Fresh Pork in the New USDA Thrifty Food Plan

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Industry Summary:

Introduction: The USDA Thrifty Food Plan (TFP) represents the lowest cost of a healthy budget-conscious diet that meets dietary guidelines while respecting existing eating habits. In 2021 Congress directed USDA to re-evaluate the TFP based on current food prices and food consumption patterns. In the protein foods category, the TFP gave priority to poultry, which was viewed as less costly than red meat. However, the red meat category used pooled prices for both pork and beef. **Objective**: Our goal was to replicate the TFP 2021 optimization model after separating fresh pork from beef. The goal was to show that the lowest-cost healthy and practical diet could be achieved using pork (rather than beef or chicken) as the only source of meat.
Methods: Five TFP models were developed using the same quadratic programming optimization algorithm as had been used to develop the revised TFP 2021. Weekly "as-consumed" food costs and amounts were calculated for a family of 4 and for 8 age-gender groups.
Results: The proof-of-concept Model 1 showed that we could replicate the TFP 2021 exactly. The meat category was then separated into fresh pork and beef. TFP Model 2 showed that once pork and beef were separated, fresh pork was selected preferentially over beef. TFP Model 3 showed that the healthy budget-conscious diet that met dietary guidelines could be achieved with fresh pork alone. Model 3 increased fresh pork to 3.4 lbs/week for a total cost of $187.81/week for a family of 4. Replacing beef and poultry with fresh pork in TFP Model 4 maintained nutritional value but led to a modest decrease in the weekly cost of protein foods. By contrast, using beef as the only source of meat other than fish in TFP Model 5 led to a major increase in weekly costs. All food plans were adequate in nutrients, met the definition of healthy diets, and respected existing eating habits.
Conclusion: Our TFP 2021 modeling showed that healthy food plans on a budget could be generated using pork as the only source of non-poultry meat. We also found that pork could replace poultry while maintaining diet quality and cost. While all five food plans met nutrition and practicality criteria, fresh pork had the price advantage.

These modeling data suggest that pork ought to be separated from beef in other studies also. In addition to monetary cost, pork and beef differ in terms of their impact on the environments, greenhouse gas emissions and water and land use. Future modeling studies will take these considerations into account.

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Key Findings:

- Our quadratic programming diet optimization algorithm replicated the Thrifty Food Plan 2021 exactly.
- Once the meat category was separated into pork and beef, the TFP algorithm preferentially selected fresh pork to arrive at the lowest cost healthy and practical diet.
- An all pork diet, with pork replacing both beef and chicken, maintained nutritional value, followed dietary guidelines, and was comparable to the TFP 2021 in terms of weekly cost.
- By contrast, an all beef diet, with beef replacing both pork and chicken, was equal in nutritional value but was much more costly.
- Pork provided high nutritional value and had a major price advantage over beef as a source of high quality protein.
- Separating non-poultry meats into pork and beef can be a useful approach to future studies on the environmental cost of livestock and the production of animal protein.

Academic colleagues: Being able to replicate the USDA Thrifty Food Plan quadratic programming algorithm is a major technical achievement. This technique can be used to generate versions of TFP 2021 for subpopulations of interest including racial/ethnic minorities and other vulnerable groups. The search for affordable nutrient rich foods that are socially and culturally acceptable will require some diet modeling. The present goal was to explore the place of fresh pork in healthy, practical and budget-conscious diets. Optimization methods used in TFP 2021 are a valuable tool for designing food patterns that are affordable, acceptable, and nutrient rich. Optimization methodology is an efficient approach to find the role of a food category in a healthy and/or low cost/environmental diet.

Pork producers: Fresh pork and beef tend to be grouped together in the "red meat" or "non-poultry meat" category; yet they are very different in terms of cost, environmental impact and nutritional value. The present analyses showed that once fresh pork was separated from beef, the USDA algorithm preferentially selected fresh pork. This has implications for other types of studies; for example, studies on the environmental impact of livestock also group pork and beef under "red meat"; they ought to be separated in future analyses.

Industry partners: The present analyses pointed to the prominent place of fresh pork in healthy, affordable, nutrient rich diets that are socially and culturally acceptable. It is worth noting that pork is an ingredient of composite dishes that can include rice, beans, vegetables, spices, and high quality carbohydrates. Pairing pork with other affordable foods in recipes should be of interest to industry partners.

Consumer media/general public: The main message is that healthy affordable diets can be built around fresh pork as a source of high quality protein. Pork should feature prominently on its own instead of being classed with beef as another "red meat". The present analyses can be extended to the design of healthy affordable food plans that are socially acceptable and culturally specific. A Latino TFP may not be too far away.

The place of fresh pork in the 2021 USDA Thrifty Food Plan:

A quadratic programming optimization of dietary guidance, nutrient density, and cost

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Running head : Fresh pork in the 2021 USDA TFP

Abbreviation list :

CNPP: USDA Center for Nutrition Policy and Promotion

DRI: Dietary Reference Intakes

FNDDS: Food and Nutrient Database for Dietary Studies

FPED: USDA Food Patterns Equivalents Database

HEI : Healthy Eating Index

NASEM : National Academies of Sciences, Engineering, and Medicine

NHANES: National Health and Nutrition Examination Survey

QP: Quadratic Programming

TPF: Thrifty Food Plan

USDA: US Department of Agriculture

WWEIA: What We Eat in America

ABSTRACT

Background: The Thrifty Food Plan (TFP), revised in 2021, is an estimate of a lowest cost healthy diet that meets dietary guidelines while respecting existing eating habits.

