\partial \,\mathrm{Q}^k(\cdot)}{\partial P^{Sj}}\right) + \sum_{l=1}^{J}\left(P^{Dl} - P^{Sl}\right)\frac{\partial^2 \,\mathrm{Q}^l}{\partial P^{Sj}\partial P^{Sk}}, \forall k, j = 1,\ldots,J,$$

$$\text{(1A-21)} \qquad \frac{\partial^2 \,\mathrm{g}(\mathbf{P},\mathbf{W})}{\partial P^{Dj}\partial P^{Sk}} = \frac{\partial \,\mathrm{Q}^j(\cdot)}{\partial P^{Sk}} - \frac{\partial \,\mathrm{Q}^k(\cdot)}{\partial P^{Dj}} + \sum_{l=1}^{J}\left(P^{Dl} - P^{Sl}\right)\frac{\partial^2 \,\mathrm{Q}^l}{\partial P^{Dj}\partial P^{Sk}}, \forall k, j = 1,\ldots,J,$$

$$\text{(1A-22)} \quad \frac{\partial^2 \mathrm{g}(\mathbf{P},\mathbf{W})}{\partial P^{Sj}\partial P^{Dk}} = \frac{\partial \mathrm{Q}^j(\cdot)}{\partial P^{Dk}} - \frac{\partial \mathrm{Q}^k(\cdot)}{\partial P^{Sj}} + \sum\nolimits_{l=1}^{J}\left(P^{Dl} - P^{Sl}\right)\frac{\partial^2 \mathrm{Q}^l}{\partial P^{Sj}\partial P^{Dk}}, \forall k, j = 1,..., J.$$

Again note that when (1A-19)–(1A-22) are evaluated at $\mathbf{P}^{(0)}$, the third term on the RHS is zero in these equations. Evaluating (1A-19)–(1A-22) at $\mathbf{P}^{(0)}$, and substituting $\nabla^2_{P^D}\,\mathrm{g}(\cdot), \nabla^2_{P^S}\,\mathrm{g}(\cdot)$, $\nabla_{P^D P^S}\,\mathrm{g}(\cdot)$, and $\nabla_{P^S P^D}\,\mathrm{g}(\cdot)$ into lines (d) and (e) in (1A-14) gives

$$\text{(1A-23)} \quad \left(\mathbf{EP}^D\right)^{\mathrm{T}} \mathbf{D}^P \nabla^2_{P^D}\,\mathrm{g}(\cdot)\,\mathbf{D}^P\mathbf{EP}^D = 2\sum\nolimits_n^N \sum\nolimits_j^N \delta^j\,\mathrm{E}\,P^{Dj} P^{j(0)} Q^{j(0)} \eta^{jn}\,\mathrm{E}\,P^{Dn},$$

$$\text{(1A-24)} \quad \left(\mathbf{EP}^S\right)^{\mathrm{T}} \mathbf{D}^P \nabla^2_{P^S}\,\mathrm{g}(\cdot)\,\mathbf{D}^P\mathbf{EP}^S = -2\sum\nolimits_n^N \sum\nolimits_j^N \delta^j\,\mathrm{E}\,P^{Sj} P^{j(0)} Q^{j(0)} \varepsilon^{jn}\,\mathrm{E}\,P^{Sn},$$

$$\text{(1A-25)} \quad \begin{aligned} &\left(\mathbf{EP}^D\right)^{\mathrm{T}} \mathbf{D}^P \nabla_{P^D P^S}\,\mathrm{g}(\cdot)\,\mathbf{D}^P\mathbf{EP}^S \\ &= \sum\nolimits_n^N \sum\nolimits_j^N \delta^j\,\mathrm{E}\,P^{Sj} P^{j(0)} Q^{j(0)} \eta^{jn}\,\mathrm{E}\,P^{Dn} - \sum\nolimits_n^N \sum\nolimits_j^N \delta^j\,\mathrm{E}\,P^{Dn} P^{n(0)} Q^{n(0)} \varepsilon^{nj}\,\mathrm{E}\,P^{Sn}, \end{aligned}$$

$$\text{(1A-26)} \quad \begin{aligned} &\left(\mathbf{EP}^S\right)^{\mathrm{T}} \mathbf{D}^P \nabla_{P^S P^D}\,\mathrm{g}(\cdot)\,\mathbf{D}^P\mathbf{EP}^D = \\ &-\sum\nolimits_n^N \sum\nolimits_j^N \delta^j\,\mathrm{E}\,P^{Sj} P^{j(0)} Q^{j(0)} \eta^{jn}\,\mathrm{E}\,P^{Dn} + \sum\nolimits_n^N \sum\nolimits_j^N \delta^j\,\mathrm{E}\,P^{Dn} P^{n(0)} Q^{n(0)} \varepsilon^{nj}\,\mathrm{E}\,P^{Sn}. \end{aligned}$$

