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A Feasibility Assessment of Alternative Approaches for Reevaluating the Thrifty Food Plan

Final Report

February 2026

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Sarah Bardin, Keith Kranker, Elizabeth Gearan, and Noémie Sportiche

Submitted to:

U.S. Department of Agriculture (USDA)
Food and Nutrition Service
1320 Braddock Place
Alexandria, VA 22314
Project Officer: Mark Lino and Kevin Mathieu
Contract Number: 47QRAA18D00BQ/12319823F0054

Submitted by:

Mathematica
P.O. Box 2393
Princeton, NJ 08543-2393
Phone: (609) 799-3535
Fax: (609) 799-0005
Project Director: Sarah Bardin

Suggested citation

Sarah Bardin, Keith Kranker, Elizabeth Gearan, and Noemie Sportiche (2026). A Feasibility Assessment of Alternative Approaches for Reevaluating the Thrifty Food Plan. Prepared by Mathematica, Contract No. 12319823F0054. Alexandria, VA: U.S. Department of Agriculture, Food and Nutrition Service, Center for Nutrition Policy and Promotion. https://www.fns.usda.gov/cnpp/tfp-implementing-alternative-approaches

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Acknowledgements

The authors acknowledge the assistance of several individuals who made important contributions to this feasibility assessment. In particular, we recognize the leadership of Mark Lino and Kevin Mathieu at the Food and Nutrition Service's Center for Nutrition Policy and Promotion. Several additional Mathematica colleagues assisted with this project, including Phil Gleason, who conducted a quality assurance review of the final report; John Hotchkiss, who conducted a quality assurance review of the programming code for the econometric and optimization analysis; Emily Tyler and Gina Stec, who assisted with project management; Judy Cannon and Brandan Pierce, who provided programming support and quality assurance review of the programming code for the purchase-based and menu-based analyses; and Mathematica's editing and production team, Sheryl Friedlander, Jess Coldren, Effie Metropoulos, and Carol Soble, who provided copyediting and formatting services.

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Executive Summary

In 2023, the Center for Nutrition Policy and Promotion (CNPP) in the U.S. Department of Agriculture's Food and Nutrition Service contracted with Mathematica to identify a set of alternative approaches for reevaluating the Thrifty Food Plan (TFP)—one of four Food Plans developed by USDA that illustrates how a healthy diet can be achieved at a low cost. Three alternative approaches resulted from those efforts. In 2024, CNPP commissioned a follow-on study to assess the feasibility of each of these alternatives. This report describes the findings of each of those assessments.

Background

Between February and June 2024, the Mathematica study team convened meetings with an expert panel of qualified researchers possessing varied methodological and subject matter expertise. The panelists were tasked with brainstorming alternative methodological options for reevaluating the TFP that met current Federal requirements. At the time, Federal law required only that the TFP be reevaluated every five years based on current food prices, food composition data, consumption patterns, and dietary guidance (PL 115-334, the 2018 Farm Bill). Based on these requirements, the expert panelists ranked three options for future consideration in reevaluating the TFP. These were:

- **Option 1: Purchase-based.** Use existing food purchase data to identify households that purchase a healthy mix of foods; the purchased foods and associated costs would be used to define the TFP.
- **Option 2: Menu-based.** Have nutritionists develop healthy, lower-cost menus that serve as the basis for determining the TFP market basket and associated cost.
- **Option 3: Econometric-based.** Use economic modeling to calculate the TFP based on criteria such as maximizing utility or finding the most efficient (least expensive) method of producing a healthy diet.

To determine the feasibility of these alternatives, CNPP contracted with Mathematica to use currently available data and technology to implement each option in a manner consistent with the expert panelists' description. We assessed feasibility along three primary dimensions: technical feasibility, barriers to implementation, and substantive difference in findings from the existing optimization-based approach. Technical feasibility refers to whether it is possible to generate a TFP market basket and cost given available data sources and analytical tools, even if current sample sizes or data limitations prevent precise or reliable estimates at this time. Barriers to implementation refers to whether technological limitations, level of uncertainty in the estimates, insufficient sample sizes, or the need to rely on strong or numerous assumptions would impede adoption of the approach at scale to consistently generate a reliable TFP market basket and cost. Substantive difference refers to whether the resulting market basket composition and estimated cost diverge in meaningful ways from those produced under the current optimization-based TFP model.

