Food Prices and Blood Cholesterol

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Economic Research Service

Selected Paper prepared for presentation at the Agricultural & Applied Economics Association's 2011 AAEA & NAREA Joint Annual Meeting, Pittsburgh, Pennsylvania, July 24-26, 2011.

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ABSTRACT

Cardiovascular diseases (CVD) cost Americans hundreds in billions of dollars. High cholesterol levels, which are closely related to diet habits, are a major contributor to CVD. In this paper we study whether changes in food prices are related to cholesterol levels and whether taxes or subsidies of particular foods would be effective in lowering cholesterol levels and, consequently, CVD costs. We find that prices of vegetables, processed foods, and whole milk and whole grains significantly affect the blood cholesterol levels. Having analyzed the costs and benefits of government interventions, we find that a subsidy of vegetables and whole grains would be the most efficient way to reduce CVD expenditures.

1 Introduction

It is well known that Americans consume too much fat (especially saturated fat), sodium, and sugar, and not enough fiber, fresh fruits and vegetables, and whole grains. The effects of these diet patterns are evident in the high prevalence of adverse health conditions in the U.S., including obesity, diabetes, and heart disease, all of which come with substantial direct costs. By one recent estimate, for example, the direct cost obesity alone in 2006 was roughly $85 billion (Finkelstein, Trogdon et al. 2009) ; furthermore, the CDC estimates direct costs due to diabetes in 2007 at $116 billion (CDC 2008). Although none of these conditions can be said to arise from the food environment alone, policy discussions aimed at addressing them have focused on the food environment--and particularly food prices -- as a way of affecting behavior. Studies of the effect of food prices on obesity have been particularly prominent in this context (Apovian 2004; Sturm and Datar 2005; Buttet and Dolar 2008; Schroeter, Lusk et al. 2008; Duffey, Gordon-Larson et al. 2010)

Perhaps because obesity is a kind of “oracle condition” that presages the development of a host of serious chronic conditions -- diabetes, hypertension, heart disease, some kinds of cancer-- there has been less research about the relationship between food prices and these conditions or their mediating factors, notable exceptions notwithstanding (Meyerhoefer and Leibtag 2010). A case in point, which we address here, is dyslipidemia, an imbalance in blood fats, particularly cholesterol. Although there is some debate about what measure of cholesterol best registers the risk of cardiovascular disease (CVD) and cardiovascular events (CVE) such as heart attack, there is no disagreement about the strong correlation between them. In fact, the relationship between obesity and CVD is often mediated by dyslipidemia. (Ogden, Yanovski et al. 2007).

To date, the policy implications of this question have largely been addressed through proposals for a “fat tax”; studies based on this possibility usually conclude that most reasonable fat tax regimes would lead to a modest improvement in health (Powell and Chaloupka 2009). Rather than focus on a fat tax exclusively, however, in this paper we focus on the way that prices for a broad array of food at home (FAH) products might affect blood serum cholesterol levels. We do this because the effect of fat prices on health depends not only on different prices for full fat substitutes but also for other goods that will affect cholesterol levels--whole grains or fresh vegetables, for example. In this respect, we are interested in the most effective method for addressing blood cholesterol, which may be a subsidy as well as a tax, and may not be applied to one of the usual food suspects--namely, meat and dairy products.

Our results suggest, first, that levels of bad cholesterol are sensitive to the prices of vegetables, whole grains, processed foods and whole milk products. For example, we find that a ten percent increase in the price of vegetables is associated with an increase of almost one standard deviation of serum non-HDL-C, our measure of unhealthy blood cholesterol. Based on our results, we calculate the welfare implications of price interventions using the estimated effects of serum cholesterol on the risk of CVD from the medical literature, estimates of national CVD expenditures, and estimates of the price elasticity of each of these foods drawn from the demand literature. We conclude that a subsidy of whole grains would be the most effective way to reduce CVD expenditures and that a subsidy of vegetables would also be effective: both of these interventions would minimize the size of government activity in food markets. Taxation of processed foods and whole milk products also leads to large reductions in CVD expenditure, albeit at the cost of much larger government intervention.

2 Background: Cholesterol

Cholesterol is necessary for maintaining life and is used in all cells of the body: it helps to absorb and digest fat and plays crucial role in the formation of Vitamin D. However, having too much cholesterol has long been associated with higher risk of CVD. If there is too much serum (blood) cholesterol, it tends to accumulate on the walls of the blood vessels, forming plaques and narrowing the vessels, which in some cases produces heart attack, stroke, and blood clotting (Greenly 2002).

Although cholesterol is frequently spoken of in general terms, there are two kinds of cholesterol, conventionally defined. High-density lipoprotein cholesterol (HDL-C) is sometimes called “good” cholesterol because it is usually carried from the cells to liver for excretion or reutilization. Low-density lipoprotein cholesterol (LDL-C), on the other hand, is “bad” cholesterol because it is carried to the cells in the body and frequently adheres to the wall of the arteries, which can produce the effects mentioned above. LDL-C, together with very-low density lipoprotein (VLDL) and intermediate density lipoprotein, form non-HDL cholesterol that is held by many to be the best cholesterol predictor of CVD (Sniderman, McQueen et al. 2010). While the human body naturally produces cholesterol for normal functions, diet has significant effect on the amount of serum cholesterol. Consumption of saturated- and trans-fats tends increase LDL cholesterol, while the consumption of whole grains and fiber modestly decrease LDL cholesterol (Lichtenstein 2006). Furthermore, consumption of plant based foods, including vegetables, fruits and nuts tend to decrease LDL cholesterol (Hu 2009). Foods with simple carbohydrates tend to increase VLDL (McKeown, Meigs et al. 2009).

3 Conceptual Model

There is a large and growing literature that addresses the relationship between food choices and health. Much of it is concerned with answering the question, "Why do people become obese?" The question behind this question is whether there is scope for policy to adjust incentives to support healthier eating. Proponents of the notion that unhealthy persons (however defined) make decisions consistently and optimally—"rationally," as economists say—suggest that such policies are inefficient and induce behavioral changes that, at the margin, are not beneficial (Levy 2002; Dragone 2009). To them, since the effects of obesity are well known, in the absence of externalities there would be no reason to adjust prices to affect consumption choices. And even in the presence of externalities, some would argue, intervention is not warranted. Philipson and Posner (2008) have argued that if private actors don't bear the full (actuarial) costs of their diet choices because of private health insurance, an "insurance externality" results. That is, the health costs of one person's diet choices are borne by the entire pool of the insured. However, they argue that this is not an argument for intervention in food markets; it is an argument for experience-rating insurance premiums based on health conditions such as obesity status or cholesterol level.