After (1A-17), (1A-18)and (1A-23)–(1A-26) are substituted into lines (c)-(d) in (1A-14), noting that equations (1A-25) and (1A-26) cancel each other out, the change in government revenue from a retail tax policy can be expressed as

$$\text{(1A-27)} \quad \begin{aligned} \Delta g \big| t^N > 0 = &\left(\mathbf{EP}^D\right)^{\mathrm{T}} \mathbf{D}^P \nabla_{P^D}\,\mathrm{g}(\cdot) + \left(\mathbf{EP}^S\right)^{\mathrm{T}} \mathbf{D}^P \nabla_{P^S}\,\mathrm{g}(\cdot) \\ &+ 0.5\left(\mathbf{EP}^D\right)^{\mathrm{T}} \mathbf{D}^P \nabla^2_{P^D}\,\mathrm{g}(\cdot)\,\mathbf{D}^P\mathbf{EP}^D \\ &+ 0.5\left(\mathbf{EP}^S\right)^{\mathrm{T}} \mathbf{D}^P \nabla^2_{P^S}\,\mathrm{g}(\cdot)\,\mathbf{D}^P\mathbf{EP}^S \\ &= \sum\nolimits_n^N \delta^n Q^{n(0)} P^{n(0)} \left(\mathrm{E}\,P^{Dn} - \mathrm{E}\,P^{Sn}\right) \\ &+ \sum\nolimits_n^N \delta^n Q^{n(0)} P^{n(0)}\,\mathrm{E}\,P^{Dn} \sum\nolimits_j^N \eta^{nj}\,\mathrm{E}\,P^{Dj} \\ &+ \sum\nolimits_n^N \delta^n Q^{n(0)} P^{n(0)}\,\mathrm{E}\,P^{Sn} \sum\nolimits_j^N \varepsilon^{nj}\,\mathrm{E}\,P^{Sj}. \end{aligned}$$

Because $\mathrm{E}\,Q^n = \sum\nolimits_j^N \eta^{nj}\,\mathrm{E}\,P^{Dj}$, $\mathrm{E}\,Q^n = \sum\nolimits_j^N \varepsilon^{nj}\,\mathrm{E}\,P^{Sj}$, and $t^n = \mathrm{E}\,P^{Dn} - \mathrm{E}\,P^{Sn}$, this equation can be more succinctly written as

(1A-28) $\Delta g = \sum_{n}^{N} t^{n} Q^{n(0)} P^{n(0)} \left(1 + \mathrm{E}\, Q^{n}\right).$

Symmetrically, the change in government revenue from a tax or subsidy policy on commodities can be expressed as

(1A-29) $\Delta g = -\sum_{l}^{L} s_l X_l^{(0)} W_l^{(0)} - \sum_{l}^{L} s_l X_l^{(0)} W_l^{(0)}\, \mathrm{E}\, X_l .$

In matrix notation, equations (1A-28) and (1A-29) can be rewritten as

$$\Delta g = \left(\mathbf{t}^{N}\right)^{\mathrm{T}} \mathbf{D}_{P}\mathbf{Q} + \left(\mathbf{t}^{N}\right)^{\mathrm{T}} \mathbf{D}_{PQ}\mathbf{EQ},$$

$$\Delta g = -\left(\mathbf{s}_{L}\right)^{\mathrm{T}} \mathbf{D}_{W}\mathbf{X} - \left(\mathbf{s}_{L}\right)^{\mathrm{T}} \mathbf{D}_{WX}\mathbf{EX},$$

where $\mathbf{D}_W\mathbf{X}$ and $\mathbf{D}^P\mathbf{Q}$ are $L \times 1$and $N \times 1$vectors of total expenditures on commodities and products, respectively.

2A. Technical Appendix: Derivation of Ad Valorem Taxes on Foods

We derived ad valorem taxes for foods that would correspond to per unit taxes on their content of fat, calories, or sugar. First, we calculated the nutrient content of a pound of each food measured as calories, fat grams or sugar grams per pound using one day of dietary recall data from the 2003-04 National Health and Nutrition Examination Survey (column (3) in Table 3A-1). The per unit tax per pound of each food category is equal to the per unit tax per calorie, gram of fat, or gram of sugar times the fat, sugar or calorie intensity of that food (column (4)) (i.e., calorie intensity is calories per pound of food consumed, and sugar and fat intensity are grams of sugar or fat per pound of food consumed). The average unit value for each food category in 2005 is calculated as personal consumption expenditures per adult per day from that National Income and Product Accounts (U.S. Department of Commerce, Bureau of Economic Analysis 2010) divided by average number of pounds of food in that category consumed per day per adult (column (6)). The ad valorem tax rate is the tax rate in dollars per pound in column (4) divided by the unit values in dollars per pound in column (6).