While these feasibility assessments were in process, Congress passed new legislation updating the requirements for future TFP reevaluations. The new law reimposed a cost neutrality requirement preventing the cost of the TFP from increasing as a result of the reevaluation (H.R.1, One Big Beautiful Bill Act 2025). This legislative change shifts the focus of future TFP reevaluations away from determining the minimum cost needed to purchase a healthy, practical diet at home to determining whether new TFP market baskets that incorporate current dietary guidance, consumption patterns, food composition data, and food prices can be developed at the inflation-adjusted cost of the most recently completed TFP reevaluation conducted in 2021. Because this requirement was not in place at the time of the expert panelists' discussions in spring 2024, the panelists did not consider the feasibility of using these alternatives to determine a market basket that is cost neutral to the 2021 TFP reevaluation. As part of our assessment, we consider this additional dimension of feasibility.

Findings

Exhibit ES.1 summarizes the key findings from our feasibility assessments. Among these options, only the demand system-based implementation of the econometric-based approach was technically feasible to implement, had low barriers to implementation, and could be feasibly implemented under cost neutrality. However, the resulting market basket corresponding to this approach did not meaningfully differ from the market basket achieved using the existing optimization-based approach used in the 2021 TFP reevaluation. As a result, the TFP cost obtained from the demand system-based implementation was nearly identical (daily cost in June 2021 dollars of $27.66 compared to $27.60).

The other alternative approaches either had high barriers to implementation or were determined to be technically infeasible to implement. The expert panelists preferred the purchase-based approach over the other alternatives, because it is grounded in the actual purchasing behavior of households, which they expected would increase the validity of its findings. However, our feasibility assessment determined that existing data sources lacked adequate sample sizes, among other shortcomings, that prevented us from determining a TFP market basket or associated cost in accordance with Federal requirements using this approach. Despite the high barriers to larger-scale implementation given current menu-planning technology, we were able to implement the menu-based approach successfully on a small-scale using predominantly manual methods. The resulting TFP market basket differed substantively from the 2021 TFP reevaluation and its resulting cost was on average 60 percent higher (daily cost in June 2021 dollars of $44.73 compared to $27.60). Finally, we were unable to obtain meaningful results using the stochastic production frontier-implementation of the econometric-based approach, rendering this approach technically infeasible.

Exhibit ES.1. Feasibility of options for reevaluating the TFP

Description of the approach	Technical feasibility	Barriers to implementation	Substantive difference in market basket	Feasibility under cost neutrality
Option 1: Purchase-based approach				
Based on household food purchase data, identify households that purchase foods making up a healthy diet. The TFP cost would be calculated based on the cost and composition of the foods purchased by the selected households.	Yes	• Insufficient sample size of TFP reference family households that purchase diets in alignment to dietary guidance in existing data sources • Strong assumptions required to translate transaction-level food purchases to a set of foods reflecting consumption for a one-week period, introducing a high degree of uncertainty and potential error into the resulting estimates	Unknown[a]	No
Option 2: Menu-based approach				
Nutritionists develop healthy, lower-cost menus that meet current dietary guidance to serve as the basis for the market basket. The TFP cost would be calculated by averaging the costs of the individual menus.	Yes	• Requires new menu-development software or other technological advancements, such as improvements in generative AI, to support larger-scale implementation • Without new technology, associating menu items to nutrient and price information requires a high degree of manual effort and involves several assumptions that could influence the cost estimate and market basket composition	Yes	Yes[b]
Option 3: Econometric-based approach				
Demand system: Based on household food purchase data, model the cost of purchasing a healthy diet at varying levels of healthfulness by maximizing utility based on preferences for food items, subject to cost and nutrition constraints.	Yes	None	No	Yes[c]
Stochastic production frontier: Based on household food purchase data, model the cost of purchasing a healthy diet at varying levels of healthfulness by minimizing the cost needed to produce a diet of a certain level of healthfulness.	No	Not applicable	Not applicable	Not applicable

[a] Although the approach was technically feasible to implement, we were unable to obtain a reliable TFP market basket or cost estimate due to small sample sizes. As a result, we are unable to determine whether the market basket would be substantively different than the current market basket.