A counterpoint to this argument is that private insurance markets are not the only source of insurance externalities. Estimates of the public health costs of obesity—which clearly overlaps with the costs of CVD and CVE—suggest that Medicare spent over $1,700 and Medicaid $1,000 more for patients who were obese relative to those who were not in 2006 (Finkelstein, Trogdon et al. 2009). Neither Medicare nor Medicaid is private and in neither case is the suggestion to experience-rate premiums feasible. Moreover, the strong correlation between low income and adverse diet related health conditions suggests that Medicaid in particular is a program that could justify food market intervention.

In thinking about the relationships between food prices and cholesterol levels, we use a model of market failure in which only a fraction medical expenditures that result from food choice are borne by the individuals. This model is plausible despite the objections summarized above and even if we don't consider insurance externalities due to public insurance. Since most insured people get their insurance from their employers, experience rated premiums still reflect group level risks—i.e. the risks of Firm A as opposed to Firm B. Thus, the marginal costs of diet decisions are not imposed on the individual even when premiums are experience rated in a practical sense. Hence, at the margin, individuals have little incentive to modify their eating behavior (moral hazard). Moreover, recent empirical work has shown that this form of moral hazard is important for understanding the prevalence of obesity: it is plausible that it is at work for CVD and related illnesses as well (Bhattacharya, Bundorf et al. 2009).

There are two conditions under which a market intervention is generally beneficial when the moral hazard is present. First, consumption of the good or goods under examination have to have a non-zero effect on the condition considered—here, CVD. Our results suggest that this is quite plausible, given the effects that food prices have on non-HDL-C. Second, the goods to be considered need to be normal goods, which we assume for the purposes of our discussion.[1]

4 Data

To assess the effect of food prices on the blood cholesterol levels, we combine individual information from the National Health and Nutrition Examination Survey (NHANES) and the food price information from the Quarterly Food At Home Price Database (QFAHPD).

The QFAHPD is a comprehensive price data base that covers prices for 52 food groups in 35 geographical markets spread across 48 contiguous states.[2] The price database is based on the Nielsen Homescan survey, which tracks the food purchases by 40,000 US households that represent the US population for a given year. The geography of the market groups is shown in Figure 1. The database also presents the shares of the expenditures for the 52 food categories covered, by quarter, which we use to construct the food prices used in our study.

We aggregate foods into 14 aggregate food groups: fruits, vegetables, sweets, eggs, nuts and oils, regular fat red meat, low fat red meat, fish, poultry, refined grains, processed foods, low fat milk products, regular fat milk products and whole grains.[3] To form a price for each of these goods, we use a weighted mean of the prices each of the component QFAHPD goods, where the weights are annual shares of total expenditure on the QFAHPD good within our 14 categories. As an example of the aggregation process, consider the case of vegetables. The QFAHPD has 6 categories of vegetables: dark green, orange, starchy, select nutrient, legumes, and other. For all but legumes, these groups are further divided into fresh/frozen and canned; legumes are divided into fresh/dried and canned. To get a market price for a particular quarter and market group for vegetables, we use a weighted average of all the prices in the vegetable group. Total national expenditure for each of the 12 categories of vegetables by quarter is the weight applied to each. Hence, the price of vegetables in a given quarter for market group *j* is given by

$$p_{Vj} = \frac{\sum_{i=1}^{K} w_i * p_{ij}}{\sum_{i=1}^{K} w_i} \quad , \tag{1}$$

where *i* indexes each of the subgroups of vegetables, *w* are expenditure weights and *p* are prices. The aggregation process leaves us with 14 product categories, listed above. The composition of these categories in terms of the QFAHPD goods is shown in Table 1.

Our individual-level data, which includes data on demographics, general health, health behaviors and blood cholesterol, comes from three two-year waves of NHANES (1999-2000,

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[1] See Arnott and Stiglitz (1986) for one elaboration of such a model.

[2] See Todd, Mancino et al. 2010 for more on the QFAHPD

[3] The price for each of these twelve food groups is constructed as the expenditure-weighted average of the component prices, by quarter and market group. For more on the QFAHPD, see (Todd, Mancino et al. 2010)

2001-02, and 2003-04). Each wave presents results for about ten thousand individuals. We divide NHANES participants according the QFAHPD market region they live in and the year and quarter the NHANES interview took place using restricted geographic data made available through the CDC. Then we match individuals in the survey to the prices they faced from QFAHPD based on this geographic location and quarter information.

During the interviews with NHANES participants professional health workers took blood samples from the participants and measured their total and High Density Lipid Cholesterol (HDL). The difference between the two gives us the non-High Density Lipid Cholesterol (non-HDL), which has been shown in several studies to be strongly related to CVD and CVE.

For our full sample estimates, we drop any individual younger than 20, because these individuals were not asked certain health and life-style questions and these individuals are rarely have CVD caused by high levels of dietary cholesterol. Throughout, we also highlight results for those over 49 years old, because the policy implications of CVD reduction are most relevant for this age group. In addition, we do this because it is reasonable to assume that, since this age group is already at higher risk of CVD, the effects of food prices could be different than for the whole sample.

Table 2 presents descriptive statistics for this age-restricted sample, which, for purposes of illustration, we have divided into individuals with high, medium and low cholesterol.[4] Individuals with high non-HDL (bad cholesterol) also have low HDL (good cholesterol), which together predispose them to CVD. In addition, these individuals with low non-HDL consume less fat, suggesting the possible effect of diet on cholesterol levels. There is no significant difference in the prices for food groups faced by individuals with high and low non-HDL levels (except low-fat red meat). However, some of the demographic characteristics of these groups are quite different. Individuals with high non-HDL tend to be older and have higher body mass index (BMI). These individuals are more likely to be male, white and they have lower education than the individuals with low non-HDL.

Table 2 also shows that individuals who have lower cholesterol are more likely to use cholesterol lowering drugs. This presents a potential selection issue: if we leave people who report that they are taking such medication in the sample, this could attenuate our results, since their cholesterol levels may be less sensitive to diet than others in the sample. So for the purposes of our main estimation results and calculation of policy benefits, we dropped people who report using cholesterol lowering medication.