Objective: To explore the place of fresh pork in the TFP 2021 using the same databases and the same quadratic programming (QP) methods as had been used by the USDA Center for Nutrition Policy and Promotion (CNPP).

Methods: Dietary intakes came from the National Health and Nutrition Examination Survey (NHANES 2015-16); nutrient composition data came from the Food and Nutrient Database for Dietary Studies (FNDDS 2015-16), and national food prices came from the 2021 TFP report. Amounts and prices were for foods as consumed. Our QP Model 1 used USDA modeling categories to generate a lowest-cost nutrient adequate food plan. The meat category was then separated into pork and beef. Model 2 examined whether the TFP QP algorithm selected pork or beef. Model 3 sought the lowest cost nutrient adequate food plan. Model 4 replaced beef and poultry with pork; whereas Model 5 replaced pork and poultry with beef. Weekly costs were calculated for a family of 4 and for 8 age-gender groups.

Results: All models met the nutrient requirement constraints. Cost estimate for a family of 4 in Model 1 was $189.88, compared to purchase price of $192.84 in the TFP. In Model 2, fresh pork was selected preferentially over beef. The lowest-cost healthy food plan in Model 3 increased fresh pork to 3.4 lbs/week. Replacing beef and poultry with pork in Model 4 led to a modest decrease in weekly cost. Replacing pork and poultry with beef ln Model 5 led to a major increase in weekly costs.

Conclusions: QP models that closely tracked the revised TFP 2021 showed that fresh pork was the preferred meat source, providing high quality protein at low cost. QP methods are a valuable tool for designing food patterns that are affordable, acceptable, and nutrient rich.

Keywords: Thrifty Food Plan 2021, USDA, Center for Nutrition Policy and Promotion, national food prices, linear programming, meat, beef, pork, nutrient density, affordability

1. Introduction

In 2021, the US Department of Agriculture (USDA) conducted an evidence-driven re-evaluation of the Thrifty Food Plan (TFP), described as the lowest-cost healthy diet that met dietary guidance while respecting current consumption patterns[1]. The USDA has four food plans that satisfy nutrient needs at different price points[2]. Of these, the TFP is the lowest cost. By law, the estimated cost of the TFP is the basis for maximum benefit allotments in the Supplemental Nutrition Assistance Program (SNAP) that begin during the following Federal fiscal year[1,3].

Beginning with the TFP 1975, all subsequent TFP updates for the next 45 years had been cost neutral[1], That gave rise to concerns that with the inflation in food prices, healthy diets were no longer affordable to the average consumer[4,5]. Many households depleted food assistance benefits before the end of the month, increasing the risk of food insecurity[6]. The 2018 Farm Bill established a new requirement for the USDA to re-evaluate the TFP repeatedly using recent dietary guidance, current food prices, and current food consumption and food composition data[7].

Since the revised TFP 2021 was no longer required to be cost neutral, it has provided more realistic cost estimates for a healthy diet on a limited budget[1]. The revised TFP 2021 Market Baskets were modeled by the USDA Center for Nutrition Policy and Promotion (CNPP) using dietary intakes from the National Health and Nutrition Examination Survey (NHANES)[8] , national food prices[9], and quadratic programming optimization methods[1].

Healthy affordable TFP market baskets were calculated for 15 different age-gender groups, listing estimated costs in $/week along with the weekly amounts of foods and beverages "as-purchased". The revised TFP increased maximum benefits by 21%[1], with average benefits rising by about a dollar per person per day[10]. The cost of the 2021 TFP for a reference family of 4 was now estimated at $192.84 per week[1].

A percentage of the weekly budget ($47.45 or 24.61% cost share) was devoted to protein foods: meats and poultry, seafood, eggs, and nuts and soy products. Meats were assigned into categories based on price and were divided into lower and higher nutrient density items. In the TFP 2021, fresh beef and pork were combined into a single modeling category referred to as non-poultry meat (called "meat" in TFP, 2021 report). Listed among higher-nutrient density meats were numerous cuts of fresh pork: pork chop (baked, broiled, stewed, fried), pork roast, and pork steak/cutlet[1]. Also included in the meat category were beef steak, beef pot roast and beef liver.

The present goal was to replicate the TFP 2021 calculations as closely as possible, while separating the USDA "meat" category into fresh pork and beef. Our objective was to assess nutritional value and affordability of a TFP that featured fresh pork as the principal meat source. Our models generated optimized food plans using the same publicly available databases and supplemental TFP 2021 data files[1,11], including 2021 national food prices. Our quadratic programming (QP) models served to estimate amounts of pork in the 2021 TFP and searched for lowest cost healthy diets with pork as the only source of meat.

There were some small differences in procedures. Whereas the TFP 2021 food amounts were presented "as purchased", our QP analyses were for foods as consumed. The five QP models generated healthy TFP market baskets for 8 separate age-gender groups, as opposed to 15[1]. Our reference family of 4 was composed of two adults aged 31-50y and two children aged 4-13y whereas reference family of 4 in TFP 2021 consisted of two adults aged 31-50 y, one child 6-8 and one child 9-11.