[b] Although none of the menus developed using this approach were cost-neutral, it is feasible to use the menu-based approach to achieve a cost-neutral market basket. As discussed in detail in Chapter 5, nutritionists would either need access to price information for every menu item and ingredient when developing each menu, or each menu would need to be priced and only those that were later determined to meet the cost neutrality requirement would be eligible for inclusion in determining the TFP market basket.

[c] Although the total cost of the TFP market basket using this approach is slightly higher than the costs obtained in the TFP, 2021 solution, the approach is feasible under cost neutrality assuming FNS modifies the model inputs or constraints.

1. Introduction

The Center for Nutrition Policy and Promotion (CNPP) in the U.S. Department of Agriculture's (USDA's) Food and Nutrition Service (FNS) produces Food Plans to illustrate how a healthy diet can be achieved at various price points (CNPP 2025). The **Thrifty Food Plan (TFP)** is the lowest cost of four Food Plans developed by the USDA. It specifies a market basket of nutrient-dense foods and beverages, their amounts, and their associated costs that can support a healthy diet at home at a low cost for a reference family of four, which is defined by law as a man and a woman ages 20 to 50 and two children (one between the ages of 6 and 8 and one between the ages of 9 and 11).[1] Per Federal law, the cost of the TFP for the reference family serves as the basis for the maximum Supplemental Nutrition Assistance Program (SNAP) benefit amounts for the following Federal fiscal year.

Beginning October 1, 2027, the USDA may reevaluate the TFP based on current food prices, food composition data, consumption patterns, and dietary guidance (H.R.1, One Big Beautiful Bill Act 2025) and is investigating the best way to reevaluate the TFP. Consistent with every reevaluation dating back to 1975, the most recent TFP reevaluation used an optimization model to identify the foods that comprise the TFP market basket and their associated cost (CNPP 2021a). The optimization model selected quantities of foods and beverages in different categories to represent a nutritious diet and then subjected this selection to a set of constraints, including dietary needs, consumption patterns, and food prices. However, given advances in data availability, data quality, and modeling techniques, along with recommendations from the Government Accountability Office (GAO) to examine other feasible methodological approaches (GAO 2022), CNPP sought to understand the feasibility of alternative approaches for future TFP reevaluations.

In 2023, CNPP contracted with Mathematica to identify alternative approaches for reevaluating the TFP. As part of this effort, the Mathematica study team convened a panel of seasoned researchers with diverse methodological and subject matter expertise. The panelists participated in a series of meetings to identify and assess promising alternatives to the current optimization-based modeling approach. A report titled Alternative Approaches for Reevaluating the Thrifty Food Plan (Jones et al. 2024) summarizes the results of these discussions. In total, the expert panelists identified three alternative methodologies: a **purchase-based approach**, a **menu-based approach**, and an **econometric-based approach**. In 2024, CNPP commissioned a follow-on study aimed at implementing each alternative to provide detailed information on each approach's feasibility. This report presents the results of those feasibility assessments based on currently available data and technologies. Findings from this work will be used to determine which, if any, of the alternative approaches identified by the expert panelists can be incorporated into future TFP reevaluations.

1.1. Approach to feasibility assessments

To assess the feasibility of the alternative approaches, the Mathematica study team sought to implement each alternative by adhering to the descriptions presented in the Alternatives Approaches report. Feasibility was assessed using three primary criteria: technical feasibility, barriers to implementation, and substantive difference in findings from the existing optimization-based approach. As discussed in greater detail at the conclusion of each feasibility assessment, the technical feasibility of an approach refers to whether it would be possible to generate a TFP market basket and cost given available data sources and analytical tools. An approach could be deemed technically feasible, even if current sample sizes or other data limitations prevent precise or reliable estimates at this time. Barriers to implementation refers to whether technological

[1] FNS publishes TFP market baskets and costs for 15 age-sex groups; four of these age-sex groups make up the reference family as defined in Federal statute.

limitations, level of uncertainty in the estimates, insufficient sample sizes, or the need to rely on strong or numerous assumptions would impede adoption of the approach at scale. Finally, a substantive difference in findings refers to whether the resulting market basket composition and estimated cost obtained from the alternative approach diverges in meaningful ways from those produced under the current optimization-based TFP model.

