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Using the Thrifty Food Plan to Assess the Cost of a Nutritious Diet

The federal government's Thrifty Food Plan (TFP) minimizes the difference between a proposed food plan and a current consumption bundle, subject to cost and nutrition constraints. This article adapted the TFP framework to estimate the cost of a nutritious diet, distinguishing between nutrition constraints based on food categories (meat, vegetables) or nutrients (saturated fat, calcium). The official cost target for the TFP was sufficient if one tolerated a very high difference from current consumption patterns, or if one used nutrition standards instead of *MyPyramid* food category standards. In other scenarios, with different constraints, the official cost target was insufficient.

How much does a nutritious diet cost?

This question is central to debates over U.S. anti-hunger and nutrition policy. The benefit level for more than 28 million low-income participants in the Supplemental Nutrition Assistance Program (SNAP), formerly called the Food Stamp Program (FSP), is related to the federal government's official estimate of the cost of a "thrifty" but nutritious diet (Carlson et al. 2007). This question also matters for nutrition policy more broadly, because one leading explanation for the current epidemic of obesity-related chronic disease emphasizes the comparatively low cost of energy-dense foods and the high cost of healthier foods (Drewnowski and Specter 2004).

The estimated cost of a nutritious diet depends systematically on the definition of "nutritious." In Stigler's famous 1945 application of linear programming, the minimum cost required to meet narrowly defined nutrition targets was only pennies per day (Stigler 1945). He acknowledged that his cost estimate would make dietitians unhappy, and implied that they were too generous in their "cultural requirements" for

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palatability, variety, and prestige, which "should not be presented in the guise of being part of a scientifically-determined budget." By contrast, researchers at the Brigham and Women's Hospital in Boston estimated the monthly cost in 2003 of a "heart-healthy" and "culturally appropriate" diet for a family of four in the low-income neighborhood of Roxbury to be $692, which was $242 higher than maximum food stamp benefit at the time (Johnson et al. 2004).

The U.S. Department of Agriculture (USDA's) Thrifty Food Plan (TFP), revised most recently in 2006, offers a useful framework for studying the cost of a nutritious diet. USDA generates the TFP by solving a constrained optimization problem, choosing a diet that is as similar as possible to the current consumption pattern for low-income Americans, while simultaneously meeting a cost constraint, food group constraints drawn from the *MyPyramid* nutrition education materials, nutrient constraints from the *Dietary Guidelines for Americans*, and other miscellaneous constraints.

The maximum benefit for the FSP is related to the value of the TFP, but this policy role is commonly misunderstood. Although the TFP is described as "the basis for maximum food stamp allotments," each revision of the TFP takes an inflation-adjusted cost of the preceding plan as the cost constraint for the new food plan. The official TFP does provide the food group quantity weights that are used in USDA's annual inflation adjustments for FSP benefits, but it would make only a modest difference in the time trends if the quantity weights in the Consumer Price Index (CPI) for food at home had been used instead. The main policy role of the TFP revision is to confirm that the previous budget allotment still suffices to purchase a nutritious diet. TFP revisions after the 1970s have not sought to reopen the more fundamental question of how much a nutritious diet should cost in the first place.

In this article, we adapted the TFP framework to investigate the cost of a healthy diet. Keeping in mind the argument between Stigler and his critics, we distinguished between the impact of nutrition constraints and preference considerations on diet costs. The article used the same official data as USDA, but we made several contributions.

First, we compared and contrasted USDA's constrained optimization problem with the theory of constrained utility maximization, which is more familiar in consumer economics. In addition to the objective function from the official 2006 TFP, we explored three alternative specifications that make the objective function more similar to a utility function that has been used in the empirical economics literature. Second, by varying the cost constraint over a wide domain, instead of imposing a single fixed cost target, we measured how the difficulty of achieving a nutritious diet increased as the cost constraint became tighter. Third, to investigate how the cost depends systematically on the definition of "nutritious," we disentangled the effects of the different kinds of nutrition constraints imposed in the 2006 TFP revision. One important contrast is between dietary advice expressed in terms of foods (Pollan 2007) and nutrients (U.S. Department of Health and Human Services and U.S. Department of Agriculture 2005). We asked: (1) if one emphasizes foods by imposing the *MyPyramid* food category constraints, how much does the solution plan cost and how well does it satisfy specific nutrient goals? and (2) conversely, if one emphasizes nutrients by imposing specific nutrient targets from the *Dietary Guidelines*, how much does the solution plan cost and how different is it from the balance of broad food categories in *MyPyramid*?

In future work, this framework can be used to address further questions about the impact of different constraints on the cost of a nutritious diet. In addition to sharing the data and programming for this article, we have developed a Microsoft Excel–based spreadsheet program that allows one to more easily evaluate the official USDA food plans or to create a new benchmark food plan that meets one's own chosen nutrition policy goals (Wilde, Llobrera, and Campbell 2008).

METHODS

Objective Function

In the official TFP framework, the goal is to choose a food plan, composed of quantities for 59 food groups ($x_1, \ldots, x_{59}$), which minimizes an objective function while simultaneously meeting a cost constraint, nutrition constraints, and other miscellaneous constraints. In the 2006 TFP report, these groups are called "categories" (Carlson et al. 2007), but to avoid confusion, we reserve the latter term for broader *MyPyramid* categories. The objective function (D) measures the "distance" between a proposed food plan and the current average consumption pattern for low-income Americans. This distance function is a weighted sum of the "distance contributions" (d_i) from each food group i.

The distance contribution for each food group i gets larger as the proposed quantity (x_i) becomes more different from the current consumption quantity (c_i). The official TFP uses a distance contribution that is a quadratic function of the natural logarithms of (x_i) and (c_i):

$$d_i(x_i) = [\ln(x_i) - \ln(c_i)]^2. \tag{1}$$

For reasons discussed later, we also investigated a simpler alternative functional form for this distance contribution:

$$d_i(x_i) = [x_i - c_i]^2. \tag{2}$$

Constraints

The first constraint is the cost constraint, which ensures that the plan is affordable. The constant parameter β_{i1} is the price for a unit of food group i in the first constraint. The cost constraint requires that the plan's total cost $\left(\sum_i \beta_{i1} x_i\right)$ cannot exceed the cost target (y_1).

The second constraint is the lower bound on food energy, which ensures that the plan provides enough food. The parameter β_{i2} is the food energy provided by a unit of food group i in the second constraint. The lower bound on food energy requires that the plan's total food energy $\left(\sum_i \beta_{i2} x_i\right)$ must be greater or equal to the target (y_2), which is equivalent to 95% of the Institute of Medicine's energy requirement for a person with a low active physical activity level and the median height and weight for his or her age–gender group (Carlson et al. 2007). The third constraint is the upper bound on food energy, which requires that the plan's total food energy $\left(\sum_i \beta_{i3} x_i\right)$ must be less than or equal to a higher target (y_3), equivalent to 105% of the requirement.

The other constraints, which vary from model to model as described in the methods section later, take a similar form. Each nutrient constraint from the *Dietary Guidelines* has a set of parameters β_{ij}, which describe how much of the jth constraint's nutrient is supplied by one unit of the ith food, and y_j is an upper or lower bound on consumption of the jth constraint's nutrient. For the broad *MyPyramid* food category targets, each parameter β_{ij} describes how many servings of broad food category j is provided by the ith specific food, and y_j is the target for total servings of that broad category. In this article, a "serving" is an ounce equivalent for the meat category, and a cup each for the grains, vegetable, fruit, and vegetable categories.