Table 2 also shows that individuals with high cholesterol are more likely to smoke, but they are more likely to have ever checked the cholesterol. These individuals are more likely to have

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[4] Doctors recommend that the non-HDL cholesterol should not be higher than the goal for LDL cholesterol + 30mg/dL (Grundy 2002) The goals for LDL cholesterol are optimal <100mg/dL, borderline >100mg/dL and <160mg/dL, high > 160 mg/dL (Lichtenstein 2006).

diabetes and cardio-vascular disease (Stroke, Heart Attack, etc.). Furthermore, individuals with low cholesterol experience these diseases at slightly older age. It is difficult to interpret these variables because people may try to lower their cholesterol levels after the learnt that they have a cardio-vascular disease. Also, individuals with high cholesterol have lower physical activity. They are less likely to exercise and when they do, they exercise less vigorously often and for a shorter time.

5 Empirical Model

Our goal is to estimate the effect of food prices on the blood cholesterol levels. Because cholesterol remains in the blood during weeks and months after consumption, food prices in the recent past affect current cholesterol levels. However, using prices lagged by one or more quarters would capture seasonal variation in food prices which might be confounded with cholesterol levels: to get rid of seasonal fluctuation of food prices, we use lagged four-quarter moving average price as the independent variable of interest. Because our theoretical model considers a subsidy (or a tax) on cholesterol reducing (augmenting) food, and because taxes and subsidies are implemented as a percent of market price, we use log prices as the variables of interest in our model. This also eases interpretation of the model coefficients: they measure how a percentage change in price affects blood cholesterol levels. The estimation equation is the following:

$$NonHDL_i = \beta LogPrice + \gamma Demograpics_i + \delta Health_i + \varphi PhyscialExerise_i + \alpha_1 t + \alpha_2 r + e_i, \quad (2)$$

where t is the time trend measured in quarters and r is a market group fixed effect. We weight regression results using sample weights and employ stratification information in the survey to make the sample nationally representative. Vectors of variables for Price, Demographics, Health and Physical exercise are presented in the Table 2. We also include time trend measure in quarters (t) and regional fixed effects (r) to capture market group level unobservables that are correlated with diet cholesterol both at the initial time of the sample and over time.

We use a linear-log specification because taxes/subsidies are usually implemented as a percentage of prices and. The vector of coefficients β measures the effect of a 100% increase in food prices on blood cholesterol; as is common, we interpret the coefficients in terms of smaller increases—i.e. $\beta/100$ gives the effect of a 1% increase in prices. We expect prices of food rich in saturated fats and refined grains to have negative coefficients: as the price of these foods goes up, less will be consumed and non-HDL will go down; on the other hand, as the prices of fruits, vegetables, low-fat milk, low-fat meat and whole grains go up we expect levels of non-HDL to go up (with lower consumption), so we expect these food prices to have positive coefficients.

6 Results

Column 1 in table 3 shows estimated coefficients for individuals older than 19 years, our full sample, while column 2 shows the coefficients for individuals older than 49 years. Both specifications use control variables presented in the Table 2. In both, the coefficients have the expected signs, in general.[5] The estimates in the column 1 show that, for the population as a whole, the prices of vegetables, processed foods, refined grains and whole grains significantly affect non-HDL-C. Similar observations could be made about the results in column 2.

In terms of the magnitudes of the effects, we find that, for the full sample (column 1), a ten percent increase in the price of vegetables would lead to a 9.2 mg/dl increase in non-HDL-C, while the same increase in the prices of whole grains would lead to a 8.9 mg/dl increase Increases in the prices of processed foods and refined grains would lead to decreases in HDL-C of 15.7 and 6.4, respectively. For the age-restricted sample, we observe that older persons' cholesterol levels are quite a bit more sensitive to prices than those of the population as a whole. Increases in non-HDL-C of 19.4 and 13mg/dl are associated with ten percent increases in vegetable and whole grain prices, respectively. HDL-C is also sensitive to prices of processed foods and whole milk products: ten percent increases in the prices of these goods would lead to decreases in cholesterol of 34.5 and 12.2 mg/dl, respectively.

As for the relative size of these effects, the mean level of non-HDL for the population above 20 years old is about 149 mg/dl, with a standard deviation of 41 mg/dl. So increases in the price of processed foods that tend to bring down level of non-HDL-C by about 16 (34) mg/dl for the full (older) sample represent a one third (seven eighths) standard deviation decrease.

We did find two results in the age-restricted sample that are somewhat counter-intuitive. First, we found that an increase in the price of Fish would decrease the level of non-HDL-C. The conventional wisdom about fish is that it is full of omega-3 fatty acids that can elevate the "good" cholesterol in one's blood, and that therefore it is good for one's cholesterol profile. This is particularly true about cold water fatty fish. However, evidence shows that fish oil can also increase LDL—a large component of non-HDL-C—by as much or more than it increases HDL-C (Balk et al, 2006). Second, we found that sweets were "good" for cholesterol in the sense that an increase in price meant an increase in non-HDL-C. We suspect that there is some complimentarity between elements of the sweets family—particularly beverages—with other foods that are beneficial to cholesterol levels. This could be true of carbonated beverages consumed with whole grain breakfast foods or snacks, for example.

Finally, a caveat about the results for processed foods is also in order: although these results are consonant with the conventional wisdom about processed foods—i.e. that they are detrimental to your health—the processed foods group includes a heterogeneous collection of items such as frozen meals, ready-to-eat meals, pizzas and soups. It is very difficult to make general statements about their quality, so we re-examine these foods below.

[5] The exception are fish and red meats, although only the fish coefficient in statistically significant. The fish category consists of two categories: fresh-frozen fish and canned fish. However when we disaggregated fish category into these two subcategories they have similar effect on cholesterol.

6.1 Processed Foods

The processed food contain a variety of goods whose nutritional value and effect on blood cholesterol is not certain. In Table 4, we disaggregate this category into subcategories to examine their effects: the subcategories that we use are processed nuts, frozen foods, canned soups and sauces, snacks, packaged meals, and ready-to-eat-deli foods. These results show that most of the negative influence of the processed food is driven by frozen processed foods, and that older persons' cholesterol levels are particularly sensitive to the price of these goods. The frozen food subcategory includes pizza, French fries, breaded vegetables, fish sticks and entrees. This result indicates that to the degree that people associate processed foods with these goods, the conventional wisdom about processed food and cholesterol is more or less correct.

Firms that produce processed foods change their goods frequently, offering new products and formulations to the consumers with some regularity. We tried to see if the effect of the processing industry on cholesterol changed over time to reflect these changes in product composition. To do this, we added an interaction term of the logged price of processed foods with the general time trend measured in quarters to the specifications shown in Table 3 (Result not shown.) The estimated coefficient of the interaction term is between -0.3 and -2.4 suggesting little improvement of processed foods. (The coefficient is statistically insignificant.) We conclude that changes in processed foods do not explain much if any of the effect of processed food on blood cholesterol.