2. Materials and methods

The present methods closely followed published TFP 2021 documentation[1]. Quadratic programming models require input data, a set of nutritional, social, or cost constraints, and an objective function[11,12]. In the TFP 2021 calculations and in the present models, input data came from the Dietary Guidelines for Americans[13] and the foods and modeling categories came from the USDA Food and Nutrient Database for Dietary Studies (FNDDS 2015-16)[14]. National food prices for over 3000 foods came from the USDA TFP supplemental data files[2]. The constraints ensured that the modeled food plans met energy requirements and nutrient recommendations for each population subgroup. The constraints ensured further that the generated food plans followed the USDA Healthy US-Style Food Pattern[15], did not deviate too much from the observed dietary habits, and generated lowest cost healthy food plans. The cost constraint was applied progressively in $0.01 decrements until no mathematical solution was obtained. The five models generated optimized food plans for 99 modeling categories (amounts and cost). The procedures are shown in **Figure 1**.

Our process followed the same two phases, each with multiple steps, that were undertaken by the CNPP[1]. Phase One was to prepare data sources, adapt the USDA Modeling Categories, and establish the inputs and constraints. Phase two was to run 5 QP optimization models to create 5 food plans for each of 8 different age-gender groups.

2.1 Input data

2.1.1 Separating pork from beef

Individual foods and beverages (i.e. "items") in the FNDDS 2015-16 were identified by an 8-digit WWEIA food code[16]. The USDA TFP 2021 supplemental data[2] included a datafile where each FNDDS item was already assigned to one of the 65 initial categories. Those TFP categories were largely based on What We Eat in America (WWEIA) 4-digit codes[16], albeit with some custom modifications by the CNPP. Selected food and beverage categories, including grains, fruit, dairy, protein foods (including meats), popcorn and beverages, were split into subcategories of "higher" or "lower" nutrient density, largely determined by sodium, saturated fat, and sugar content. Inclusion criteria for the higher nutrient density categories are all detailed in the USDA TFP Supplemental Table S1[2].

In our coding scheme, pork items and beef items that were included in "meats, higher nutrient density" were separated into "pork, higher nutrient density" and "beef, higher nutrient density". Similarly, our TFP analyses separated the category of "meats, lower nutrient density" into "pork, lower nutrient density" and "beef, lower nutrient density". The distinction was largely based on saturated fat content below or above 4.5g/100g. This increased the number of TFP initial categories from the original 65 to 67. Aggregating initial categories separated according to nutrient density yielded a total of 46 so-called "combined" categories.

2.1.2 Re-creation of modeling categories based on food prices

National food prices for 3072 foods and beverages were obtained from the USDA supplemental data files for the 2021 TFP[2]. The prices came from the 2015-2016 Purchase to Plate Price Tool[2] directly from retailers and were adjusted for inflation in June 2021 by the CNPP. Price outliers had been excluded – items such as lobster or lamb were not included in the calculations of Modeling Category prices. The TFP 2021 created higher and lower price categories, based on the 35%ile cut-point, for 30 out of 65 Modeling Categories. Finally, the food and beverage choices of higher income households (>350% of federal poverty) were excluded from the weighted average Modeling Category price.

The 2015-2016 Purchase to Plate Price Tool provides mean national retail prices for 3,231 FNDDS food codes, i.e. for almost 97% of food and beverages reported in the WWEIA studies. The WWEIA is the dietary intakes component of the 2015-16 National Health and Nutrition Examination Survey (NHANES 2015-16). In developing the TFP, the USDA excluded from analysis 159 food codes (e.g., infant formula, food codes with small sample sizes).

Following the 2021 TFP, inflation adjusted food prices were merged with the FNDDS nutrient composition data and mean weighted prices were then calculated for each TFP food category and combined category, as described above. Missing prices and price outliers were excluded from the calculation of the weighted mean or, in other words, had a weight of zero. Outliers were defined as items with a price more than 1.5 interquartile ranges above the first quartile of each TFP category and subcategory.

Following the TFP methods, the distribution of weighted prices was then used to re-create the 99 modeling categories that were to be used as input variables in the optimization model (see 2.2). Foods and beverages with price at or below the 35th percentile of prices for the category were defined as “lower cost” items, whereas foods and beverages with prices above the 35th percentile were defined as “higher cost” items. These cut points were the same as those used in the 2021 TFP. One aim of the TFP was to create categories reflecting “thrifty” food choices, based on nutrient density relative to cost. One of those categories was red meat (i.e. fresh pork and beef but not lamb), shortened to “meat”. In the present analyses, beef and pork items were separated and assigned to lower-cost and higher-cost groups. In the present analyses, the higher-cost versus lower-cost distinction thus applied to 32 out of the 67 initial categories (Supplemental Table S1).

2.1.3 Weighted nutrient profiles and food pattern components in the modeling categories

Following 2021 TFP protocols[1], we calculated mean weighted nutrient profiles for each TFP modelling category. The 2021 TFP documentation notes that the weights of foods and beverages were for items sourced from stores by individuals ages >1 y with a poverty-to-income ratio >3.5 on the 1st day dietary recall in NHANES 2015-2016[8]. The same method was used to estimate the mean amounts consumed. Items used in the modeling categories were linked to USDA Food and Nutrient Database for Dietary Studies (FNDDS) 2015-2016[14] and USDA Food Patterns Equivalents Database (FPED) 2015-16[17]. The FNDDS provides energy and nutrient values per 100g for foods and beverages consumed by NHANES participants. The FPED converts individual foods and beverages into the 37 food-pattern components (e.g. fruits, vegetables, dairy) that make up the USDA Healthy Food Patterns and are used to calculate HEI-2015 values. The FPED also lists added sugars.