The Constrained Optimization Problem

Together, the objective function and constraints constitute a nonlinear programming problem:

$$\text{Choose } (x_1, \ldots, x_{59}) \text{ to minimize} D(x_1, \ldots, x_{59}) = \sum_i w_i d_i(x_i),$$

$$\begin{aligned}
\text{subject to } \sum_i \beta_{i1} x_i &\leqslant y_1 && \text{(cost constraint)},\\
\sum_i \beta_{i2} x_i &\geq y_2 && \text{(lower bound on food energy)},\\
\sum_i \beta_{i3} x_i &\leqslant y_3 && \text{(upper bound on food energy)},\\
\sum_i \beta_{ij} x_i &\geq y_j && \text{(other constraints} j = 4, 5, \ldots, K). \quad (3)
\end{aligned}$$

In the official TFP, the weights in the objective function equal the expenditure shares of each food group i in current consumption:

$$w_i = \beta_{i1} c_i / \Bigl(\sum_j \beta_{j1} c_j \Bigr). \quad (4)$$

For reasons discussed later, we also explore using weights equal to the food energy shares of each food group in current consumption.

For each model, the solution quantities and the minimum value of the objective function were found using the dual quasi-Newton algorithm for least squares minimization, implemented using the "proc nlp" procedure in SAS statistical analysis software (SAS Institute Inc. 2004).

The official functional form has an interesting feature, which apparently has not previously been noted in the literature. When the nonlinear programming problem is solved subject to the cost constraint alone, using the Lagrangian method, the prices cancel throughout, and the solution quantity can be expressed as a simple constant multiplied by the corresponding base quantity: $x_i* = kc_i$, where x_i* is the solution quantity. For example, if the TFP cost target is 80% of the cost of current average consumption, then the solution is simply to set each of the 59 quantities at 80% of the current average. Matters become more complicated as the functional form is varied or as nutrition constraints are added, but understanding this pattern in the simple case with just a cost constraint makes it easier to understand the solutions in the full model as well.

For very low cost targets, there is no food plan that satisfies all of the constraints, so the solution is infeasible. In all of the problems studied here that have a feasible solution, the solution appears to be unique.

Comparison to Utility Maximization

Constrained optimization in the TFP framework, using just the cost constraint, is reminiscent of constrained utility maximization in the economic theory of consumer choice. In both the TFP framework and utility maximization, one chooses quantities by seeking the optimum value of an objective function, subject to a budget constraint. The bundle of goods preferred by an unconstrained consumer, for whom money is no object, is sometimes called a "bliss point" in consumer economics. One could think of $-D$ in the consumer problem (equation 3) as a utility function that reaches a maximum at a bliss point equal to the current consumption quantities ($c_1, \ldots, c_{59}$).

The weighting of the objective function used in the official TFP is not one that has been used for research in consumer economics. In consumer economics, one thinks of the utility function as a representation of consumer preferences, whereas the budget constraint reflects prices and consumer income. In the official TFP objective function, by contrast, the expenditure weights in equation (4) also depend on the prices (β_{i1}). If one thought of the objective function as a utility function, the shape of the function and its indifference curves would shift or rotate as prices changed. Our alternate specifications using food energy weights avoid the use of prices in the objective function, while maintaining USDA's intent in according more importance to the food groups that have a greater share of current consumption.

Likewise, the quadratic-in-logarithms functional form for the distance contribution in equation (1) is not one we have seen used in the consumer economics literature. USDA's reasonable goal in choosing this function was to assign a greater penalty to food plan choices that fall short of current consumption, while assigning a smaller penalty to food plan choices that exceed current consumption (Hanson 2006).

In one respect, the official functional form in equation (1) seems more realistic than the alternate functional form for the distance contribution in equation (2). The alternate functional form assigns a quantity of zero to food groups that have unfavorable nutritional and economic qualities, whereas the official quadratic-in-logarithms functional form assigns small positive solution quantities to such food groups. The latter approach seems reasonable, for example, by allowing for a rare regular soft drink that an otherwise healthy eater might reasonably consume on New Year's Eve.

In another respect, the official functional form seems less realistic. It assigns a severe penalty to small food quantities, with the penalty becoming infinitely steep as the food quantities approach zero. A small change in a tiny food quantity can influence the objective function more than a large change in a large food quantity does. Hence, we focus on results using the alternative objective function in this article, while recognizing that the resulting zero quantities for some food groups are just approximations of realistic behavior for the representative consumer. Much as the *Dietary Guidelines* allow for additional discretionary calories (U.S. Department of Health and Human Services and U.S. Department of Agriculture 2005) beyond the calories in foods that are necessary to satisfy needs for other nutrients, we imagine the representative consumer having a small amount of additional discretionary income that allows for small positive quantities of food groups that have a zero quantity in the formal solution.

While interpreting the TFP framework as a utility maximization problem, additional issues are raised by the nutrition constraints. What would it mean for a consumer to maximize utility subject to nutrition constraints? One might think of the TFP framework as a normative problem, describing a nutritious food pattern that a low-income consumer *should* choose. However, the current consumption bundle for low-income Americans is already associated with comparatively high rates of obesity, heart disease, and other chronic diseases. It is not clear why a normative approach should choose the current consumption bundle as the unconstrained optimum.

Alternatively, one might think of the TFP framework as a positive problem in consumer economics, describing the food pattern that a representative low-income consumer realistically *would* choose if he or she were determined to select only nutritious and affordable options. One problem is that this framework is recursive. It supposes that the representative low-income consumer seeks a diet as similar as possible to the average consumption bundle for low-income consumers. If all low-income consumers made choices in this fashion, then the average consumption bundle would be derived from the constrained solution to each consumer's TFP problem. It is difficult to see how the same average consumption bundle can be both the unconstrained optimal value of the objective function and simultaneously the average of the constrained solutions for low-income consumers. Furthermore, there is no empirical evidence that consumers do seek to minimize their distance from the average consumption bundle of low-income Americans.

Scenarios

We solved the nonlinear programming model under several constraint sets. Preliminary estimates imposed a cost constraint alone, and subsequent scenarios all retained the cost constraint. There were four main scenarios, distinguished by the additional constraints imposed: (1) food energy constraints, (2) food energy constraints and *MyPyramid* food category constraints, (3) food energy constraints and specific nutrient constraints, and (4) all of the above constraints together.

We did not impose miscellaneous constraints that were used in the official TFP. USDA used an upper bound, which varied across the 59 food groups, to prevent solution quantities from exceeding current consumption quantities by greater than a factor of three to ten. USDA imposed additional constraints for the meat and beans food groups: "each of the subgroups (beef, pork, veal, lamb, and game; chicken, turkey, and game birds, etc.) was constrained within a narrower range of average consumption to ensure that no one subgroup dominated the pattern" (Carlson et al. 2007). Because legumes and nuts are low-cost nutrient sources within the meat/beans category, and several other food groups (such as mixed grains) contain some meat, the miscellaneous constraints are needed if the analyst views positive quantities of the main meat food groups as part of the definition of a nutritious diet. We chose not to include the miscellaneous constraints, because the objective function already has the purpose of preventing solutions that are unreasonably different from current consumption, and we preferred to study the model's solution for the composition of meat group quantities. In the results section later, we noted the impact of USDA's miscellaneous constraints by comparing our solution from scenario (4) with the official TFP bundles.

Age–Sex Groups

The analyses using the official cost constraint were conducted separately for the four age–sex groups that USDA uses in determining the maximum food stamp benefit: an adult male aged 20–50 years, an adult female aged 20–50 years, and two children aged 6–8 years and 9–11 years. We focus for brevity on adult women in the results section, and results for the other three demographic groups are presented in the Appendices.

Variable Cost Constraints

The cost target in the official TFP differs by age–sex group. For example, the daily cost target for an adult woman in this article was \$3.89 in 2001 dollars, which was equivalent to \$4.98 for an adult woman in the June 2008 TFP. For each of the four main scenarios, we first solved the programming problem using the official TFP cost target. Then, to investigate the cost of a nutritious diet, we repeated the algorithm iteratively, allowing the cost constraint to vary over a wide range from \$0 to \$10 per person per day in steps of \$0.05.