6.2 Vegetables

Another striking result from our empirical models is the strong effect of the price of vegetables on cholesterol. As mentioned above, vegetables in the QFAHPD are classified according to nutrient values (dark green, orange, starchy, select nutrient) and packaging (fresh, frozen, canned). In order to get a better sense of what kinds of vegetables are driving our results, we estimate models with vegetables disaggregated by nutrient family and packaging. The results are shown in Table 5 and Table 6, respectively.

The results for vegetables disaggregated by nutrient family indicate that what the QFAHPD calls "select nutrient" vegetables and legumes are driving the results in the main models. The select nutrient category of vegetables in the QFAHPD is comprised of vegetables such as artichokes, avocado, Brussels sprouts, cabbage, cauliflower, parsnips and tomatoes (Todd et. al., 2010). An increase in the price of these vegetables is fairly strongly correlated with an increase in non-HDL-C: our estimates suggest that a ten percent increase in price is associated with between 5 and 15 mg/dl increase in "bad" cholesterol. Legumes' effects are particularly strong for those over 49 years old: a ten percent increase in the price of legumes is associated with between 5.6 mg/dl increase in non-HDL-C.

The results for vegetables categorized by package style, shown in Table 6, confirm the conventional wisdom and dietary guidelines about vegetables: fresh/frozen vegetables have large, significant effects on serum cholesterol. Our results suggest that these kinds of vegetables are driving the results shown in our main models. Depending on the specification, the effect of a ten percent increase in the price of fresh/frozen vegetables yields an increase in non-HDL-C of 14.8 to 20.4 mg/dl.

6.3 Falsification Tests

Our primary hypothesis is that food prices affect blood cholesterol through changes in diet. We test that this relationship is not a spurious correlation of all blood measurements and food price by showing that the food prices are generally uncorrelated with blood cells regulated by the immune system, which responds to infection and presence of foreign materials through regulation of these cells. We consider white blood cells count, number of lymphocytes, number of monocytes and the number of segmented neutrophils. Chemotherapy and a number of diseases such as leukemia, lymphoma, HIV, chronic inflammation and others can affect the number of these cells.[6] We assume the incidence of these diseases and infections are not correlated with food prices, i.e. $\beta=0$.

We repeat the estimation of the effect of food prices on immune blood cell using the same equation as with blood cholesterol for individuals over 49 years old. Table 7 shows the results of the estimation. In the table, there are 56 coefficients: even for null hypothesis that is true, for tests at $\alpha=.05$, we can expect that 5 percent of the time we will get a result that suggests rejecting the null hypothesis that $\beta=0$. In our table, we got results significant at $p<.05$ twice, or about 3.5 percent of the time. Similarly, for a test at $\alpha=.10$, we expect to get results significant at least at that level 10 percent of the time; in these estimates, we get them 6 times, or 10.7 percent of the time. All of this suggests that our results with respect to cholesterol are not being driven by spurious correlation or correlation with other serum attributes.

7 Welfare Calculations

The net benefits of a subsidy or a tax are usually calculated by subtracting deadweight loss of a tax/subsidy from the gains of reduction in external damage (moral hazard). It is very difficult to estimate deadweight loss from the government interventions in the food market, so instead we discuss the size of the necessary government interventions, i.e., the amount of taxes to collected and subsides provided. We assume that a large government intervention all else equal reduces public welfare more than a small intervention, although the exact reduction of welfare is difficult to estimate. We calculate the benefit of taxation/subsidy in terms of the reduction of CVD costs.

To calculate gross savings due to reduced CVD, we need, first, an estimate of the costs (direct and indirect) of CVD. Second, we need an estimate of the change in the probability of CVD for a given change in cholesterol. The product of these two would be our estimate of the gross cost savings—the benefits—due to price intervention. For the first, we use cost estimates from a recent authoritative study (Lloyd-Jones, Adams et al. 2009), as shown in Table 8.

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[6] For more information about immune response please see (Mak and Saunders 2008).

As for the second, there is a large body of medical literature that measures the effect of non-HDL cholesterol on the risk of CVD, coronary heart disease and other conditions associated with high blood cholesterol. Table 9 highlights the results from a recent sample of these studies. In general, these studies follow their subjects over a specific time period and measure the change in the risk of CVD as a function of the change in the concentration of non-HDL. We normalize the results of the studies to estimate the changes of risk per one mg/dL decrease per year:

$$Effect\ of\ 1\frac{mg}{dL}per\ year = \frac{Change\ in\ Risk\ of\ CVD(\%)}{Difference\ in\ nonHDL\ \frac{mg}{dL} * \ Followup\ period\ (years)} \quad (3)$$

We subsequently multiply this effect by the marginal effect derived from our regression results in Table 3 for the most relevant food groups that we examined. As most of medical studies research the effect of cholesterol on risk of CVD for adults above 49 years old, we use the estimated effect of change in the prices on cholesterol from the population over 49 years old (column 2, table 3) as the most broad and relevant population for CVD.

To calculate the cost of the subsidy, we use estimates of the price elasticity of demand for each of the goods in question as established in the literature (These elasticities are shown in Table 10). We multiply this elasticity by our estimate of the average yearly consumption of the relevant goods in the QFAHPD. This would be the expenditure amount subsidized/taxed by the government.[7] We multiply this by .10—the proposed tax or subsidy—to find the cost to the government/consumers. Table 11 shows the estimated effects from the public policy that reflect the findings in the studies listed in Table 9, the elasticities in Table 10, as well as the average effect found in our models.[8] We use average elasticities found in the literature. We find that a ten percent tax on processed foods yields savings of $5.5 bn. due to decrease in medical expenditures. A ten percent subsidy of whole grains yields savings of $2.1 bn., while the same subsidy of vegetables yields $3.1 billion in savings. The tax of regular milk products yields savings of $2.0 bn.

The respective sizes of government interventions required to achieve these savings are shown in the rightmost columns of Table 11 . The costs to consumers of taxes on processed foods and regular milk products are $4.6 and $1.8 billion, respectively, while the cost to the government of subsidies of vegetables and whole grains are $1.5 and $.3 billion, respectively. Subsidy of whole grains yields the highest benefit per dollar of government intervention, yielding an impact on CVD related expenditures 7 times greater than the cost of intervention. A subsidy of vegetables has a calculated benefit more than twice the size of its cost. The taxation of

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[7] In this calculation we assume a perfectly elastic supply.