2.1.4 Current food and beverage consumption patterns

Food patterns optimized by quadratic programming models ought to differ as little as possible from the existing eating habits. The USDA calculates the TFP using a quadratic programming model that takes into account nutrient adequacy, food prices, dietary guidance and what Americans normally eat. The present estimates of the US population eating habits came from the first day dietary recalls in two cycles of NHANES 2013-16. Average consumption patterns were calculated for males and females in age groups defined by ages: 4-13 y, 14-19 y, 20-50 y and 51-70 y, that is for 8 age-gender groups in all. The USDA TFP stratified the population into 15 groups by age and gender, from age 1 y to age 74 y. Our preference was to limit the age range from 4 y to 70 y.

Following the TFP, the present goal was to create high quality (i.e. nutrient dense) food patterns at an affordable cost. The HEI-2015 score, a measure of compliance with Dietary Guidelines for Americans[18] was first calculated for each NHANES participant. An unweighted median HEI-2015 score was then estimated for males and females in each age group. For TFP modeling purposes, we only included NHANES participants with HEI-2015 scores above the group median. This was to ensure that nutrient-dense food items were included in the optimization model. The more nutrient-dense foods tend to be consumed by individuals with higher HEI-2015 scores. Current consumption patterns were expressed as quantities of combined categories whose average cost was already calculated (see 2.1.2). Following TFP protocols that adjusted for plate waste and/ or foods that may go uneaten before they spoil, a food waste adjustment factor of +5% was applied to the average consumption of each of the modeling categories for the 8 age-gender groups.

2.1.5 Energy, nutrients and dietary recommendations

Food plans developed by quadratic programming need to satisfy minimum energy and nutrient requirements, stay below maximum recommended values for nutrients of public health concern, and follow dietary recommendations for specific food groups or subgroups. The USDA Healthy U.S.-Style Dietary Pattern[15] is the recognized standard.

Following the 2021 TFP report, the present analyses used nutrient standards based on the Dietary Reference Intakes (DRI) issued by National Academies of Sciences, Engineering, and Medicine (NASEM) and on the last issue of the Dietary Guidelines for Americans, 2020-2025. The values, taken from the TFP, 2021 report, were adapted to age groups used in the present modeling studies. Lower and upper bounds of the dietary constraints for the present 4-13y age group corresponded to the average recommendation for 4-5y, 6-8y, 9-11y and 12-13y age ranges, weighted by the size of each age group in the modified NHANES 2013-2016 data (see 2.1.3). They were also adjusted by 5 percent for food waste[1].

2.2 Quadratic Programing models for food plan optimization

An optimization model is defined by a set of input variables, a list of constraints, and an objective function which needs to be optimized (either minimized or maximized)[12]. The constraints in food plan optimization modeling, such as the TFP, generally correspond to nutrient requirements and the recommended distribution of food groups as set forth in agency standards and in dietary guidelines. For the present analyses, nutrient standards came from the National Academies (NASEM)[19], whereas the recommended amounts of foods and beverages came from the Healthy U.S.-Style Dietary Pattern[15].

2.2.1 Input variables

The input variables were the quantities x_i of each modeling category i, i = 1, .., 99. Modeling categories that describe the same food or beverage but declined into low-cost and high-cost and into low nutrient density and high nutrient density (Supplemental table S1) were assigned to the combined category j, j = 1, .., 46.

2.2.2 Objective function

The *objective function* of the current optimization model was a quadratic function that minimizes the overall distance between the quantity x_j of the combined category j, and the average consumption c_j, weighted by the expenditure shares of each combined category. This is given by Equation 1:

$$\min \sum_{j=1}^{46} \beta_j (x_j - c_j)^2 \ (Eq. 1)$$

$$\beta_j = \frac{p_j c_j}{\sum_{j=1}^{46} p_j c_j}$$

Where p_j is the mean national price and c_j is the average amount of observed intake of combined category j

2.2.3 Nutritional and food group constraints

Food plans generated by the present model had to meet the same meet same nutrient and energy recommendations as the 2021 TFP. Those came from DRI values established by NASEM. The first QP equation (Eq. 2) is given by:

$$D_n^{LB} \leq \sum_{i=1}^{99} x_i d_{i,n} \leq D_n^{UB} \ (Eq. 2)$$

Where $d_{i,n}$ is the nutrient content per gram, D_n^{LB} is the minimum daily recommendation and D_n^{UB} is the maximum daily recommendation for nutrient n in the modeling category i for each age-gender group.

The recommendations needed to be met were for energy, protein, carbohydrates, fiber, added sugars, total lipid, saturated fatty acids, 18:2 linoleic acid, 18:3 linolenic acid, calcium, copper, iron, magnesium, phosphorus, potassium, sodium, zinc, vitamin A, thiamin, riboflavin, niacin, vitamin B6, folate, folic acid, vitamin B12, vitamin E, vitamin K, and choline. Vitamin D was not included because it is difficult to achieve the recommended intake of this nutrient through food sources alone.