Weights and Functional Form

For each scenario and each age–sex group, we estimated the model using the official expenditure weights in equation (4) and the alternate food energy weights. The choice of weighting did not matter greatly, so we reported the results with our alternate weights, which have the advantage of increasing the similarity between the TFP model and a traditional utility function. We also used two functional forms: the official TFP quadratic-in-logarithms functional form in equation (1) and the alternate plain quadratic functional form in equation (2). In the main results section, we focused on the results for the plain quadratic functional form, although we noted any differences for the official functional form.

DATA

USDA made available the following data sets, which were used in creating the 2006 TFP revision (Carlson et al. 2007).

Nutrient Characteristics and Average Consumption Quantities

For each of the 15 age–sex groups and 58 food groups, USDA computed average consumption from a single day food intake instrument in the 2001–2002 National Health and Nutrition Examination Survey (NHANES), a complex, multistage probability sample of the civilian noninstitutionalized population of the United States. NHANES survey weights were used so that sample consumption averages are estimates of the corresponding population averages. The food group for legumes can count toward the meat and protein category or toward the vegetable category, so there are 59 food groups in the estimation given later. USDA selected 3,527 individuals in households with income at or below 130% of the U.S. poverty threshold, which is the gross income cutoff for food stamp eligibility. The NHANES sample included intake amounts for 4,152 different foods, which were classified into 59 food groups according to their nutritional and economic characteristics. For example, red meats have four food groups according to whether the food product is low-fat or regular-fat and low-cost or regular-cost. For each food group, USDA determined the amounts per 100 g for each important micronutrient (such as vitamin C, calcium), macronutrient (protein, saturated fat), food energy (calories), and *MyPyramid* food category (in servings).

Food Prices

As NHANES does not contain price or expenditure information of foods consumed, USDA created the 2001–2002 Food Price Database from the ACNielsen Homescan Panel, a commercial nationally representative panel survey of 16,821 households who recorded their purchases using automated bar-code scanners in their homes. Attaching the prices to the 59 food groups was complex: (1) USDA researchers broke each food as consumed in NHANES into purchased foods (a TV dinner or an apple) or component ingredients as purchased (flour and sugar), (2) researchers priced each purchased food or ingredient, (3) they combined the purchased foods and ingredients back again to get prices for foods as consumed, and (4) they produced a quantity-weighted price index of foods as consumed in each of the 59 food groups. Because the combinations of detailed foods within a food group may differ for persons in different age–sex groups, the food group “prices” differ slightly across age–sex groups.

Thresholds for Nutrition Constraints

The food category constraints were based on USDA’s *MyPyramid* recommendations. These include the broad categories (milk and related foods, meat/beans and related foods) and also more specific food group recommendations (minimum dark green vegetables, minimum orange vegetables, maximum added fats and sugars). The nutrient constraints were based on the most recent available recommendations for micronutrients, macronutrients, and food energy, from the *Dietary Guidelines for Americans* and the Institute of Medicine at the National Academies. These nutrient constraints include upper limits, recommended dietary allowances (RDAs), adequate intake (AI) standards, and more complex thresholds that involve multiple nutrients (saturated fat should be less than 10% of total calories). Some of these limits are the same across age–sex groups, whereas others vary. The food energy constraints restrict the total food energy in kilocalories to a narrow range from 95% to 105% of the recommended target for each demographic group.

Following decisions made in the official 2006 TFP revision (Carlson et al. 2007), the constraints for vitamin E and potassium were adjusted slightly, and the constraint for sodium was adjusted substantially upward, because USDA found that these changes were required to achieve a feasible solution for some demographic groups. The original nutrition standards come from an array of different sources, requiring considerable effort to reconcile technical details such as different age ranges used by different sources. The best single source for the full list of nutrition constraints is USDA's official report for the 2006 TFP revision (Carlson et al. 2007).

RESULTS

Current Consumption

In Table 1, for females aged 20–50 years, important food groups in current consumption included grain mixtures (98.3 g, 10.5% of average food energy, including foods such as pizzas, burritos, and pasta mixtures), non-whole grain breads (75.4 g, 9.4% of food energy), meat mixtures (48.3 g, 4.9% of food energy, including meats with grains or vegetables with median or higher amounts of fat), low-fat meat mixtures (50.1 g, 2.5% of food energy), and regular soft drinks (669.4 g including the water content, 12.5% of food energy).

The current consumption bundle failed to meet several constraints (Table 2). The current expenditure of $5.34 per day greatly exceeded the official cost target of $3.89 per day. The current food energy of 2,262 kcal fell within the target range of 2,090 to 2,310 kcal. The objective function value or distance function value for current consumption was 0.00 units by definition.

Among the *MyPyramid* food category constraints, the current consumption bundle fell short of targets for milk, whole grains, fruits, and vegetables, and exceeded two times the upper limit for added fats and sugars. Among the nutrient constraints, the current consumption bundle fell within the wide ranges provided for the percentage of total food energy from macronutrients such as carbohydrates, fats, and protein. The

TABLE 1
Amounts of Selected Food Groups in Current Consumption and the Official TFP (Adult Women)

	Daily Amount (grams)	
Food Group	Current	Official TFP
Milk	62.9	0.1
Low-fat milk	70.6	714.7
Low-cost lean poultry	2.2	84.3
Meat mixtures	48.3	0.2
Low-fat meat mixtures	50.1	0.2
Legumes (vegetables)	26.5	105.3
Non-whole grain breads	75.4	0.4
Whole grain cereals	14.4	56.1
Whole grain rice and pasta	5.6	218.4
Non-whole grain rice and pasta	33.9	78.3
Grain mixtures	98.3	0.3
Low-fat grain mixtures	52.1	0.4
Citrus, melon, and berry juice	54.3	0.9
Other fruits	46.8	270.4
Low-fat potatoes	15.6	121.6
Orange vegetables, no fat	6.0	61.7
Tomatoes	2.5	90.0
Mixed vegetables	4.0	59.0
Fats and oils	26.5	60.4
Coffee	417.0	43.8
Soft drinks	669.4	0.6
Low-calorie soft drinks	120.1	0.4
All others[a]	473.0	275.6

Note: Amounts shown for food groups with greater than or equal to 45 g in current bundle or official TFP.
[a]Total for all other food groups.

plan fell short of targets for fiber, calcium, vitamin A, and several other nutrients.

Official TFP

For females aged 20–50 years, the TFP consumption bundle greatly differed from current consumption (Table 1). For example, the official TFP bundle allowed only 0.6 g of regular soda, as near zero as possible with the logarithmic form of the official objective function. Compared with current milk consumption that was split between regular and low-fat milk, the TFP bundle included 0.1 g daily of regular milk and 714.7 g of low-fat milk (equal to three 8-oz servings). Whole grain rice and pasta

TABLE 2
Cost and Nutrition Characteristics of Several Food Plans, Distinguished by Different Constraint Sets (Adult Women)