[8] We were not able to find elasticities for the whole category of processed foods, we used the elasticitiy of demand for potato chips, a subcategory of processed foods. This makes our estimated of a size of government interventions for the processed food much less reliable.

processed foods and whole milk products are less effective, because a dollar of government interventions leads to fewer saving from lower CVD expenditures.

8 Discussion and Conclusion

The total losses due to coronary heart disease in the US deserve public attention not only because of their financial implications, but also because they are arguably in part due to moral hazard. The fact that persons at high dietary risk for CVD do not pay the marginal cost to treat their diet-related health conditions suggests that insurance externalities exist. In this context, interventions in food markets could be beneficial.

Whereas other studies have focused on a "fat tax" as a method for changing diet behavior, we focus on food prices more generally, with the idea that it is not just dietary fat that explains high cholesterol and CVD. We find that prices for vegetables, grains, whole milk and processed foods affect levels of non-HDL-C. Furthermore we find that subsidies of healthier foods would yield larger effects than taxation of foods thought to be detrimental to cardiovascular health.

There are several important assumptions that we make in presenting these estimates. First, our results are based on the assumption of exogeneity of prices in the demand model. While we don't have good instrumental variables to test this assumption, the exogeneity of food prices to consumption has been assumed in important studies of the effects of prices on obesity and so it is reasonable to apply that same assumption here (Lakdawalla and Philipson 2002; Chou, Grossman et al. 2004). Second, we assume that there is no deadweight loss due to food taxes or subsidies. We assume this in part because the data necessary to estimate deadweight loss are not readily available in this context. But even under reasonable assumptions, the outcomes that we outline here would remain. Even if half of the extra consumption of vegetables under a 10% subsidy were deemed to be deadweight loss, the net gain due to reduced CVD would still be almost $3 billion per year. Similarly, even if half of all of the extra consumption of whole grains is determined to be deadweight loss, the gain to intervention would be over $1.5 billion.

These assumptions notwithstanding, our results offer the basis for broadening the scope of health-related food policy beyond the "fat-tax" possibility. Although subsidies themselves would not be new to food policy, current subsidies are heavily skewed toward meat and dairy products. Our results suggest that, although Pigouvian taxes of such products have until now been the focus of policy discussion, subsidies of whole grains and vegetables would be more cost-effective as a price intervention to address the costs of blood cholesterol.

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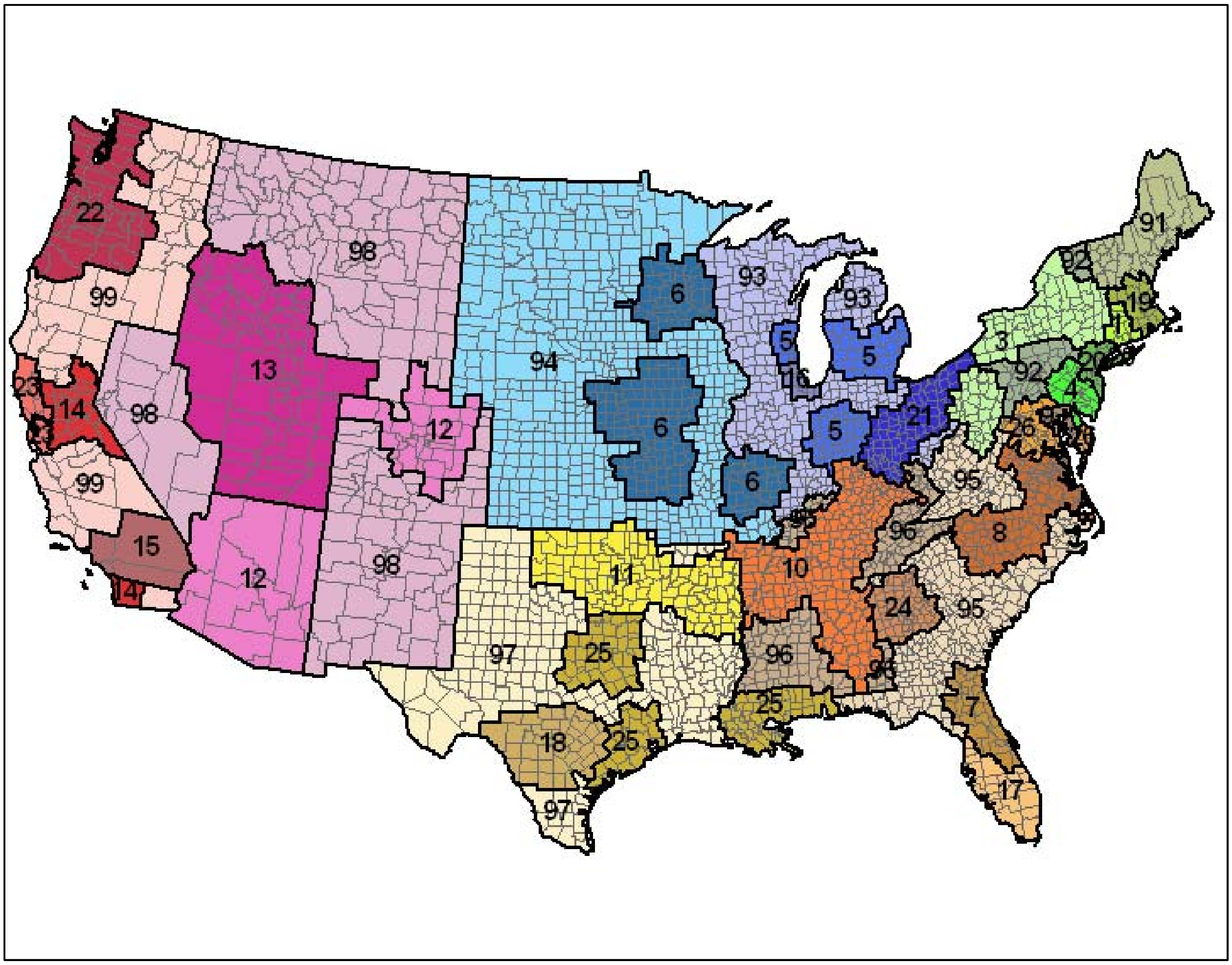
10 Tables and Figures