In addition to meeting nutrient requirements, the optimized food plan must provide those food groups, subgroups and other dietary components that make up healthy dietary patterns. Typically, acceptable ranges with upper and lower bounds are provided. The second QP equation (Eq. 3) is given by:

$$F_p^{LB} \leq \sum_{i=1}^{99} x_i f_{i,p} \leq F_p^{UB} (Eq. 3)$$

Where $f_{i,p}$ is the amount per gram; F_p^{LB} is the lower bound and F_p^{UB} is the upper bound of the FPED food groups or subgroups p in the modeling category i for each age-sex group.

Following TFP, 2021, the food groups and subgroups in the present model were for the most part food pattern components of the Healthy U.S.-Style Dietary Pattern. In the FPED datafile, those were vegetables (group and subgroups), fruits, grains, dairy, protein foods, meats-poultry-eggs, seafood, nuts-seeds-soya, oils. For those food groups, F_p^{LB} was the recommended amount in the Dietary Guidelines for Americans, 2020-2025 and F_p^{UB} was the 95th percentile of reported dietary intake[20]. In those case where the 95th percentile of reported dietary intake was below the recommended amount, F_p^{UB} corresponded to the recommended amount increased by 10%[1]. For aggregated food groups (i.e, meat, poultry, eggs, nuts and seeds, soy)**,** that did not directly correspond to Healthy U.S.-Style Dietary Pattern component, F_p^{LB} lower bound was 25th percentile of reported dietary intake and F_p^{UB} upper bound was the 95th percentile (or 75th percentile for eggs) of reported dietary intake.

Further constrains followed the Dietary Guidelines for Americans[13]. One half or more of the fruit group needs to come from whole fruit sub-group (Eq. 4.a) and one half or more of the total grains needs to come from whole grains (Eq. 4.b) . One half or more of the total amount of dairy needs to come from the higher nutrient density milk and yogurt category (Eq. 4.c). These food group constraints were addressed by equations 4a,b,c.

$$\sum_{i=1}^{99} x_i f_{i,p=\text{whole fruit}} \geq 0.5 \sum_{i=1}^{99} x_i f_{i,p=\text{total fruit}} \quad (Eq.4.\text{a})$$

$$\sum_{i=1}^{99} x_i f_{i,p=\text{whole grains}} \geq 0.5 \sum_{i=1}^{99} x_i f_{i,p=\text{total grains}} \quad (Eq.4.b)$$

$$x_{i=milk\ and\ yogurt,hnd} \geq x_{i=milk\ and\ yogurt,lnd} \quad (Eq.4.c)$$

Combined categories that did not match a Healthy US Style Dietary Pattern component were limited no more than two standard deviations above the average amount of the observed intake (Eq. 4). Those were Milk substitutes, nutritional beverages and smoothies; Fruit drinks; Soda; Biscuits, muffins, quick breads; Condiments and Sauces; Mixed dishes; Butter and animal fats; Margarine, oils, cream, cream substitutes; Potatoes; Sweet bakery products; Snack bars; Candy; Tortilla, corn, other chips; Crackers; Other desserts; Pretzels/Snacks mix; Popcorn; Sugar and sugars substitutes. That constraint was addressed by Equation 5.

$$for\ j \notin \{\text{Healthy US Style Dietary Pattern component}\}, \qquad 0 \leq x_j \leq c_j - 2 * sd_j \ (Eq.5)$$

Where c_j is the average amount of observed intake and sd_j the standard-deviation of observed intake of combined category j

The 2021 TFP addressed selected beverages. Most of US adults drink coffee or tea. The optimized food plan for adults ≥20y contained a minimum of 1 cup per day (= 240 g) of coffee or tea. The plan for children and teenagers ages 19 and younger did not contain any coffee or tea (Eq. 5). The equation 6 is:

$$for\ j = Coffee\ \&\ Tea,\ x_j \geq\ 240\ for\ adults\ and\ x_j =\ 0\ for\ \text{ages} \geq 19\ \text{y}\ (Eq.6)$$

Finally, the 2021 TFP limited the total number of calories associated with the breakfast eating occasion to 23 percent. Equation 7 is given by:

$$\sum_{i=1}^{99} x_i breakfast\ energy_i \leq 0.23 \sum_{i=1}^{99} x_i energy_i \quad (Eq. 7)$$

Where $breakfast\ energy_i$ is the number of calories in the modeling category i that is associated with the breakfast eating occasion and $total\ energy_i$ is the total number of calories in the modeling category i.

2.2.4 Cost constraints

Cost constraint was imposed depending on the type of the model, as defined in **Table 1.** For Model 1 (a replica of the TFP 2021), lowest cost was determined by decreasing or increasing the observed diet cost by \$0.01. For Model 2, designed to estimate the contribution of beef and pork separately, the cost constraint was set to the cost of M1 model, that is TFP 2021. For all other models (M3, M4, M5) the minimal cost was searched for by decreasing the cost of the observed diet by \$0.01. The cost constraint is given by Equation 8:

$$\sum_{i=1}^{99} x_i p_i \leq C_{obs} - C \text{ for M1, M3, M4, M5 } or \sum_{i=1}^{99} x_i p_i = C_{TFP} \text{ for } M2\ (Eq. 8)$$

$$C_{obs} = \sum_{j=1}^{46} c_j\, p_j \ \ and\ C \ \in \{0, 0.01, 0.02, 0.03, \dots\}$$

Where $\mathrm{p_i}$ is the national average price of modeling category i, $\mathrm{C_{obs}}$ is the observed cost of the diet, C the cost decrease and $\mathrm{C_{TFP}}$ is the cost in 2021 TFP optimized diet.