				Constraints Imposed				
Characteristic	Target	Official TFP	Current	Cost	Cost, Energy	Cost, Energy, Pyramid	Cost, Energy, Nutrients	All
Scenario #					(1)	(2)	(3)	(4)
Cost ($)	$3.89	$3.89	$5.34	**$3.89**	**$3.89**	**$3.89**	**$3.89**	**$3.89**
Energy (kcal)	2,090 to 2,310	2,298	2,262	1,887	**2,090**	2,214	**2,310**	**2,310**
Distance function	0.0000	6.6538	0.0000	0.0015	0.0020	2.5918	0.0907	5.0097
Pyramid servings								
Milk	>3.00	3.15	1.38	1.23	1.27	3.00	1.78	3.00
Meat/beans	>6.00	6.3	6.27	3.39	3.77	6.46	4.95	6.00
Grains	>7.00	7.35	7.65	6.89	8.48	**7.00**	4.69	**7.00**
Whole grains	>3.50	3.68	0.52	0.26	1.33	6.48	0.52	3.96
Fruits	>2.00	2.10	0.97	0.84	0.83	**2.00**	0.69	**2.00**
Whole fruit	>1.00	1.98	0.58	0.48	0.47	1.78	0.45	1.08
Vegetables	>3.00	3.37	1.53	1.13	1.13	**3.00**	6.00	4.15
Dark green	>0.43	0.45	0.07	0.01	0.01	**0.43**	0.02	**0.43**
Orange	>0.29	0.52	0.08	0.01	0.01	0.29	2.58	1.44
Legumes	>0.43	0.45	0.14	0.13	0.14	**0.43**	0.32	**0.43**
Starchy	>0.86	0.90	0.51	0.43	0.45	**0.86**	1.50	**0.86**
Other vegetables	>1.00	1.05	0.77	0.57	0.55	**1.00**	1.60	**1.00**
Added fats/sugars (kcal)	<290	305	806	726	765	**290**	698	**290**
Oils (grams)	>29	30	18	14	17	**29**	26	37
Macronutrients[a]								
Fat	20% to 35%	31%	33%	26%	29%	28%	32%	33%
Saturated fat	<10%	8%	10%	8%	9%	7%	9%	8%
Linoleic acid	5% to 10%	8%	6%	5%	6%	7%	8%	9%
Linolenic acid	0.6% to 1.2%	0.7%	0.6%	0.5%	0.5%	0.3%	0.6%	0.6%

(*continued*)

TABLE 2
(continued)

Characteristic	Target	Official TFP	Current	Constraints Imposed: Cost	Cost, Energy	Cost, Energy, Pyramid	Cost, Energy, Nutrients	All
Scenario #					(1)	(2)	(3)	(4)
Carbohydrates	45% to 65%	54%	52%	48%	53%	58%	60%	57%
Protein	10% to 35%	17%	14%	10%	11%	14%	11%	14%
Other nutrients								
Calcium (mg)	1,000 to 2,500	1,315	796	689	737	1,202	**1,000**	1,306
Cholesterol (mg)	<300	223	292	210	222	52	83	67
Copper (mg)	0.9 to 10.0	2.0	1.3	1.0	1.2	2.2	2.1	2.3
Fiber (g)	>30.8	32.7	16.4	13.3	16.5	34.7	35.5	36.8
Folate (micrograms)	400 to 1,000	670	562	476	539	411	616	673
Iron (mg)	18 to 45	19	16	13	15	12	**18**	**18**
Magnesium (mg)	>320	503	263	202	248	667	423	579
Niacin (mg)	14 to 35	28	22	16	18	24	23	25
Phosphorus (mg)	700 to 4,000	1,907	1,288	989	1,118	1,969	1,448	1,879
Potassium (mg)	>4, 700	4,266	2,536	1,992	2,163	3,700	**4,700**	**4,700**
Riboflavin (mg)	>1.1	3.0	2.0	1.7	1.8	2.1	2.1	2.5
Sodium (mg)	<2, 300	2,808	2,774	2,204	2,481	1,445	**2,693**	2,601
Thiamin (mg)	>1.1	2.1	1.6	1.3	1.5	1.7	1.9	1.9
Vitamin B6 (mg)	1.3 to 100	3	2	1	1	2	3	3
Vitamin B12 (micrograms)	>2.4	7.2	4.6	3.0	3.2	3.6	3.1	4.2
Vitamin C (mg)	75 to 2,000	105	93	76	76	148	144	133
Vitamin E (mg)	15 to 1,000	12	7	5	6	11	**15**	**15**
Vitamin A (micrograms)	700 to 3,000	1,524	509	342	364	946	**3,000**	2,078
Zinc (mg)	8 to 40	16	12	8	9	14	11	14

[a]Macronutrients expressed as percentage of food energy. Bold formatting indicates that a constraint is binding.

was less than 0.5% of food energy in current consumption and more than 10% of food energy in the official TFP.

By definition, the official TFP met or exceeded all of the constraints used in this article plus other miscellaneous constraints (Table 2). The cost constraint is binding, so the official TFP cost is $3.89. The food energy was near the upper end of the acceptable range. The distance function value was 6.65 units, of which 5.52 units were contributed by just one of the 59 food groups, regular soft drinks.

As noted in the data section earlier, the official TFP used a relaxed sodium constraint. The official TFP sodium level of 2,808 mg would not have met the recommendation in the *Dietary Guidelines* of 2,300 mg. The official TFP sodium level exceeded that of the current consumption, 2,774 mg.

Cost Constraint

A food plan imposing the cost constraint alone fell short of targets in nearly every respect, providing insufficient quantities for each *MyPyramid* category. The food energy of 1,887 kilocalories was inadequate. The food plan met the broad ranges for the percentage of food energy provided by macronutrients, because these constraints relate to the relative composition of the diet, and hence remain easy to meet even in a diet with inadequate food energy. The food plan failed to meet other nutrient requirements, such as calcium, fiber, iron, vitamin E, vitamin A, zinc, and others. The bold formatting on the $3.89 cost for this plan indicates that the cost constraint is binding (Table 2, column 4). The distance function value was 0.0015 units. This spare model served only as a basis for comparison to later scenarios.

Scenario (1) Food Energy Constraint

Imposing the cost and food energy constraints alone, this food plan provided inadequate amounts of many nutrients and all *MyPyramid* food categories except grains (Table 2, column 5). The model reduced the amount of some food groups with low energy density, such as low-fat meat mixtures and low-calorie soft drinks, while increasing the amount of some food groups with high energy density. Consumption of grains increased from 6.89 servings under the cost-only scenario to 8.48 servings under this scenario. Consumption of whole grains increased by more than one serving. Although whole grain products are a good source of fiber, this increase was not enough to meet the fiber target. Aside from meeting the energy and grain targets, this food plan was similar in nutritional quality to the cost-only food plan.

Scenario (2) Food Energy and *MyPyramid* Category Constraints

When "nutritious" was defined as meeting the *MyPyramid* recommendations for food categories, the diet necessarily deviated substantially from current consumption. The distance function value was 2.59 units (Table 2, column 6).

Most of the *MyPyramid* food category constraints were binding. To meet them, the model increased the amount of low-fat milk, whole grain rice and pasta, fruits and fruit juice, vegetables, nuts, seeds, and legumes. At the same time, the model reduced the amount of food groups like coffee and soft drinks, which do not belong to the five main *MyPyramid* food categories and contribute to added fats and sugars. To stay within the cost constraint, the model substituted lower cost food groups for higher cost food groups within each *MyPyramid* food category. For example, the amount of low-fat milk (a relatively low-cost source of dairy) was increased whereas the amount of regular milk, cheese, and milk-based desserts (relatively high-cost sources of dairy) were reduced. The target for meat and beans was met entirely by increasing the amount of nuts and legumes, whereas the amount of many food groups featuring animal meat was reduced. Although most of the *MyPyramid* constraints were binding, the resulting food plan exceeded the target for meat and beans, whole grains, and whole fruit. In particular, the number of servings of whole grains increased dramatically from 1.33 servings to 6.48 servings. This may reflect the fact that whole grain rice and pasta not only contributed to meeting the *MyPyramid* target for whole grains, but this group was also an inexpensive source of energy.

A food plan that met the cost, energy, and *MyPyramid* constraints did well in terms of meeting most other nutrient targets, even though the nutrient constraints were not imposed on the model. The food plan met the macronutrient targets for fat, carbohydrates, and protein. It also met all the micronutrient targets included in this analysis except for linolenic acid, iron, potassium, and vitamin E.

Scenario (3) Food Energy and Nutrient Constraints

When "nutritious" was defined in terms of nutrients, instead of food categories, the solution remained closer to the current consumption bundle. The distance function value was 0.0907 units (Table 2, column 7).