INSERT Table 3A-1 HERE

Table 1. Price and Quantity Effects of Taxes and Subsidies on Retail Products and Farm Commodities for Nested Cases of the General Model

	Perfectly Elastic Commodity Supply $\varepsilon_{ll} = \infty$	Perfectly Inelastic Commodity Supply $\varepsilon_{ll} = 0$	Fixed Factor Proportions $\sigma_{lj} = 0$
EQ	$\bar{\mathbf{X}}^{\alpha} - \boldsymbol{\eta}^{N}\mathbf{SR}\bar{\mathbf{X}}_{\beta}$	$(\mathbf{I}^{N} - \boldsymbol{\eta}^{N}\mathbf{SR}\tilde{\mathbf{f}}^{-1}\mathbf{SC})\tilde{\mathbf{X}}^{\alpha} + \boldsymbol{\eta}^{N}\mathbf{SR}\tilde{\mathbf{f}}^{-1}\tilde{\mathbf{X}}_{\beta}$	$(\mathbf{I}^{N} - \boldsymbol{\eta}^{N}\mathbf{SR}\hat{\mathbf{f}}^{-1}\mathbf{SC})\hat{\mathbf{X}}^{\alpha} + \boldsymbol{\eta}^{N}\mathbf{SR}\hat{\mathbf{f}}^{-1}\hat{\mathbf{X}}_{\beta}$
EP^{S}	$-\mathbf{SRX}_{\beta}$	$\mathbf{SR}\tilde{\mathbf{f}}^{-1}\mathbf{SC}\tilde{\mathbf{X}}^{\alpha} + \mathbf{SR}\tilde{\mathbf{f}}^{-1}\tilde{\mathbf{X}}_{\beta}$	$\mathbf{SR}\hat{\mathbf{f}}^{-1}\mathbf{SC}\hat{\mathbf{X}}^{\alpha} + \mathbf{SR}\hat{\mathbf{f}}^{-1}\hat{\mathbf{X}}_{\beta}$
EX	$\mathbf{SC}\bar{\mathbf{X}}^{\alpha} - (\mathbf{SC}\boldsymbol{\eta}^{N}\mathbf{SR} + \boldsymbol{\eta}_{L}^{*})\bar{\mathbf{X}}_{\beta}$	$\tilde{\mathbf{X}}_{\beta}$	$(\mathbf{I}_{L} - \mathbf{SC}\boldsymbol{\eta}^{N}\mathbf{SR}\hat{\mathbf{f}}^{-1})\mathbf{SC}\hat{\mathbf{X}}^{\alpha} + \mathbf{SC}\boldsymbol{\eta}^{N}\mathbf{SR}\hat{\mathbf{f}}^{-1}\hat{\mathbf{X}}_{\beta}$
EW$_{D}$	$-\bar{\mathbf{X}}_{\beta}$	$\tilde{\mathbf{f}}^{-1}\mathbf{SC}\tilde{\mathbf{X}}^{\alpha} + \tilde{\mathbf{f}}^{-1}\tilde{\mathbf{X}}$	$\hat{\mathbf{f}}^{-1}\mathbf{SC}\hat{\mathbf{X}}^{\alpha} + \hat{\mathbf{f}}^{-1}\hat{\mathbf{X}}_{\beta}$

Source: Authors' calculations.

Notes: $\bar{\mathbf{X}}^{\alpha} = \boldsymbol{\alpha} + \boldsymbol{\eta}^{N}\mathbf{t}^{N}$, $\bar{\mathbf{X}}_{\beta} = \bar{\boldsymbol{\beta}} + \mathbf{s}_{L}$

$\tilde{\mathbf{X}}^{\alpha} = \boldsymbol{\alpha} + \boldsymbol{\eta}^{N}\mathbf{t}^{N}$, $\tilde{\mathbf{X}}_{\beta} = \boldsymbol{\beta}$, $\tilde{\mathbf{f}}^{-1} = (\boldsymbol{\eta}_{L}^{*} + \mathbf{SC}\boldsymbol{\eta}^{N}\mathbf{SR})^{-1}$

$\hat{\mathbf{X}}^{\alpha} = \boldsymbol{\alpha} + \boldsymbol{\eta}^{N}\mathbf{t}^{N}$, $\hat{\mathbf{X}}_{\beta} = \boldsymbol{\beta} + \boldsymbol{\varepsilon}_{L}\mathbf{s}_{L}$, $\hat{\mathbf{f}}^{-1} = (-\boldsymbol{\varepsilon}_{L} + \mathbf{SC}\boldsymbol{\eta}^{N}\mathbf{SR})^{-1}$