2.3. Five QP optimization models

Five different QP optimization models were developed for each of the 8 age-gender groups.

- Model 1 was intended to replicate the USDA TFP 2021 as closely as possible, using the same modelling categories and costs constraints. Minimal cost was determined by imposing the cost constraint in \$0.01 decrements or increments from the observed cost (Eq. 8) until no solution was found. This model generated the lowest-cost nutrient adequate food plan using the single category “meat”.

- Model 2 separated the meat category into fresh pork and fresh beef, adding four new modeling categories. The sum of beef and pork in Model 2 was set to be the same as the amount of “meat” category in Model 1, which corresponded to the TFP 2021. The amounts of other protein foods were determined by the model. The cost was set to be the same as the Model 1. The question was whether Model 2 would choose only pork to arrive at the lowest cost food plan.

- Model 3 also separated fresh pork from beef and searched for the lowest cost solution, following the USDA TFP approach. The amounts of pork, beef, and other protein foods in Model 3 were determined by the model.

- Model 4 replaced red meat and poultry (both set to zero) with fresh pork. The amounts of other protein foods were defined by the model. Minimal cost was determined by imposing the cost constraint in \$0.01 decrements or increments

(Eq. 8) until no solution was found. The goal was to determine the lowest cost of healthy diets where pork was the only source of meat.

- Model 5 replaced pork and poultry (both set to zero) with beef. The amounts of other protein foods were defined by optimization. Minimal cost was determined by imposing the cost constraint in $0.01 decrements or increments (Eq. 8) until no solution was found. The goal was to estimate the lowest cost of healthy diets where beef was the only source of animal meat.

2.4. Analysis

Modeling categories were combined into "as consumed" Market Basket categories according to the aggregations shown in Supplemental Table S1. In the USDA Market Basket categories, meats and cured meat modelling categories were aggregated into one category, also called "meat". In our analysis, we decided to separate cured meat from beef and pork in the 'as-consumed" Market Basket categories. Optimized amounts were converted from daily to weekly quantities by multiplying them by 7. Weekly costs were estimated for the entire diet and for food categories "as consumed". Weekly costs, total and by category, were also estimated for a family of 4 persons consisting of one male 20-50y, one female 20-50y, one male 4-13y and one female 4-13y. For comparison, the USDA reference family of 4 is composed of adult male and female and two children aged 6-8y and 9-11y.

3. Results

3.1. TFP weekly cost for a family of four: USDA 2021 TFP and QP Model 1.

Our QP Model 1 followed the TFP 2021 model exactly. The estimated costs and the amounts "as consumed" were the same as determined by the CNPP for the same age groups. The meat category included both pork and beef and the QP optimization searched for the lowest-cost food plan, same as the TFP. First, the weekly cost of the Model 1 market basket for our reference family of 4 was $189.88, as compared to the TFP 2021 estimate of $192.84. As noted above, the TFP report listed amounts as purchased, whereas our calculations dealt with foods as consumed. For some food categories, notably vegetables and fruit, there was a difference in yield because of preparation and waste. As a result, food amounts as consumed are generally less than food amounts as purchased. Food prices are calculated by the USDA per 100g for edible portion, already corrected for preparation and waste[1].

Figure 2 shows the cost distribution of the USDA TFP and Model 1 by category and the percentage cost share by category. There was a close correspondence between the USDA 2021 TFP and our Model 1.

The weekly cost of the protein foods in our QP Model 1 was $48.13 (or 25.3% cost share) as compared to the TFP 2021 estimate of $47.45 (or 24.6% cost share) (**Figure 3**). The cost of meats in QP Model 1 was $9.0/week compared to $8.96 in the TFP 2021.

Our QP Model 1 estimated the amount of protein foods at 14.18 lbs/week for a family of 4, compared to the TFP 2021 estimate of 16.18 lbs/week. The amount of meats as consumed was 2.05 lbs/week, compared to 2.26 lbs/week in the TFP 2021. The cost shares for different food categories were much the same as those reported in the USDA TFP 2021.

3.2. The place of pork in optimized TFP models.

Our QP Model 2 was designed to test whether the TFP would preferentially select pork or beef. The USDA single "meat" modeling category was now divided into pork and beef. Total weekly cost of the TFP was set to be the same as in Model 1, that is $189.87. The weekly cost of protein foods was $46.68, including $6.90 for meats. For the lowest cost healthy food plan, Model 2 selected only fresh pork (but no beef) and increased the amount of poultry. The amounts of eggs, seafood, nuts, and soy remained the same as before.

Our QP Model 3 continued to separate fresh pork from beef and searched for the lowest-cost nutrient adequate food plan. Weekly cost of the market basket as determined by Model 3 was $187.81, very close to the reported optimized TFP 2021 values. The weekly cost of the protein foods was $47.42, including $11.48 for fresh pork (**Figure 4**). In the protein foods meat category, Model 3 also selected only fresh pork (no beef or cured meats), increasing the amount of pork from 2.05 lbs/week to 3.40 lbs/week. The amount of poultry was reduced to 4.52 lbs/week. The amounts of eggs, seafood, nuts, seeds and soy remained the same. Model 3 showed that a nutrient adequate lowest cost diet can be obtained using pork as the only source of non-poultry meat.