As in the preceding scenarios, the macronutrient ranges for protein, carbohydrates, and fats were not binding. The constraints for many other nutrients were binding (indicated by bold formatting), including calcium, iron, potassium, vitamin E, and vitamin A. The model reached these targets by increasing the amount for food groups that are rich sources of these specific nutrients. For example, the calcium target was met primarily by increasing the amount of milk products. The fiber and iron targets were met through increased amounts of legumes, nuts, and seeds, instead of meats. Increasing the amount of orange vegetables and tomatoes helped meet the targets for potassium and vitamin A. An increase in potatoes contributed to fiber and potassium intake. The upper energy constraint was binding, which reflects the switch to certain food groups that are both nutrient and energy dense, like potatoes and nuts and seeds. As with scenario (2), this plan reduced the amount of food groups such as regular soft drinks, sugars, fats and oils, which contribute to energy but not to nutrient content. The relaxed sodium constraint used in the official TFP was binding in this scenario.

While meeting nutrient targets, this plan did not satisfy some *MyPyramid* food category targets. Because vegetables tend to be nutrient-dense, this food plan did meet the *MyPyramid* targets for vegetables and vegetable subgroups for orange, starchy, and other vegetables. However, *MyPyramid* targets for milk, meat and beans, and grain were not met, even though the targets for calcium, protein, iron, and food energy were met.

Scenario (4) Food Energy, *MyPyramid*, and Nutrient Constraints

The last scenario imposed the cost, energy, *MyPyramid*, and nutrient constraints simultaneously (Table 2, final column). The distance function value was 5.01 units, suggesting that it is substantially more difficult at this cost level to meet all the constraints together than to meet the *MyPyramid* or nutrient constraints separately.

In addition to the cost and energy constraints, many of the *MyPyramid* category constraints were binding. On the other hand, only a handful of nutrient constraints were binding (linolenic acid, iron, potassium, and vitamin E). This reflects the fact that meeting the broad *MyPyramid* food category constraints resulted in a food plan that met a majority of the macro- and micronutrient targets.

The food quantities selected were somewhat similar to those generated in scenario (2), with amounts for 41 of the 59 food groups unchanged. The adjustments to the remaining 18 food groups were necessary to meet

TABLE 3
Amounts of Selected Food Groups in Two Specifications of Scenario 4, With All Constraints (Adult Women)

Food Group	Daily Amount (grams)	
	Alternate Specification	Official Specification
Low-fat milk	684.8	675.3
Legumes (vegetables)	100.4	99.7
Nuts and seeds	88.6	90.2
Whole grain breads	93.4	122.2
Whole grain low-calorie cereals	58.9	6.8
Whole grain cereals	0.0	17.0
Whole grain rice and pasta	104.6	18.0
Non-whole grain rice and pasta	139.2	150.0
Citrus, melon, and berry juice	0.0	18.5
Citrus, melon, and berries	21.4	8.2
Other fruit juice	229.9	231.9
Other fruits	126.5	126.6
Low-fat potatoes	144.1	132.4
Dark green vegetables, no fat	55.0	53.8
Orange vegetables, no fat	209.4	184.0
Tomatoes	146.4	119.0
Other vegetables, no fat	0.3	21.6
Fats and oils	51.5	39.9
Coffee	0.0	30.8
Soft drinks	106.8	15.8
Low-calorie soft drinks	0.0	11.1
All others[a]	0.0	74.4

Note: Amounts shown for food groups with greater than or equal to 10 g in alternate or official specification.
[a]Total for all other food groups.

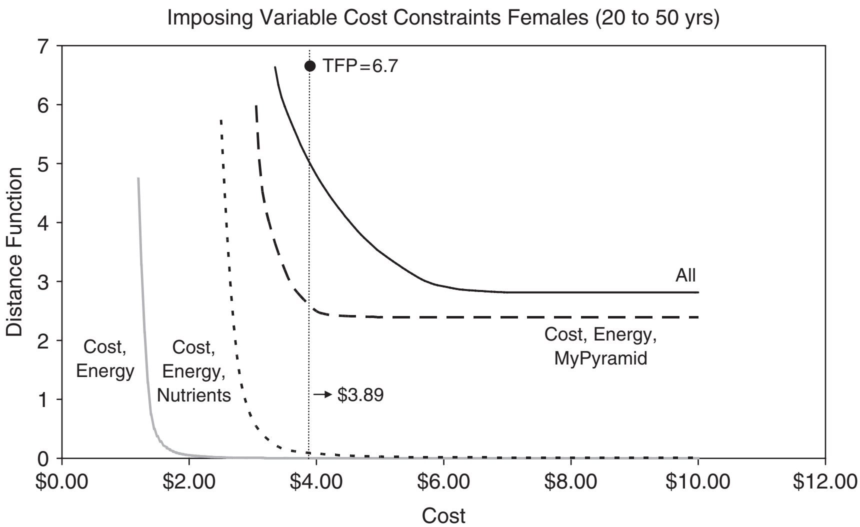
the handful of nutrient targets that remained unmet in scenario (2). In scenario (4), an increase in orange vegetables, tomatoes, and potatoes met the potassium and vitamin E targets. Certain grain products were increased to meet the iron target, whereas fats and oils were increased to meet the targets for linolenic acid and vitamin E (Table 3).

Varying Cost Targets

The preceding results imposed the official cost target of $3.89. We next ran the models using varying cost targets over a wide range, from $0.00 to $10.00 in intervals of $0.05 (Figure 1).

For scenario (1), imposing the cost and food energy constraints, a feasible solution was found for cost targets of $1.20 and higher. To

FIGURE 1
The Distance Value of the Optimal Solution, as a Function of the Cost Target, Under Four Scenarios for Additional Nutrition Constraints: (1) Energy, (2) Energy and MyPyramid Categories, (3) Energy and Nutrients, (4) All of the Preceding Constraints



meet a cost target of \$1.20 (on the horizontal axis), one had to accept a comparatively high distance function value of 4.74 units (on the vertical axis), implying that the solution quantities are substantially different from current average consumption patterns. When the cost target increased rightward, the distance function value fell rapidly, because one could afford a food bundle that was closer to current consumption. Similarly, each of the remaining scenarios were characterized by failure to achieve a solution at the very lowest cost levels, followed by declining distance function values over the next range of cost levels, and finally followed by a flat distance function at higher cost levels as the cost constraint ceased to bind.

For scenario (2), imposing cost, food energy, and *MyPyramid* category constraints, a solution was found for cost targets of \$3.05 and higher. As the cost target was raised, the distance function fell, but the function leveled off at a value of 2.39 units, indicating that a substantial deviation from current consumption would be required even with an unlimited budget.

For scenario (3), imposing cost, food energy, and nutrient constraints, a solution was found for cost targets of \$2.50 and higher. As the cost target was raised, the distance function fell rapidly, eventually reaching a comparatively low value of 0.0128 units with higher cost targets.

For scenario (4), imposing cost, food energy, *MyPyramid*, and nutrient constraints together, a solution was found for cost targets of $3.35 and higher. The distance function did not level off until the cost target exceeded $6.00, eventually reaching a distance value of 2.81 units. With an unlimited budget, it would be comparatively easy to meet the nutrient requirements in scenario (3), but comparatively difficult to meet the *MyPyramid* category targets in scenarios (2) and (4).

For comparison, the official TFP met the cost target of $3.89 and incurred a distance value of 6.7, substantially higher than the distance values discussed in the scenarios given earlier. The higher distance from current consumption was a result of the additional miscellaneous constraints, beyond those analyzed in this article.

Alternate Specifications

The preceding results were for adult women aged 20–50 years. Results for the other age–gender groups in the TFP's representative family of four were qualitatively similar and are presented in the Appendices. The only model that failed to solve was for the scenario with all constraints (4) for the young children group. In all the other scenarios and age–gender groups, there was a feasible solution at the official cost target.