Table 2. Marshallian Elasticities of Demand for FAH and FAFH Products

Elasticity of Demand for	**With Respect to Price of**										**With Respect to Total Expenditure**
	Cereals & bakery	Meat	Eggs	Dairy	Fruits & vegetables	Other food	Non-alcoholic beverages	FAFH	Alcoholic beverages	Nonfood	
Cereals & bakery	-0.93	0.04	0.02	0.14	0.13	0.45	-0.04	-0.42	-0.06	0.39	0.28
	(0.13)	(0.10)	(0.03)	(0.09)	(0.10)	(0.10)	(0.07)	(0.19)	(0.13)	(0.38)	(0.26)
Meat	0.02	-0.40	0.05	0.00	0.16	-0.12	-0.09	0.23	0.20	-0.69	0.64
	(0.05)	(0.13)	(0.02)	(0.05)	(0.05)	(0.07)	(0.05)	(0.10)	(0.06)	(0.33)	(0.32)
Eggs	0.24	1.00	-0.73	0.66	-0.47	-0.54	0.27	0.25	-0.20	0.22	-0.69
	(0.29)	(0.36)	(0.14)	(0.28)	(0.30)	(0.32)	(0.22)	(0.54)	(0.37)	(1.25)	(0.95)
Dairy	0.16	0.00	0.08	-0.91	-0.09	0.26	0.20	-0.26	0.17	-0.59	0.97
	(0.11)	(0.13)	(0.04)	(0.14)	(0.11)	(0.11)	(0.08)	(0.21)	(0.14)	(0.46)	(0.34)
Fruits & vegetables	0.14	0.32	-0.05	-0.07	-0.58	-0.15	0.11	0.20	-0.03	-0.16	0.27
	(0.11)	(0.11)	(0.03)	(0.09)	(0.14)	(0.10)	(0.07)	(0.19)	(0.13)	(0.38)	(0.26)
Other food	0.33	-0.17	-0.04	0.15	-0.11	-0.62	0.05	0.12	0.00	-0.50	0.79
	(0.07)	(0.10)	(0.02)	(0.07)	(0.07)	(0.11)	(0.06)	(0.12)	(0.08)	(0.34)	(0.28)
Nonalcoholic beverages	-0.06	-0.22	0.03	0.21	0.13	0.08	-0.77	-0.08	0.18	-0.37	0.86
	(0.08)	(0.12)	(0.03)	(0.08)	(0.08)	(0.10)	(0.10)	(0.14)	(0.10)	(0.42)	(0.36)
FAFH	-0.15	0.13	0.01	-0.07	0.06	0.05	-0.02	-0.55	-0.12	-0.19	0.84
	(0.06)	(0.06)	(0.02)	(0.05)	(0.06)	(0.05)	(0.04)	(0.20)	(0.09)	(0.24)	(0.13)
Alcoholic beverages	-0.05	0.24	-0.02	0.10	-0.02	0.00	0.10	-0.22	-0.50	-0.13	0.50
	(0.09)	(0.08)	(0.03)	(0.07)	(0.08)	(0.08)	(0.05)	(0.18)	(0.16)	(0.34)	(0.19)
Nonfood	0.00	-0.03	0.00	-0.01	-0.01	-0.02	-0.01	-0.02	-0.02	-0.94	1.07
	(0.00)	(0.01)	(0.00)	(0.00)	(0.00)	(0.01)	(0.00)	(0.01)	(0.01)	(0.03)	(0.02)

Source: Okrent and Alston (2011).

Table 3. Own-price Elasticities of Supply of U.S. Farm Commodities and a Marketing Input

Oilseed crops	0.60
Sugar cane & beets	0.60
Other crops	0.60
Food grains	0.59
Vegetables & melons	0.42
Fruits & tree nuts	0.44
Cattle	0.81
Other animals	0.81
Milk	0.81
Poultry	0.81
Fish	0.40
Marketing input	1000

Source: Authors' assumptions based on Chavas and Cox (1995).