Figure 1 QFAHPD Market Groups



Source: Todd, Mancino et al. 2010

Table 1 Composition of Prices in Regression Models

Prices	QFAHPD Goods
Vegetables	Fresh/Frozen dark green vegetables Canned dark green vegetables Fresh/Frozen orange vegetables Canned orange vegetables Fresh/Frozen starchy vegetables Canned starchy vegetables Fresh/Frozen select nutrient vegetables Canned select nutrients Fresh/Frozen other vegetables Canned other vegetables Frozen/Dried Legumes Canned Legumes
Fruits	Fresh/Frozen fruit Canned Fruit Fruit Juice
Sweets	Non-alcoholic carbonated beverages Non-carbonated caloric beverages Ice cream and frozen desserts Baked good mixes Packaged sweets/baked goods Bakery items, ready to eat
Oils and Nuts	Oils Raw nuts and seeds
Regular Fat Meat	Fresh/frozen regular fat meat Canned meat
Low Fat Meat	Fresh/frozen low fat meat
Fish	Fresh/frozen fish Canned fish
Poultry	Fresh/frozen poultry Canned poultry
Eggs	Eggs
Processed Food	Processed nuts, seeds and nut butters Frozen entrees and sides Canned soups, sauces, prepared foods Packaged snacks Ready to cook meals and sides Ready to eat deli items (hot and cold)
Whole Milk	Regular fat milk Regular fat cheese Regular fat yogurt & other dairy

	Solid fats
Low-fat Milk	Low fat milk Low fat cheese Low fat yogurt & other dairy
Refined Grains	Non-whole-grain bread, rolls, rice, pasta, cereal Non-whole-grain flour and mixes Non-whole-grain frozen/ready to cook grains
Whole Grain Products	Whole grain bread, rolls, rice, pasta, cereal Whole grain flour and mixes Whole grain frozen/ready to cook

Table 2 Descriptive Statistics

	Low non-HDL	Medium non-HDL	High non-HDL
Non-HDL Cholesterol (mg/dL)	109***	157	221
HDL-cholesterol (mg/dL)	60.3***	53.5	48
Total cholesterol (mg/dL)	169***	210	269
Saturate fat consumption (g)	23.3**	26	26.6
Price of vegetables ($/100g)	0.23	0.23	0.23
Price of fruits ($/100g)	0.20	0.21	0.21
Price of Sweets ($/100g)	0.36	0.36	0.36
Price of Oils and Nuts ($/100g)	0.72	0.72	0.73
Price of Eggs ($/100g)	0.18	0.18	0.18
Price of regular red meat ($/100g)	0.63	0.63	0.63
Price of low-fat red meat ($/100g)	0.78*	0.78	0.79
Price of Fish ($/100g)	0.99	0.99	1.00
Price of Poultry ($/100g)	0.59	0.59	0.59
Price of processed foods ($/100g)	0.60	0.59	0.59
Price of refined grains ($/100g)	0.35	0.35	0.35
Price of whole wheat products ($/100g)	0.49	0.49	0.49
Price of regular milk products ($/100g)	0.47	0.47	0.47
Price of low-fat milk products ($/100g)	0.24	0.24	0.24
Body mass index	28.1***	28.2	29.5
Age	62.8***	61.4	60.6
Male	0.49	0.55	0.53
Hispanic	0.05	0.08	0.08
White	0.82	0.83	0.82
Black	0.09*	0.06	0.06
Multirace	0.03	0.03	0.04
Born in Mexico	0.01**	0.01	0.02
Born outside US (not Mexico)	0.07	0.1	0.11
Completed less than 9th grade	0.06***	0.07	0.1
Completed 9-11th grade	0.11	0.11	0.14
High school diploma or GED	0.24	0.24	0.22
Some College	0.28	0.3	0.32
College or above	0.31**	0.29	0.22
Married	0.65	0.7	0.69
Widowed	0.14*	0.1	0.1
Divorced	0.12	0.11	0.13
Separated	0.02	0.02	0.01
Never married	0.05	0.03	0.04
Cohabitating	0.03	0.03	0.02
Family income <$5K	0.01**	0.01	0

Family income >$5K and <$10K	0.04	0.04	0.03
Family income >$10K and <$15K	0.07**	0.06	0.1
Family income >$15K and <$20K	0.06	0.04	0.05
Family income >$20K and <$25K	0.09	0.06	0.07
Family income >$25K and <$35K	0.12	0.14	0.1
Family income >$35K and <$45K	0.1	0.1	0.11
Family income >$45K and <$55K	0.11	0.09	0.12
Family income >$55K and <$65K	0.06	0.07	0.07
Family income >$65K and <$75K	0.06	0.06	0.06
Family income >$75K	0.23	0.27	0.23
Family income >$20K	0.04	0.04	0.04
Family income <$20K	0.01	0.01	0.02
Household size	2.1***	2.2	2.3
Take Cholesterol lowering drugs	0.31***	0.2	0.17
Relatives with heart attacks	0.15	0.13	0.15
Relatives with stroke or hypertension	0.27	0.25	0.25
Have health insurance	0.93*	0.93	0.89
Smoke everyday	0.14*	0.15	0.2
Ever checked cholesterol	0.92*	0.92	0.88
Told about high blood pressure	0.49*	0.43	0.4
Had Diabetes	0.16**	0.11	0.1
Had heart failure	0.05	0.03	0.03
Had coronary disease	0.12*	0.08	0.08
Had heart attack	0.12***	0.05	0.06
Had stroke	0.05	0.03	0.04
Age when had a heart failure	57.4	56.2	58.4
Age when had a corronary disease	58.6*	55.9	54.4
Age when had a heart attack	57.3	55.8	56.1
Age when had a stroke	59.5	61.6	57.3
Alcoholic drinks per week	1	1.1	1.3
Eating-out per week	2.7	2.7	2.8
Walked or bycicled last 30 days	0.24*	0.2	0.19
Times walked or bycicled	4.8	4.8	4.4
Minutes walked or bycicled	10.1	7.2	8.9
Duration of vigor. phys. activity	0.24	0.24	0.21
Obs.	648	1,290	460

***,**,* denote statistically significant difference between the means of individuals with high and low non-HDL cholesterol levels. The descriptive statistics is presented for all individuals above 19 years old with non-missing observations used in the regression.