As shown in Figure 4, when the weekly cost was pegged to the TFP 2021, Model 2 selected only fresh pork and no beef or cured meat. When the QP Model 3 searched for the lowest cost healthy diet, the market basket contained more pork, less chicken and no cured meats or beef.

3.3 A direct comparison of food plans with only pork or beef.

Our QP Models 4 and 5 searched for lowest cost healthy diets with fresh pork replacing both beef and poultry (but not seafood). Model 4 set beef and poultry amounts to zero and searched for lowest cost nutrient adequate food plan, with pork as the only source of all meat (other than seafood). The weekly cost of the food plan as determined by Model 4 was $188.57, lower but very close to the USDA TFP values (**Figure 5**). The weekly cost of the protein foods was $47.53, with $26.71 going to fresh pork. In this model pork replaced both beef and poultry. The amounts of eggs, seafood, nuts, seeds and soy remained the same as before.

Our QP Model 5 set pork and poultry amounts to zero and searched for lowest cost nutrient adequate food plan, with beef as the only source of all meat (other than seafood). The weekly cost of the Model 5 food plan was $220.58/week, with $77.73 going to protein foods (Figure 5). The cost of the healthy beef-only diet was substantially above the USDA TFP 2021 and was also higher than the estimated cost of the present QP models 1 through 4. Poultry was set as zero. The amounts of eggs, seafood, nuts, seeds and soy remained the same.

These data are also summarized in **Tables 2 and 3**. Table 2 shows, for each of the QP models, quantities of foods as consumed (lbs/wk) by food category. Also shown are the costs of each food plan ($/wk) by category. The data are calculated for a family of 4. Table 3 shows, for each of the QP models, quantities of foods as consumed (lbs/wk) by protein food category. Also shown are the costs of each food plan ($/wk) by category. The data are calculated for a family of 4.

3.4 The place of pork in low cost healthy diets for adults age 20-50y.

Figure 6 shows the place of pork in each of the five QP food plans. The data are presented separately for women (A) and for men (B) aged 20-50y. Shown are the weekly costs in $/week for protein foods: meat, poultry, eggs, seafood and nuts and soy. Cured meat costs were not shown because always equals to 0$/week. Model 1 combined pork and beef into a single category. Model 2 separated pork from beef. Here, Model 2 preferentially selected pork in the place of beef to arrive at the healthy food plan at the USDA TFP 2021 cost. Model 3 showed that pork was the only non-poultry meat in the lowest cost food plan. Model 4 showed that pork could substitute for beef and poultry without an increase in cost. Model 5 showed that replacing pork and poultry with beef led to a substantial increase in weekly cost. All models generated healthy food patterns than met energy and nutrient requirements and the distribution of food groups following the Dietary Guidelines for Americans.

3.5. Optimized food plans calculated for 8 age-gender groups.

Table 4 shows that the overall cost of each food plan $/week and the costs of the protein foods closely tracked the USDA TFP 2021 estimates for the same age-gender groups. However, whereas the USDA calculated costs for children aged 4-5y, 6-8y and 9-11y and for males and females aged 12-13y, our analyses only had males and females aged 4-13y.

Our prices for foods as consumed in Model 1 were exactly the same as the TFP 2021 estimates. There was also substantial agreement between Models 2-4 and the TFP 2021 estimates of the lowest cost healthy diets. Only Model 5, where beef replaced both red meat and poultry, was associated with a much higher weekly cost. One group for whom the costs of a beef only diet were particularly elevated were young males aged 14-19y. Modeled QP food plans are designed not to depart too much from the population group's habitual diet.

3.6. Optimized food plans by age gender group and food category

Figure 7 shows, for each of age gender group and for each QP models, the cost of foods as consumed ($/week) by food category.

4. Discussion

The USDA Thrifty Food Plan 2021 was not intended to be an item-specific shopping list[1]. Rather it provided an optimization structure for a nutrient adequate healthy food plan on a limited budget[1]. The TFP 2021 protocols[1] selected the most nutrient dense foods from among lower cost options within each food group. The present QP methods closely followed those of the USDA – we used the same publicly available input data and the same modeling categories. For the modeling categories, foods and beverages reported in the What We Eat in America surveys were categorized based on price, nutrient density, and nutrient composition.

The present focus was on protein foods, which accounted for about 25% of the TFP 2021 total costs. Protein foods in the TFP were represented by meat (i.e. beef and pork); poultry; eggs; seafood; and nuts, seeds, and soy products. With some exceptions, meat is generally more expensive than poultry. Since the June 2021 prices were higher for meat than for poultry, the proportion of poultry in the TFP 2021 Market Baskets was higher compared to the amounts of meat; eggs; seafood; and nuts. Seafood was particularly expensive with a cost of $12.80/week for a reference family of 4. The TFP 2021 limited selections within the seafood category to lower cost items such as tilapia or canned tuna.