Table 4. Farm-Retail Product Shares

Attributable to	Share of Total Cost for Retail Product								
	Cereals & bakery	Meat	Eggs	Dairy	Fruits & vegetables	Other food	Non-alcoholic beverages	FAFH	Alcoholic beverages
Farm Commodity									
Oil-bearing crops	0.0000	0.0000	0.0000	0.0000	0.0000	0.0619	0.0000	0.0027	0.0000
Grains	0.0593	0.0000	0.0000	0.0000	0.0027	0.0345	0.0000	0.0038	0.0164
Vegetables & melons	0.0000	0.0000	0.0000	0.0000	0.2722	0.0167	0.0000	0.0020	0.0000
Fruits & tree nuts	0.0027	0.0000	0.0000	0.0012	0.2062	0.0184	0.0294	0.0018	0.0213
Sugar cane & beets	0.0000	0.0000	0.0000	0.0000	0.0000	0.0131	0.0000	0.0006	0.0000
Other crops	0.0009	0.0000	0.0000	0.0000	0.0000	0.0210	0.0038	0.0010	0.0024
Cattle production	0.0000	0.1907	0.0000	0.0000	0.0000	0.0000	0.0000	0.0094	0.0000
Other livestock production	0.0000	0.0726	0.0000	0.0000	0.0000	0.0030	0.0000	0.0046	0.0000
Dairy farming	0.0000	0.0000	0.0000	0.2739	0.0000	0.0009	0.0000	0.0096	0.0000
Poultry & egg production	0.0063	0.0923	0.6851	0.0022	0.0006	0.0039	0.0000	0.0051	0.0000
Fish production	0.0000	0.0638	0.0000	0.0000	0.0039	0.0003	0.0000	0.0072	0.0000
Marketing inputs†	0.9309	0.5806	0.3149	0.7227	0.5144	0.8264	0.9668	0.9523	0.9599

Source: Authors' calculations based on 2002 Benchmark I-O Tables (U.S. Department of Commerce, Bureau of Economic Analysis 2007).

Table 5. Farm-Commodity Shares

Share of Total Cost of	**Attributable to Retail Product**								
	Cereals & bakery	Meat	Eggs	Dairy	Fruits & vegetables	Other food	Non-alcoholic beverages	FAFH	Alcoholic beverages
Farm Commodity									
Oil-bearing crops	0.0000	0.0000	0.0000	0.0000	0.0000	0.8525	0.0000	0.1475	0.0000
Grains	0.3812	0.0000	0.0000	0.0000	0.0134	0.3811	0.0000	0.1670	0.0573
Vegetables & melons	0.0000	0.0000	0.0000	0.0000	0.8337	0.1133	0.0000	0.0530	0.0000
Fruits & tree nuts	0.0113	0.0000	0.0000	0.0041	0.6812	0.1347	0.0665	0.0528	0.0494
Sugar cane & beets	0.0000	0.0000	0.0000	0.0000	0.0000	0.8525	0.0000	0.1475	0.0000
Other crops	0.0186	0.0000	0.0000	0.0000	0.0000	0.7665	0.0428	0.1440	0.0281
Cattle production	0.0000	0.8374	0.0000	0.0000	0.0000	0.0000	0.0000	0.1626	0.0000
Other livestock production	0.0000	0.7769	0.0000	0.0000	0.0000	0.0313	0.0000	0.1918	0.0000
Dairy farming	0.0000	0.0000	0.0000	0.7682	0.0000	0.0054	0.0000	0.2264	0.0000
Poultry & egg production	0.0254	0.6465	0.1517	0.0073	0.0018	0.0270	0.0000	0.1403	0.0000
Fish production	0.0000	0.6777	0.0000	0.0000	0.0187	0.0027	0.0000	0.3010	0.0000
Marketing inputs	0.0781	0.0849	0.0015	0.0493	0.0335	0.1191	0.0430	0.5469	0.0439

Source: Authors' calculations based on 2002 Benchmark I-O Tables (U.S. Department of Commerce, Bureau of Economic .Analysis 2007).

Table 6. Total Annual Value of Food Products, Farm Commodities and Marketing Inputs

	millions of dollars
FAH	
Cereals and bakery	55,069
Meat	103,490
Eggs	3,921
Dairy products	46,762
Fruits & vegetables	48,552
Other foods	100,308
Nonalcoholic beverages	28,672
FAFH	372,264
Alcoholic beverages	36,025
Farm commodities	
Oil-bearing crops	8,874
Grains	11,039
Vegetables & melons	17,740
Fruits & tree nuts	16,690
Sugar cane & beets	1,877
Other crops	3,321
Cattle production	28,246
Other livestock production	11,541
Dairy farming	20,632
Poultry & egg production	17,426
Fish production	11,361
Marketing inputs	646,315

Source: Authors' calculations based on 2002 Benchmark I-O Tables (U.S. Department of Commerce, Bureau of Economic Analysis 2007).