Table 3 Food Prices and Cholesterol

	More than 19 y.o.	More than 49 y.o.
Price of vegetables ($/100g)	92.4*	194.3**
	(50.7)	(98.3)
Price of fruits ($/100g)	0.4	82.0*
	(34.4)	(45.8)
Price of Sweets ($/100g)	16.8	76.1**
	(17.5)	(32.7)
Price of Oils and Nuts ($/100g)	-8.7	7.2
	(23.4)	(29.1)
Price of Eggs ($/100g)	-29.0	-41.2
	(20.1)	(30.5)
Price of regular red meat ($/100g)	73.5	36.6
	(62.9)	(86.2)
Price of low-fat red meat ($/100g)	4.7	26.0
	(33.1)	(55.9)
Price of Fish ($/100g)	-24.2	-55.9**
	(29.0)	(22.7)
Price of Poultry ($/100g)	7.5	20.7
	(36.1)	(48.0)
Price of processed foods ($/100g)	-157.2***	-345.0***
	(57.7)	(117.4)
Price of refined grains ($/100g)	-64.4*	-10.6
	(37.6)	(54.0)
Price of whole grain products ($/100g)	89.4*	129.5***
	(51.0)	(43.4)
Price of regular milk products ($/100g)	-59.4	-121.7***
	(47.1)	(38.1)
Price of low-fat milk products ($/100g)	33.7	2.8
	(23.5)	(30.0)
N	5,810	2,398

Note: *** p<0.01, ** p<0.05, * p<0.1. Regression coefficients adjusted to account for the sampling weights and stratification. Prices are logged. Estimations include age, age-squared, bmi, gender, race, country of birth, education, marital status, income and household size and regional fixed effects. In addition the estimations include indicator whether an individual walked or biked in the last 30 days, how many times and for how long, for how long an individual was engaged in vigorous physical activity, number of alcoholic drinks per day, number of times eating out per week, smoking status, health insurance status, ever checked cholesterol indicator, told about high blood pressure indicator, information about diabetes, heart failure, coronary disease, heart attack and stroke , as well as the age when these diseases occurred. We also control whether an individual takes cholesterol lowering drugs and whether an individual has family history of heart attacks, strokes or hypertension.

Table 4 Processed Food Prices and Cholesterol

	>19 years old	>49 years old
Processed Nuts	21.1	-3.6
	(46.3)	(65.0)
Frozen Foods	-62.6	-146.5
	(82.5)	(122.3)
Canned Soups, Sauces	-81.3	28.6
	(66.5)	(108.2)
Packaged Snacks	-7.6	-7.2
	(53.8)	(68.8)
Meals	24.5	-34.7
	(39.1)	(48.3)
Deli, ready-to-eat items	24.3	-19.4
	(39.2)	(68.6)
N	5,810	2,398

Note: *** p<0.01, ** p<0.05, * p<0.1. Regression coefficients adjusted to account for the sampling weights and stratification. Prices are logged. Estimations include age, age-squared, bmi, gender, race, country of birth, education, marital status, income and household size and regional fixed effects. In addition the estimations include indicator whether an individual walked or biked in the last 30 days, how many times and for how long, for how long an individual was engaged in vigorous physical activity, number of alcoholic drinks per day, number of times eating out per week, smoking status, health insurance status, ever checked cholesterol indicator, told about high blood pressure indicator, information about diabetes, heart failure, coronary disease, heart attack and stroke , as well as the age when these diseases occurred. We also control whether an individual takes cholesterol lowering drugs and whether an individual has family history of heart attacks, strokes or hypertension.

Table 5 Nutrition of Vegetables and non-HDL-C

	more than 19 y.o.	more than 49 y.o.
Dark green veg.	-14.0	-48.1
	(25.1)	(38.3)
Orange veg.	0.5	-1.7
	(39.0)	(53.3)
Starchy veg.	32.0	-23.9
	(37.0)	(51.7)
Select nutrient veg.	50.6	150.6***
	(40.8)	(51.4)
Other watery veg.	37.2	47.5
	(33.1)	(84.5)
Legumes	-0.7	56.8*
	(19.0)	(33.0)
N	5,810	2,398

Note: *** p<0.01, ** p<0.05, * p<0.1. Regression coefficients adjusted to account for the sampling weights and stratification. Prices are logged. Estimations include age, age-squared, bmi, gender, race, country of birth, education, marital status, income and household size and regional fixed effects. In addition the estimations include indicator whether an individual walked or biked in the last 30 days, how many times and for how long, for how long an individual was engaged in vigorous physical activity, number of alcoholic drinks per day, number of times eating out per week, smoking status, health insurance status, ever checked cholesterol indicator, told about high blood pressure indicator, information about diabetes, heart failure, coronary disease, heart attack and stroke , as well as the age when these diseases occurred. We also control whether an individual takes cholesterol lowering drugs and whether an individual has family history of heart attacks, strokes or hypertension.

Table 6 Packaging of Vegetables and non-HDL-C

	more than 19 y.o.	more than 49 y.o.
Fresh and frozen veg.	147.6***	203.8***
	(44.7)	(68.2)
Canned veg.	-21.2	-9.1
	(49.1)	(65.6)
N	5,810	2,398

Note: *** p<0.01, ** p<0.05, * p<0.1. Regression coefficients adjusted to account for the sampling weights and stratification. Prices are logged. Estimations include age, age-squared, bmi, gender, race, country of birth, education, marital status, income and household size and regional fixed effects. In addition the estimations include indicator whether an individual walked or biked in the last 30 days, how many times and for how long, for how long an individual was engaged in vigorous physical activity, number of alcoholic drinks per day, number of times eating out per week, smoking status, health insurance status, ever checked cholesterol indicator, told about high blood pressure indicator, information about diabetes, heart failure, coronary disease, heart attack and stroke , as well as the age when these diseases occurred. We also control whether an individual takes cholesterol lowering drugs and whether an individual has family history of heart attacks, strokes or hypertension.

Table 7 Immune Response Blood Cells and Food Prices.