As with adult women, for each of the other three age–gender groups the distance function value was higher when the cost and *MyPyramid* constraints were imposed in scenario (2) than when the cost and nutrient constraints were imposed in scenario (3). Likewise, as with adult women, for each of the other three age–gender groups the majority of nutrient constraints were met when the *MyPyramid* category constraints were imposed in scenario (2). By contrast, several *MyPyramid* category constraints were not met when just the nutrient constraints were imposed in scenario (3). Instead, the nutrient requirements were met using more vegetables and less food from animal sources. Thus, the finding that the *MyPyramid* category constraints were more difficult to meet than the nutrient constraints was consistent across the age–gender groups.

Returning to the adult women, when the official TFP quadratic-in-logarithms functional form from equation (1) was used, the results were qualitatively similar to the summary information from the simple quadratic functional form displayed in Table 2. In scenarios (1) and (2), the same constraints were binding and nonbinding with either functional form. In scenario (3), the same constraints were binding and nonbinding, with two exceptions: the iron constraint was binding in Table 2 using the alternate functional form, but nonbinding using the official functional form; the fiber constraint was nonbinding in Table 2 using the alternate functional form, but binding using the official function form.

Despite the similarities in the summary results, changing the functional form did generate an important difference in the specific quantities for the 59 food groups. As noted previously, the official functional form in equation (1) gives a very high penalty to small food group quantities, and the solution never contains zero quantities for any food group. With the alternate functional form in equation (2), used in this article, the solution may contain zero quantities (Table 3). For example, for scenario (4) with the alternate functional form, the quantity was zero for 45 food groups, because these food groups were displaced by less expensive food groups that sufficed to meet the *MyPyramid* constraints. For scenario (4) with the official functional form, the quantities for the same 45 food groups were reduced by 70%–90% from current consumption, rather than being zeroed out entirely.

DISCUSSION

The TFP framework has important advantages for the research question studied here. It is the most developed existing framework for analyzing trade-offs between economic and nutrition considerations in budget-constrained consumer choices from detailed food groups. It is well known within the disciplines of nutrition science and economics, so it provides an established starting point for research in this interdisciplinary area. Finally, the TFP framework is already closely tied to federal anti-hunger and nutrition policy, so analysis within this framework is connected to policy-relevant applications. For these reasons, although we make some modest changes to the weights and functional form of the specification, we retain the main features of the TFP framework for the empirical analysis in this article.

Still, alternative approaches also deserve exploration in future research. On the one hand, one could set aside the formal nonlinear programming model and assign a committee of experts in nutrition, consumer economics, and gastronomy the task of choosing some model diets that are affordable at the maximum food stamp benefit level. Several food plans could illustrate different ways of meeting constraints regarding cost, nutrition, and consumer appeal.

Although the TFP framework includes an objective function that is designed to reflect gradations in the consumer acceptability of different diets, the official TFP also supplements the constraint set with miscellaneous constraints that reflect expert judgment about the consumer acceptability of quantity ranges for particular food groups, particularly within the meat and beans category. Without these miscellaneous constraints, traditional meat sources such as red meat and poultry are displaced in the solution by legumes, nuts, and seeds within the meat category, and by other inexpensive food groups such as mixed grains that contain smaller amounts of meat. In this sense, the official TFP already is a hybrid between a quantitative programming model and expert judgment.

On the other hand, one could reconcile the TFP framework more explicitly with positive economic models of consumer choice. Currently, the TFP framework has a mix of positive and normative elements, with similarities to and differences from a traditional economic model. One could instead use a health production model from disciplines of health economics or consumer economics. For example, in the SLOTH model (Cawley 2004), food consumption affects utility directly, by providing pleasure and satiety, and indirectly, as an input to production functions that influence health and weight. Such models would require considerable further development and empirical testing before being ready for use as a potential replacement for the TFP in policy-relevant applications, assessing the implications of food choices in specific food groups.

Even within the basic structure of the current TFP framework, one could make more substantial modifications than we explored in this article. We follow USDA's practice in using the current consumption bundle for low-income Americans as the unconstrained optimum for the objective function, in order to avoid deviating from the current official method in too many ways at the same time. Instead, one could use a different consumption bundle as the unconstrained optimum. For example, one might consider using the average consumption bundle of the next higher-income group as the optimum. Unfortunately, these higher-income consumers may differ in other respects from low-income consumers. To identify a consumption bundle that correctly describes the unconstrained aspirations of low-income consumers, one might study natural experiments where a group of low-income consumers gained income, or one might simply survey low-income consumers to ask about their food aspirations. Each of these options would be difficult.

This article opened by asking, "How much does a nutritious diet cost?" The TFP framework offers an approach toward clarifying the question and developing an answer. To make the question sufficiently precise to address empirically, one must stipulate a particular definition of “nutritious” and a tolerance for the distance from current consumption. The cost of a nutritious diet rises systematically with the severity of the nutrition standards; the cost falls with increasing tolerance for differences from current consumption.

Because the objective function values or distance function values are in units that are not easy to interpret on their own, a sensible approach is to describe the tolerance for differences from current consumption in practical terms. For example, a woman with unrestricted budget could simultaneously meet all of the constraints studied in this article with a distance function value of 2.81 units or higher (Figure 1). With the stipulation that the distance function value must be less than or equal to 2.81 units, it costs $1.30 in 2001 dollars to meet just the food energy standards in scenario (1), $3.70 to meet the food energy and *MyPyramid* standards in scenario (2), just $2.70 to meet the food energy and nutrient standards in scenario (3), and $7.00 to meet all of the constraints in this article together (Figure 1).

A stricter tolerance for deviations from current consumption leads to higher cost estimates. A woman with a budget equal to the official cost target could meet just the food energy and nutrient requirements in scenario (3) with a distance function value of 0.0907 units (Table 2 and Figure 1). With the stipulation that the distance function value must be less than or equal to 0.0907 units, it costs $1.85 to meet just the food energy standards in scenario (1), $3.89 to meet the food energy and nutrient standards in scenario (3), and it is not feasible on any budget to meet the *MyPyramid* category standards in scenarios (2) and (4) (Figure 1). With this distance tolerance, it would also not be possible to meet the full set of constraints, including miscellaneous constraints, used in the official TFP.

The natural and difficult next question is: “What nutrition standards and tolerance for differences from current consumption should be used for public policy purposes?” Reasonable readers may review Figure 1 and reach different conclusions. Here, we discuss three alternatives.

First, one could use all of the nutrition standards together, while tolerating a very high distance function value, as in the official approach. If one tolerates the distance function of 6.7 units for the official TFP food bundle, then one may conclude that the official cost target of $3.89 in 2001 dollars is adequate. There are disadvantages to choosing a food plan that differs so greatly from current consumption. The thrust of the TFP framework is to impose nutrition standards while minimizing the distance from current consumption. The objective function loses its influence over the food plan when the constraints push the solution values so far from current consumption. On the other hand, as noted in the results section, a large fraction of these 6.7 units is contributed by caloric soft drinks alone. If one chooses not to count the loss of soft drinks as a real welfare loss, then the official approach may appear in a better light.

Second, one could use the food energy and nutrient standards while omitting the *MyPyramid* food category constraints, as in scenario (3). The notable feature of this scenario's solution is that it meets nutrient requirements by relying heavily on food from plant sources, especially vegetables of various colors, while providing smaller quantities of the meat and beans group, dairy products, and fruits. There are some differences in the bioavailability of nutrients from animal and plant sources, but the *Dietary Guidelines* consider plant sources adequate so long as nutrient requirements are met, as in scenario (3) (U.S. Department of Health and Human Services and U.S. Department of Agriculture 2005). Not everybody would accept the small amounts of meat proposed in this solution. However, within the TFP framework, the objective function is treated as the measure of the overall consequence of expecting consumers to choose a diet different from current average consumption. It is possible in scenario (3) to meet the nutrition standards at the official cost target of $3.89, while incurring a lower distance function value than that incurred in the official TFP.