Table 7. Average Daily Quantities of Food, Sugar and Fat and Energy Intake by Food Group for Individuals Aged 18 and Older, 2003–2004 and 2002 Per Capita Budget Shares

	Energy	Quantity	Sugar	Fat	Budget Share
	kcal	*grams*	*grams*	*grams*	*percent*
Total	2,274.79	2,609.23	86.23	129.38	
FAH					
Cereals & bakery	351.94	133.04	9.38	16.37	9.46
Meat	162.20	67.59	9.85	0.22	11.02
Eggs	34.26	20.72	2.47	0.36	0.57
Dairy	166.13	186.49	8.38	13.80	4.35
Fruits & vegetables	124.36	195.58	2.41	12.88	6.97
Other food	362.30	183.11	18.25	13.43	13.14
Nonalcoholic beverages	178.48	925.31	1.10	36.29	6.44
FAFH	821.38	710.94	35.19	36.31	34.48
Alcohol	122.05	272.12	0.01	1.38	13.58

Source: The calculations of consumption of foods and associated nutrient and energy content based on one-day of dietary recall data for respondents 18 years of age or older from the 2003-2004 NHANES (Centers for Disease Control and Prevention, National Center for Health Statistics 2007). The budget shares are based on 2002 personal consumption expenditures (U.S. Department of Commerce, Bureau of Economic Analysis, National Income and Product Accounts 2010).

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Table 8. Commodity Policies Simulated

	Elimination of grain subsidies	Elimination of grain subsidies and trade barriers based on CSEs in 2006	Elimination of grain subsidies and trade barriers based on CSEs in 2000-2009	Elimination of grain subsidies and trade barriers based on CSEs in 1989-1999	16.24% subsidy on fruit & vegetable commodities
			Percent Tax Equivalents		
Oilseed	0.00	0.00	0.00	0.00	0.00
Food grains	-8.40	-8.40	-8.40	-8.40	0.00
Vegetables & melons	0.00	4.00	4.00	4.00	16.24
Fruits & tree nuts	0.00	6.00	6.00	6.00	16.24
Sugar cane & beets	0.00	31.00	54.2	55.69	0.00
Other crops	0.00	0.00	0.00	0.00	0.00
Beef cattle	-2.85	-2.85	-2.85	-2.85	0.00
Hogs & other meat animals	-2.85	-2.85	-2.85	-2.85	0.00
Milk‡	-2.85	9.55	24.95	31.78	0.00
Poultry & eggs	-4.75	-4.75	-4.75	-4.75	0.00
Fish & aquaculture	0.00	0.00	0.00	0.00	0.00

Source: Authors' calculations based on Sumner (2005), Rickard, Okrent, and Alston (2011).
Note: Entries are ad valorem tax equivalents in the context of the model. A commodity policy with $s_l < 0$ denotes a tax on commodity l and a commodity policy with $s_l > 0$ denotes a subsidy on commodity l.
‡Elimination of the subsidies to corn would implicitly increase the price of milk by 2.85%. If grain subsidies and trade barriers as captured by the CSE for milk in 2006 were removed, then the price of milk would increase by 9.55% (=–2.85% + 12.4%).

Table9. Change in Annual Calorie Consumption per Adult by Food Category and Change in Body Weight

	Change in calorie consumption										Change in Average Body Weight		Change in Average BMI
	Cereals & bakery	Meat	Eggs	Dairy	Fruits & veg.	Other food	Non-alcohol drinks	FAFH	Alcohol drinks	Total			
	Calories										*kg*	*% change*	*kg/m²*
Exogenous Prices of Commodities ($\varepsilon = \infty$)													
Removal of grain subsidies	-218	-155	-90	-179	85	-302	15	-59	84	-819	-0.11	-0.13	-0.03
Removal of all subsidies (2006 CSE)	-1,451	-370	-204	1,720	827	-203	-599	446	0	165	0.02	0.03	0.01
Removal of all subsidies (2000-2009 CSE)	-2,307	-379	-538	4,018	970	-829	-1,187	1,477	-166	1,059	0.14	0.17	0.04
Removal of all subsidies (1989-2009 CSE)	-2,623	-391	-694	5,054	1,025	-1,200	-1,441	1,944	-240	1,435	0.19	0.23	0.05
10 % Fruit & vegetable product subsidy	-1,712	-961	589	560	2,644	1,499	-849	-1,625	110	254	0.03	0.04	0.01
16.24% Fruit & vegetable commodity subsidies	-1,529	-728	484	267	2,067	1,570	-489	-1,083	148	707	0.09	0.11	0.03
Fat tax	-1,999	40	-951	-3,820	-306	-3,529	869	-9,790	184	-19,302	-2.51	-3.08	-0.71
Calorie tax	-5,629	252	-159	-1,893	-239	-486	-1,469	-9,455	-225	-19,304	-2.51	-3.08	-0.71
Sugar tax	-4,232	-42	902	-2,817	-521	2,269	-6,761	-8,687	587	-19,301	-2.51	-3.08	-0.71
Uniform tax	-4,294	157	298	-1,159	-256	-1,979	-1,619	-9,610	-841	-19,303	-2.51	-3.08	-0.71
Upward-Sloping Supply of Commodities ($\varepsilon < \infty$)													
Fruit & vegetable product subsidy	-1,012	-571	356	375	1,707	907	-554	-1,303	16	-79	-0.01	0.00	0.00
Fruit & vegetable commodity subsidies	-960	-424	290	158	1,317	1,044	-263	-801	73	434	0.06	0.00	0.02
Fat tax	-2,452	55	-944	-3,092	-95	-3,197	633	-9,557	118	-18,531	-2.41	-0.03	-0.68
Calorie tax	-5,675	239	-175	-1,460	-92	-372	-1,588	-9,165	-246	-18,533	-2.41	-0.03	-0.68
Sugar tax	-4,330	-63	771	-2,101	-310	2,115	-6,777	-8,370	528	-18,538	-2.41	-0.03	-0.68
Uniform tax	-4,400	154	279	-871	-81	-1,681	-1,704	-9,391	-843	-18,537	-2.41	-0.03	-0.68