	White blood cells count	Lymphocyte number	Monocyte number	Segmented neutrophils number
Price of vegetables ($/100g)	-1.669	-1.268	0.212	-0.342
	(6.496)	(2.830)	(0.445)	(4.782)
Price of fruits ($/100g)	4.089	2.676*	-0.114	1.406
	(3.497)	(1.558)	(0.274)	(3.151)
Price of Sweets ($/100g)	1.297	2.201	0.441**	-1.295
	(2.891)	(1.721)	(0.178)	(1.827)
Price of Oils and Nuts ($/100g)	-1.143	-1.632	0.191	0.022
	(2.716)	(1.653)	(0.126)	(1.844)
Price of Eggs ($/100g)	-1.336	-1.007	0.079	-0.460
	(2.260)	(1.071)	(0.156)	(1.836)
Price of regular red meat ($/100g)	2.865	1.987	-0.014	1.071
	(6.995)	(3.891)	(0.334)	(5.329)
Price of low-fat red meat ($/100g)	-4.824*	-3.866**	-0.068	-1.176
	(2.562)	(1.523)	(0.195)	(2.043)
Price of Fish ($/100g)	2.893	2.522*	0.047	0.446
	(2.446)	(1.321)	(0.165)	(1.993)
Price of Poultry ($/100g)	1.799	1.363	-0.053	0.722
	(4.936)	(2.088)	(0.262)	(3.767)
Price of processed foods ($/100g)	-3.458	-0.111	-0.305	-3.102
	(7.679)	(3.956)	(0.512)	(5.360)
Price of refined grains ($/100g)	-2.756	-2.271	-0.547*	-0.259
	(4.308)	(1.615)	(0.321)	(3.725)
Price of whole grain products ($/100g)	-3.695	-3.715*	-0.072	-0.542
	(3.060)	(2.104)	(0.239)	(2.319)
Price of regular milk products ($/100g)	-1.144	0.320	-0.112	-1.132
	(3.425)	(2.124)	(0.289)	(2.701)
Price of low-fat milk products ($/100g)	-0.363	0.110	0.109	-0.538
	(3.276)	(1.381)	(0.182)	(2.680)
N	2,434	2,422	2,422	2,422

Note: *** p<0.01, ** p<0.05, * p<0.1. Only individuals older than 49 years old are included in the regression. Regression coefficients adjusted to account for the sampling weights and stratification. Prices are logged. Estimations include age, age-squared, bmi, gender, race, country of birth, education, marital status, income and household size and regional fixed effects. In addition the estimations include indicator whether an individual walked or biked in the last 30 days, how many times and for how long, for how long an individual was engaged in vigorous physical activity, number of alcoholic drinks per day, number of times eating out per week, smoking status, health insurance status, ever checked cholesterol indicator, told about high blood pressure indicator, information about diabetes, heart failure, coronary disease, heart attack and stroke , as well as the age when these diseases occurred. We also control whether an individual takes cholesterol lowering drugs and whether an individual has family history of heart attacks, strokes or hypertension.

Table 8 Estimated Direct and Indirect Costs (in Billions Dollars) of CVD and Stroke: United States, 2009 (Lloyd-Jones, Adams et al. 2009)

	Heart Diseases	CHD	Stroke	HD	HF	Total
Direct cost						
Hospital	$106.30	$54.60	$20.20	$8.20	$20.10	$150.10
Nursing home	$23.40	$12.30	$16.20	$4.80	$4.50	$46.40
Physicians/other professional	$23.80	$13.40	$3.70	$13.40	$2.40	$46.40
Drugs/other						
Medical durables	$22.10	$10.30	$1.40	$25.40	$3.30	$52.30
Home health care	$7.40	$2.20	$4.40	$2.40	$3.40	$16.80
Total expenditures	$183	$92.80	$45.90	$54.20	$33.70	$313.80
Indirect costs						
Lost Productivity/morbidity	$24.00	$10.60	$7.00	$8.40	…	$39.10
Lost Productivity/mortality	$97.60	$62.00	$16.00	$10.80	$3.50	$122.40
Grand totals	$304.60	$165.40	$68.90	$73.40	$37.20	$475.30

Table 9 Estimated health benefits of reductions in non-HDL cholesterol

Study	Follow-up years	Disease	Change in non-HDL-C	Risk Change		
				men	women	both
(Lloyd-Jones, Leip et al. 2006)	25	CVD	30mg/dL	5.30%	5.40%	.
(Mora, Otvos et al. 2009)	10	CVD	22mg/dL	.	20%	.
(Cromwell, Otvos et al. 2007)	14.8	CVD	39mg/dL	17%	27%	21%
(Sniderman, McQueen et al. 2010)	10	CVD	42mg/dL	22%	28%	25%
(Tohidi, Hatami et al. 2010)	8.6	CVD	47.2mg/dL	36%	18%	.
(Robinson, Wang et al. 2009)	4.5	CHD	1%	.	.	1%
(Pischon, Girman et al. 2005)	6	CHD	20mg/dL	32%	.	.
(Arsenault, Rana et al. 2009)	11	CHD	45.2mg/dL	46%	59%	54%
(Kurth, Everett et al. 2007)	11	Stroke	38.7mg/dL	.	19%	.

When the study measures the effect of change in cholesterol on risk of CVD using quartiles of CVD, we estimate the effect averaging the two middle quartiles.

Table 10 Price Elasticities for Relevant Food Groups

QFAHPD Group	Author(s)	Date	Product(s)	Own-Price Elasticity
Processed Foods	(Kuchler, Tegene et al. 2005)	2005	Potato Chips	-0.4541
Vegetables	(Jensen and Smed 2007)	2007	Vegetables	-1.23
	(Andreyeva, Long et al. 2010)	2010	Vegetables	-0.58
	(Huang, Lin et al. 2000)	2000	Vegetables	-0.7238
Whole Milk	(Chouinard, Davis et al. 2005)	2005	Whole Milk	-0.652
	(Jones, Akbay et al. 2003)*	2003	Whole Milk	-0.6315
	(Chouinard, Davis et al. 2007)	2007	Whole Milk	-0.742
Whole Grain	(Ishdorj and Jensen 2008)*	2008	Whole Grain	-1.06

* Average of elasticities presented.

Table 11 Effects of Public Policies ($bn).

Food Group	Policy	CVD cost savings Total	Direct	Gov. Direct	Government Intervention	Effect per dollar of intervention
Processed foods	10% tax	$5.5	$3.63	$1.16	$4.60	$1.20
Vegetables	10% subsidy	$3.1	$2.05	$0.65	$1.50	$2.07
Regular Milk Products	10% tax	$2.0	$1.32	$0.42	$1.70	$1.18
Whole grain products	10% subsidy	$2.1	$1.39	$0.44	$0.30	$7.00

The effect of prices on non-HDL is taken from general population above 49 years old (column 4 of Table 3). The range of savings computed from studies with maximum and minimum effect of non-HDL-C on the risk of CVD. Mean savings represent the average effect across studies. Government direct costs are estimated based on Medicare and Medicaid expenditures on CVD (Trogdon, Finkelstein et al. 2007; CMS 2010). Government intervention is amount of taxes or subsidies government needs to collect or distribute. It calculated using average yearly expenditures on each of the goods in the table. This amount is adjusted based on elastiticities estimated in the literature and then multiplied by 10%.