Not all meat is equally expensive. Higher overall prices for the "meat" modelling category may have been due to the fact that the non-poultry meats included both beef and pork. The TFP 2021 assigned numerous cuts of fresh pork: pork chop (baked, broiled, stewed, fried), pork roast, and pork steak/cutlet into higher nutrient density meats for modeling purposes[1]. Also included were multiple cuts of beef. The present departure from the TFP 2021 was to separate the non-poultry meats into fresh pork and fresh beef. Given the disparity in prices, we specifically wanted to assess the place of fresh pork in the TFP 2021 – and for that we needed to separate pork from beef.

The 5 QP models were used to generate healthy food plans for each of 8 age-gender groups, subject to nutrition, cost and practicality constraints. Model 1 confirmed that were able to confirm the TFP 2021 main results. The generated food plan price was the same as in the TFP 2021. The cost share by food group was much the same as in the TFP 2021[1].

Model 2 showed that the QP algorithm selected pork rather than beef or cured meat. Model 3 showed that lowest cost healthy diet could be achieved with pork. Models 4 and 5 replaced all meat and poultry (but not fish) with either pork of beef. All food plans were adequate in nutrients, met the definition of healthy diets, and did not depart too far from the observed eating habits. The main differences were in estimated weekly cost. The pork only diet was much lower in cost than the beef only diet.

For a long time, the TFP has been used to set the amounts of food assistance[22]. By law, the USDA must reevaluate the TFP every 5 years[7]. This first reevaluation was an iterative process conducted by economists, nutrition scientists, and analysts at the USDA CNPP in consultation with internal and external stakeholders. Since the 2018 Farm Bill requirement did not require these reevaluations to be cost neutral, the planned regular updates will provide an opportunity to tailor the low cost practical healthy diets to budget constrained households based on the latest food prices and the latest dietary guidelines. There may be a future need to show how a variety of nutrient-dense, lower price options can support a healthy diet aligned with personal preferences and cultural foodways for population subgroups.

A recent report from the Government Accountability Office[23] has noted that the complexity of the TFP 2021 quadratic programming models raises concerns that *external parties would face difficulties reproducing the TFP, which further decreases transparency and accountability*. MS-Nutrition, an external party based in France, relied on published and disclosed CNPP documentation to replicate the main TFP 2021 protocols. We used publicly available USDA databases and supplemental data on modeling categories and food prices, all published online. The data inputs, constraints, technical assumptions, and optimization model were publicly available. We had no difficulty reproducing the main points of the TFP 2021, but we also benefited from direct advice from and repeated consultations with CNPP leadership and technical staff.

Our analyses had some weaknesses. When it came to food amounts (rather than prices), there was one point of difference between the TFP 2021 and our models. We did follow the TFP 2021 in converting the modeling categories into market basket categories, following the same USDA aggregation codes. Market basket categories correspond to the food groups and subgroups featured on the Dietary Guidelines. The TFP 2021 went a step further using foods as consumed to calculate the amounts of foods as purchased. That requires reverse adjusting for yield, preparation and loss (adding peels, stems, bones etc)[24]. We aggregated foods into the same categories but stayed with foods as consumed (not purchased). There are differences in weight because of preparation and loss, especially for vegetables, but there is no effect on food plan cost. For example, for males 20-50, the “as-consumed” price is $59.78/week vs $59.65 for “as-purchased” price as shown in TFP 2021.

One concern both for us and the CNPP is the continuing lack of current national food prices that can be linked to FNDDS database. The 2021 TFP prices were 2015-16 national food prices that were adjusted for inflation. Food prices for 2015-16 and those for 2017-18 have not yet been released to individual researchers by the ERS USDA.

5. Conclusion

We were able replicate the TFP 2021 with respect to estimated costs and food amounts as consumed for the same age-gender groups. Our optimization analyses went beyond the TFP 2021 by separating non-poultry meats into pork and beef. First, our version of the TFP 2021 showed that the optimization model preferentially selected pork to arrive at the lowest cost healthy diets that met all nutrient requirements, followed dietary guidance, and respected existing eating habits. Subsequent models showed that healthy food plans on a budget could be generated using pork as the only source of non-poultry meat or as the only source of all meat, other than fish. While all five food plans met nutrition and practicality criteria, fresh pork had the price advantage. Future efforts may be directed at developing versions of the TFP 2021 for individuals and families at nutrition risk. Food plans created by QP optimization analyses will inform research, education, and policy.**Author Responsibilities:** AD and MM conceptualized the study. RP and MM prepared the data for analyses. RP and MM worked on the quadratic programming model and nutritional analysis. AD took the lead on presentation of results and drafted the manuscript. All authors contributed to, critically revised, and approved the final version manuscript

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Conflicts of Interest: A.D. is the original developer of the Naturally Nutrient Rich and the Nutrient Rich Food (NRF) indices. That work was supported at the time by the Nutrient Rich Coalition whose members were The Beef Checkoff Program through the National Cattlemen’s Beef Association, California Avocado Commission, California Kiwifruit, California Strawberry Commission, Egg Nutrition Center, Florida Department of Citrus, Grain Foods Foundation, National Dairy Council, National Pork Board, United States Potato Board, Wheat Foods Council, and Wild Blueberry Association of North America. A.D. has received grants, contracts, and honoraria from entities both public and private with an interest in nutrient density metrics and nutrient profiling of foods.

RP and MM are with MS-Nutrition, a company specializing in advanced modeling analyses of international dietary intake and nutrient composition databases.

Data Availability: The datasets analyzed for this study can be found on FoodData Central and in the supplemental datafiles for the TFP 2021

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