Source: Authors' calculations based on the general price transmission model and its special case of exogenous commodity prices.

Table 10. Food Policies Simulated: Ad Valorem Tax Equivalents

	10 % subsidy on fruit and vegetables	$0.005 tax per gram fat	$0.000165 tax per calorie†	$0.002688 tax per gram sugar†	5.03% tax uniform tax on food products†
			percentage taxes		
Cereals & bakery	0.00	5.50	6.81	5.16	5.03
Meat	0.00	4.95	2.69	0.06	5.03
Eggs	0.00	24.06	11.01	1.86	5.03
Dairy	0.00	10.69	7.00	9.47	5.03
Fruits & vegetables	-10.00	1.92	3.27	5.51	5.03
Other food	0.00	7.70	5.05	3.05	5.03
Nonalcoholic beverages	0.00	0.94	5.07	16.81	5.03
FAFH	0.00	5.66	4.25	3.07	5.03
Alcoholic beverages	0.00	0.0035	1.64	0.30	5.03

Source: Authors' calculations.
Note: Entries are ad valorem tax equivalents in the context of the model. A retail product policy with $t^n > 0$ denotes a tax on food product *n* and a retail food product policy with $t^n < 0$ denotes a subsidy on food product *n*.
† These tax rates reflect the assumption of exogenous commodity prices and are constructed to achieve approximately the same calorie reduction as the $.005 tax per gram fat. The tax rates on sugar and calories for the case of endogenous commodity prices differ slightly (i.e., t = $0.002637 tax per gram sugar, t = $0.0001632 tax per calorie, and t = 4.973% uniform tax). Hence, the ad valorem taxes for each food product for the case of endogenous commodity prices are slightly different as well.
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Table 11. Net Social Costs of Changes in Body Weight of U.S. Adults Resulting From Selected Commodity and Food Policies

	Benefits to Consumers	Benefits to Producers	Direct Cost to Government	Dead Weight Loss Excluding Changes in Public Heath Care Costs	Change in Public Heath Care Costs†	Dead Weight Loss Including Change in Public Health Care Costs	Change in Pounds per Year of Body Weight for all U.S. Adults‡	*Cost per Pound Change in Body Weight*: Excluding Changes in Public Health Care Costs	*Cost per Pound Change in Body Weight*: Including Changes in Public Health Care Costs
	Millions of Dollars						*Millions of Pounds*	*Dollars per Pound*	
Exogenous Prices of Commodities (ε=∞)									
10% subsidy on f&v products	5,680	0	-5,846	166	19	186	17	9.77	10.91
17% tax on f&v commodities	5,737	0	-5,846	109	54	163	47	2.30	3.44
$0.005 tax per gram fat	-55,763	0	53,909	1,854	-1,477	377	-1,289	1.44	0.29
$0.00017 tax per calorie	-44,047	0	42,835	1,212	-1,477	-265	-1,289	0.94	-0.21
$0.0065 tax per gram sugar	-37,328	0	36,058	1,270	-1,477	-207	-1,289	0.99	-0.16
5% tax uniform tax on food products	-50,527	0	49,032	1,495	-1,477	17	-1,289	1.16	0.01
Upward-sloping Supply of Commodities (ε<∞)									
10% subsidy on f&v products	3,728	1,898	-5,732	106	-6	100	-5	20.14	18.99
17% subsidy on f&v commodities	4,098	1,566	-5,732	68	33	101	29	2.34	3.49
$0.005 tax per gram fat	-52,161	-3,528	54,019	1,669	-1,418	251	-1,238	1.35	0.20
$0.00017 tax per calorie	-41,496	-2,050	42,441	1,105	-1,418	-313	-1,238	0.89	-0.25
$0.0065 tax per gram sugar	-34,692	-1,950	35,498	1,145	-1,419	-274	-1,238	0.92	-0.22
5% tax uniform tax on food products	-47,736	-2,197	48,566	1,367	-1,419	-52	-1,238	1.10	-0.04

Source: Authors' calculations.
†In 2002, the enrollment in Medicare and Medicaid was 40,489,000 and 49,329,000, respectively (U.S. Census 2007).
‡The U.S. population aged 18 and older in 2002 was 233,783,000 (U.S. Census 2007).