Third, if one believes instead that higher meat and dairy consumption levels in the *MyPyramid* category constraints are important to the definition of a nutritious diet, but one is unwilling to tolerate very high distance function values, then one must conclude that more money is required. The full set of constraints in scenario (4) in this article required more than $6.00 before the distance function nearly flattened out at a level near 3 units. The cost estimate would be even higher than $6.00 using the full set of official constraints including miscellaneous constraints.

In summary, the official cost target for the TFP appears reasonable if one tolerates a very high difference from current consumption patterns, or if one uses more nutrient-based standards that permit a healthy diet heavy in vegetables of all colors. By contrast, if one imposes the full set of current nutrition and *MyPyramid* food category standards, while being unwilling to tolerate a high degree of deviation from current consumption, then a more generous food budget would be required.

APPENDIX: RESULTS FOR ADDITIONAL AGE–SEX GROUPS

APPENDIX 1
Cost and Nutrition Characteristics of Several Food Plans, Distinguished by Different Constraint Sets (Adult Men)

				Constraints Imposed				
Characteristic	Target	Official TFP	Current	Cost, Cost	Cost, Energy	Cost, Energy, Pyramid	Cost, Energy, Nutrients	All
Scenario #					(1)	(2)	(3)	(4)
Cost ($)	$4.30	$4.30	$6.86	**$4.30**	**$4.30**	**$4.30**	**$4.30**	**$4.30**
Energy (kcal)	2,660 to 2,940	2,925	2,450	1,844	2,660	2,794	2,709	2,940
Distance function	0.0000	7.2231	0.0000	0.0068	0.0168	1.2680	0.0582	1.8785
Pyramid servings								
Milk	>3.00	3.15	1.52	1.25	1.42	**3.00**	1.48	**3.00**
Meat/beans	>7.00	7.35	7.68	3.3	5.15	7.03	4.67	**7.00**
Grains	>10.00	10.50	7.98	6.71	11.71	**10.00**	9.14	**10.00**
Whole grains	>5.00	5.25	0.39	0.11	3.11	7.05	2.36	8.71
Fruits	>2.50	2.62	0.94	0.73	0.72	**2.50**	1.11	**2.50**
Whole fruit	>1.25	2.15	0.60	0.45	0.44	2.05	0.72	2.04
Vegetables	>3.50	3.67	1.81	1.22	1.27	**3.50**	5.61	3.72
Dark green	>0.43	0.45	0.07	0.01	0.01	**0.43**	0.33	**0.43**
Orange	>0.36	0.38	0.09	0.02	0.01	0.36	2.44	0.58
Legumes	>0.50	0.52	0.15	0.12	0.14	**0.50**	0.28	**0.50**
Starchy	>1.00	1.06	0.58	0.48	0.54	**1.00**	1.15	**1.00**
Other vegetables	>1.21	1.27	0.95	0.62	0.58	**1.21**	1.44	**1.21**
Added fats/sugars (kcal)	<426	411	847	705	888	**426**	822	**426**
Oils (grams)	>36	38	19	13	24	**36**	26	40
Macronutrients[a]								
Fat	20% to 35%	31%	28%	19%	29%	27%	28%	29%
Saturated fat	<10%	8%	9%	6%	9%	6%	8%	7%

(*continued*)

APPENDIX 1
(continued)

Characteristic	Target	Official TFP	Current	Constraints Imposed: Cost, Cost	Cost, Energy	Energy, Pyramid	Cost, Energy, Nutrients	All
Scenario #					(1)	(2)	(3)	(4)
Linoleic acid	5% to 10%	9%	5%	4%	6%	7%	7%	8%
Linolenic acid	0.6% to 1.2%	0.9%	0.5%	0.4%	0.5%	0.3%	**0.6%**	**0.6%**
Carbohydrates	45% to 65%	55%	43%	37%	52%	59%	57%	60%
Protein	10% to 35%	16%	13%	8%	11%	12%	10%	13%
Other nutrients								
Calcium (mg)	1,000 to 2,500	1,365	857	676	857	1,291	**1,000**	1,279
Cholesterol (mg)	<300	315	338	211	270	56	182	112
Copper (mg)	0.9 to 10.0	2.4	1.4	1.0	1.6	2.7	2.2	2.8
Fiber (g)	>39.2	41.2	16.9	12.4	22.2	39.4	**39.2**	39.9
Folate (micrograms)	400 to 1,000	837	599	454	682	540	699	477
Iron (mg)	8 to 45	21	17	12	19	15	19	15
Magnesium (mg)	>420	581	284	197	362	761	455	793
Niacin (mg)	16 to 35	30	25	15	25	29	24	31
Phosphorus (mg)	700 to 4,000	2,165	1,433	967	1,445	2,188	1,552	2,257
Potassium (mg)	>4, 700	5,042	2,844	1,999	2,562	4,437	**4,700**	**4,700**
Riboflavin (mg)	>1.3	3.1	2.2	1.6	2.2	2.4	2.2	2.4
Sodium (mg)	<2,300	3,504	3,043	2,055	3,007	2,244	**3,337**	2,568
Thiamin (mg)	>1.2	2.4	1.8	1.2	1.9	2.1	2.0	2.2
Vitamin B6 (mg)	1.3 to 100	3	2	1	2	3	2	3
Vitamin B12 (micrograms)	>2.4	6.4	5.5	3.0	4.0	3.6	2.6	4.0
Vitamin C (mg)	90 to 2,000	137	102	77	79	202	166	200
Vitamin E (mg)	15 to 1,000	13	7	5	8	15	**15**	**15**
Vitamin A (micrograms)	900 to 3,000	1,376	564	329	455	1,090	**3,000**	1,423
Zinc (mg)	11 to 40	17	14	8	13	15	11	16

[a]Macronutrients expressed as percentage of food energy. Bold formatting indicates that a constraint is binding.

APPENDIX 2

Cost and Nutrition Characteristics of Several Food Plans, Distinguished by Different Constraint Sets (Children, 9–11 Years)

				Constraints Imposed:				
Characteristic	Target	Official TFP	Current	Cost	Cost, Energy	Cost, Energy, Pyramid	Cost, Energy, Nutrients	All
Scenario #					(1)	(2)	(3)	(4)
Cost ($)	$3.76	$3.76	$3.96	**$3.76**	**$3.76**	$3.42	**$3.76**	**$3.76**
Energy (kcal)	1,710 to 1,890	2,090	1,962	1,907	**1,890**	**1,890**	**1,890**	**1,890**
Distance function	0.0000	2.8842	0.0000	0.0000	0.0000	1.2600	0.0982	1.8844
Pyramid servings								
Milk	>3.00	3.25	1.92	1.91	1.9	**3.00**	2.56	**3.00**
Meat/beans	>5.50	5.78	4.32	3.87	3.81	**5.50**	2.07	**5.50**
Grains	>6.00	6.41	6.98	6.85	6.79	**6.00**	3.77	**6.00**
Whole grains	>3.00	3.15	0.36	0.30	0.27	4.14	0.13	4.21
Fruits	>2.00	2.10	0.91	0.91	0.91	**2.00**	1.05	**2.00**
Whole fruit	>1.00	1.62	0.47	0.47	0.47	1.93	0.55	1.16
Vegetables	>2.50	3.66	1.07	0.99	0.99	**2.50**	6.30	3.86
Dark green	>0.43	0.83	0.03	0.01	0.01	0.43	1.31	1.15
Orange	>0.29	0.96	0.06	0.04	0.04	**0.29**	0.45	0.92
Legumes	>0.43	0.45	0.08	0.08	0.08	**0.43**	0.34	**0.43**
Starchy	>0.43	0.45	0.30	0.29	0.29	**0.43**	1.67	**0.43**
Other vegetables	>0.93	0.97	0.63	0.59	0.60	**0.93**	2.55	**0.93**
Added fats/sugars (kcal)	<267	280	698	685	680	**267**	607	**267**
Oils (grams)	>27	33	14	14	14	**27**	**4**	**27**
Macronutrients[a]								
Fat	25% to 35%	37%	34%	33%	33%	34%	27%	32%
Saturated fat	<10%	10%	12%	12%	12%	10%	**10%**	9%
Linoleic acid	5% to 10%	9%	6%	5%	5%	8%	5%	8%
Linolenic acid	0.6% to 1.2%	0.9%	0.6%	0.6%	0.5%	0.4%	0.7%	**0.6%**