Table A-1. Derivations of Ad Valorem Taxes on Food Based on a Per Unit Tax Per Gram of Fat, Per Gram of Sugar, and Per Calorie

	Sources of Fat / Sugar / Calories	Weight of Foods	Fat / Sugar / Calorie Intensity of Food	Per Unit Tax Per Pound of Food	Expenditure on Food (2002$)	Average Unit Value of Food	Ad Valorem Tax
	(1)	(2)	(3) = (1) / (2)	(4) = *t* × (3)	(5)	(6) = (5) / (2)	(7) = (4) / (6)×100
				***t* = $0.005 Tax per Gram of Fat**			
	grams/day	*lbs/day*	*grams/lb*	*$/lb*	*$/day*	*$/lb*	*percent*
Cereals & bakery	9.38	0.29	32.05	0.16	0.85	2.91	5.50
Meat	9.85	0.15	66.22	0.33	0.99	6.68	4.95
Eggs	2.47	0.05	54.33	0.27	0.05	1.13	24.04
Dairy	2.41	0.43	5.61	0.03	0.63	1.46	1.92
Fruits & vegetables	18.25	0.40	45.28	0.23	1.18	2.94	7.70
Other food	1.10	2.04	0.54	0.00	0.58	0.29	0.94
Nonalcoholic beverages	35.18	1.48	23.75	0.12	3.11	2.10	5.66
FAFH	0.01	0.60	0.01	0.00	1.22	2.05	0.0035
Alcohol	9.38	0.29	32.05	0.16	0.85	2.91	5.50
				***t* = $0.002688Tax per Gram of Sugar†**			
	grams/day	*lbs/day*	*grams/lb*	*$/lb*	*$/day*	*$/lb*	*percent*
Cereals & bakery	16.37	0.29	55.94	0.15	0.85	2.91	5.16
Meat	0.22	0.15	1.47	0.00	0.99	6.68	0.06
Eggs	0.36	0.05	7.84	0.02	0.05	1.13	1.86
Dairy	12.88	0.43	29.94	0.08	0.63	1.46	5.51
Fruits & vegetables	13.43	0.40	33.31	0.09	1.18	2.94	3.05
Other food	36.29	2.04	17.83	0.05	0.58	0.29	16.81
Nonalcoholic beverages	35.55	1.48	24.00	0.06	3.11	2.10	3.07
FAFH	1.38	0.60	2.31	0.01	1.22	2.05	0.30
Alcohol	16.37	0.29	55.94	0.15	0.85	2.91	5.16
				***t* = $0.000165 Tax Per Calorie†**			
	kcal/day	*lbs/day*	*kcal/lb*	*$/lb*	*$/day*	*$/lb*	*percent*
Cereals & bakery	351.94	0.29	1202.45	0.20	0.85	2.91	6.81
Meat	162.20	0.15	1090.80	0.18	0.99	6.68	2.69
Eggs	34.24	0.05	753.98	0.12	0.05	1.13	11.01
Dairy	124.36	0.43	289.01	0.05	0.63	1.46	3.27
Fruits & vegetables	362.33	0.40	899.04	0.15	1.18	2.94	5.05
Other food	178.48	2.04	87.68	0.01	0.58	0.29	5.07
Nonalcoholic beverages	801.13	1.48	540.91	0.09	3.11	2.10	4.25
FAFH	122.05	0.60	203.87	0.03	1.22	2.05	1.64
Alcohol	351.94	0.29	1202.45	0.20	0.85	2.91	6.81

Source: Authors' calculations based on one-day dietary recall data from the 2003-04 NHANES (Centers for Disease Control and Prevention, National Center for Health Statistics 2007) and 2002 Personal Consumption Expenditures (U.S. Department of Commerce, Bureau of Economic Analysis 2010).

†These tax rates reflect the assumption of exogenous commodity prices and are constructed to achieve approximately the same calorie reduction as the $.005 tax per gram fat. The tax rates on sugar and calories for the case of endogenous commodity prices differ slightly (i.e., *t* = $0.002637 tax per gram sugar and = $0.0001632 tax per calorie). Hence, the ad valorem taxes for each food product for the case of endogenous commodity prices are slightly different as well.