(*continued*)

APPENDIX 2
(continued)

Characteristic	Target	Official TFP	Current	Constraints Imposed: Cost	Cost, Energy	Cost, Energy, Pyramid	Cost, Energy, Nutrients	All
Scenario #					(1)	(2)	(3)	(4)
Carbohydrates	45% to 65%	58%	56%	56%	55%	54%	62%	56%
Protein	10% to 30%	19%	14%	14%	13%	16%	13%	16%
Other nutrients								
Calcium (mg)	1,300 to 2,500	1,365	894	879	876	1,268	**1,300**	**1,300**
Cholesterol (mg)	<300	211	222	209	207	67	100	68
Copper (mg)	0.7 to 5.0	1.8	1.1	1.0	1.0	1.8	2.0	2.0
Fiber (g)	>28.0	34.1	13.2	12.7	12.5	30.6	30.3	35.4
Folate (micrograms)	300 to 600	534	523	511	507	587	**600**	**600**
Iron (mg)	8 to 40	15	14	14	14	16	15	14
Magnesium (mg)	>240	471	224	215	212	549	363	538
Niacin (mg)	12 to 20	21	19	18	17	21	16	20
Phosphorus (mg)	1,250 to 4,000	1,836	1,180	1,133	1,125	1,795	1,363	1,765
Potassium (mg)	>4,500	4,336	2,149	2,060	2,051	3,468	**4,500**	**4,500**
Riboflavin (mg)	>0.9	2.8	2.0	1.9	1.9	2.3	2.1	2.4
Sodium (mg)	<2,200	2,902	2,304	2,217	2,196	1,734	**3,122**	1,958
Thiamin (mg)	>0.9	1.8	1.5	1.4	1.4	1.7	1.6	1.7
Vitamin B6 (mg)	1 to 60	2	1	1	1	2	2	2
Vitamin B12 (micrograms)	>1.8	6.2	4.7	4.4	4.4	4.4	3.2	3.7
Vitamin C (mg)	45 to 1,200	131	75	73	73	166	212	221
Vitamin E (mg)	11 to 600	11	5	5	5	10	14	12
Vitamin A (micrograms)	600 to 1,700	1,785	528	488	486	1,069	**1,700**	**1,700**
Zinc (mg)	8 to 23	13	10	10	10	14	9	12

[a]Macronutrients expressed as percentage of food energy. Bold formatting indicates that a constraint is binding.

APPENDIX 3

Cost and Nutrition Characteristics of Several Food Plans, Distinguished by Different Constraint Sets (Children, 6–8 Years)

					Constraints Imposed			
Characteristic	Target	Official TFP	Current	Cost	Cost, Energy	Cost, Energy, Pyramid	Cost, Energy, Nutrients	All[a]
Scenario #					(1)	(2)	(3)	(4)
Cost ($)	$3.18	$3.18	$3.57	**$3.18**	**$3.18**	$2.56	**$3.18**	
Energy (kcal)	1,520 to 1,680	1,672	1,568	1,473	**1,520**	**1,520**	**1,680**	
Distance function	0.0000	1.2112	0.0000	0.0001	0.0001	0.9769	0.0279	
Pyramid servings								
Milk	>2.00	2.1	1.73	1.71	1.71	**2.00**	1.74	
Meat/beans	>5.00	5.25	3.74	3.04	3.17	**5.00**	2.95	
Grains	>5.00	5.67	5.11	4.90	5.22	**5.00**	3.35	
Whole grains	>2.50	2.63	0.30	0.21	0.44	4.82	0.05	
Fruits	>1.50	1.57	0.87	0.86	0.86	**1.50**	1.16	
Whole fruit	>0.75	1.10	0.43	0.42	0.42	0.90	0.64	
Vegetables	>2.00	2.10	0.71	0.58	0.58	2.03	4.87	
Dark green	>0.29	0.30	0.02	0.00	0.00	0.32	0.01	
Orange	>0.21	0.22	0.05	0.02	0.02	**0.21**	0.43	
Legumes	>0.36	0.37	0.04	0.04	0.04	**0.36**	0.30	
Starchy	>0.36	0.38	0.23	0.21	0.22	**0.36**	1.11	
Other vegetables	>0.79	0.83	0.39	0.32	0.32	**0.79**	3.02	
Added fats/sugars (kcal)	<132	229	554	535	543	**132**	513	
Oils (grams)	>22	23	11	10	11	**22**	11	
Macronutrients[b]								
Fat	25% to 35%	33%	32%	30%	31%	29%	31%	
Saturated fat	<10%	9%	12%	11%	11%	7%	**10%**	
Linoleic acid	5% to 10%	8%	5%	4%	5%	8%	6%	
Linolenic acid	0.6% to 1.2%	0.7%	0.5%	0.5%	0.5%	0.3%	0.6%	

(*continued*)

APPENDIX 3
(continued)

Characteristic	Target	Official TFP	Current	Cost	Constraints Imposed: Cost, Energy	Cost, Energy, Pyramid	Cost, Energy, Nutrients	All[a]
Scenario #					(1)	(2)	(3)	(4)
Carbohydrates	45% to 65%	52%	49%	47%	48%	51%	60%	
Protein	10% to 30%	17%	14%	12%	12%	14%	12%	
Other nutrients								
Calcium (mg)	800 to 2,500	885	763	740	749	810	825	
Cholesterol (mg)	<300	160	199	180	183	43	83	
Copper (mg)	0.44 to 3.0	1.4	0.8	0.8	0.8	1.6	1.6	
Fiber (g)	>22.4	23.7	9.9	8.9	9.7	24.5	23.9	
Folate (micrograms)	200 to 400	417	395	372	385	286	**400**	
Iron (mg)	10 to 40	12	12	11	11	9	12	
Magnesium (mg)	>130	353	183	167	178	488	302	
Niacin (mg)	8 to 15	17	15	14	14	18	15	
Phosphorus (mg)	500 to 3,000	1,386	996	922	952	1,392	1,108	
Potassium (mg)	>3,800	2,894	1,811	1,666	1,706	2,740	**3,800**	
Riboflavin (mg)	>0.6	2.0	1.7	1.6	1.6	1.5	1.6	
Sodium (mg)	<1,900	2,426	1,853	1,693	1,751	999	**2,593**	
Thiamin (mg)	>0.6	1.5	1.2	1.1	1.1	1.2	1.3	
Vitamin B6 (mg)	0.6 to 40	2	1	1	1	2	2	
Vitamin B12 (micrograms)	>1.2	4.5	4.1	3.8	3.8	2.4	2.3	
Vitamin C (mg)	25 to 650	77	61	57	57	129	154	
Vitamin E (mg)	7 to 300	7	4	4	4	9	11	
Vitamin A (micrograms)	400 to 900	756	460	404	407	677	**900**	
Zinc (mg)	5 to 12	11	9	8	8	10	8	

[a]Model did not have a feasible solution when the official TFP cost constraint was imposed.
[b]Macronutrients expressed as percentage of food energy. Bold formatting indicates that a constraint is binding.

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