At times, the study team needed to make well-reasoned decisions about how best to implement a methodology when more than one option was available; at other times, the study team needed to conduct additional research to ensure that it could implement the alternative methodology sufficiently to assess its feasibility. In these circumstances, we strove to adhere as closely as possible to the spirit of the expert panelists' descriptions of the approaches. Where relevant, in each chapter, we present the decisions that we ultimately made and offer reasonable alternatives that could have been pursued instead. To the extent possible, we used data sources consistent with those used in the 2021 TFP reevaluation, which were primarily collected in 2015 and 2016, to facilitate comparisons across each of the alternatives as well as comparisons with the most recently completed reevaluation. At the beginning of each chapter, we provide details about the data sources and methods used to assess each approach's feasibility.

While these feasibility assessments were in process, Congress passed new legislation preventing the cost of the TFP from increasing beyond the inflation-adjusted value of the TFP, 2021 (H.R.1, One Big Beautiful Bill Act 2025). This legislative change, referred to as cost neutrality, shifts the focus of future TFP reevaluations away from determining the minimum cost needed to purchase a diet in alignment with current dietary guidance, consumption patterns, food composition data, and food prices to determining whether new TFP market baskets that reflect these requirements can be developed at the inflation-adjusted cost. Both the Alternative Approaches report and much of the work conducted as part of these feasibility assessments were completed prior to this legislative change. Nonetheless, throughout the report we discuss the implications of cost neutrality as it relates to the feasibility of each approach.

1.2. Report organization

The report is divided into three sections. In the first section, we describe our assessment of the feasibility of using a purchase-based approach to reevaluate the TFP. We draw on existing data on household food purchases to determine the TFP market basket and cost. In the second section, we describe our assessment of the menu-based approach, which uses healthy, lower-cost menus developed by nutritionists as the basis for determining the TFP. Finally, in the third section, we describe our assessment of the feasibility of an econometric-based approach that relies on one of two separate modeling implementations to reevaluate the TFP: (1) a demand system model and (2) a stochastic production frontier model. The order of these report sections reflects the expert panelists' preferences as described in the Alternative Approaches report. Additional technical details and findings from sensitivity analyses corresponding to each feasibility assessment appear in Appendices A–E.

Feasibility Assessment of the Purchase-Based Approach

2. Overview of the purchase-based approach

Among the three alternative approaches identified by the expert panelists, the most commonly preferred alternative was the **purchase**-based approach. It uses household food purchase data to identify households that both match the reference family definition and purchase foods that make up a healthy diet in alignment with current dietary guidance. The TFP is then calculated based on the cost and composition of the foods purchased by the reference family households. Given that the purchase-based approach relies on actual food purchases to reevaluate the TFP, the expert panelists expected that this approach, as compared with other approaches, would yield a TFP market basket and associated cost that better reflects the true costs of purchasing a healthy, low-cost, and practical diet for a family of four. As described in greater detail in Chapter III of the Alternative Approaches report, the expert panelists further expected that the purchase-based approach would better account for factors that are difficult to measure and incorporate into statistical models, such as palatability, practicality, and affordability of foods and beverages. Assuming that households purchase nutritionally adequate quantities of food and beverages, the panelists also expected that this approach would implicitly account for food waste, which would eliminate the need to make additional assumptions or apply a food waste adjustment factor, as is currently incorporated in the optimization-based approach, to account for food that is purchased but not consumed by households.

To assess the feasibility of the purchase-based approach, we conducted exploratory analyses by using two data sources identified by the expert panelists: (1) National Household Food Acquisition and Purchase Study (FoodAPS) data and (2) Circana Consumer Network data. For each exploratory analysis, we drew on available information on the age and sex composition of households to identify households that matched the reference family defined in the TFP authorizing legislation. Next, to identify households with “healthy” food purchases, we calculated a Healthy Eating Index (HEI)-2020 score corresponding to each household’s food purchases.[2] Finally, we estimated the cost and composition of households’ weekly food purchases to identify the TFP cost and associated market basket. In Chapters 3 and 4, we provide additional details on the data and methods that we used to implement the purchase-based approach, along with the results of each analysis.

As with other approaches described in the Alternative Approaches report, the purchase-based approach was presented at a conceptual level and did not consider the reasonableness of several assumptions. For instance, the expert panelists did not consider the likelihood that existing data sources would permit the identification of an adequate number of households that purchase diets in alignment with current nutritional guidance while also meeting the definition of the TFP reference family. They also did not consider the extent to which households may supplement their food-at-home purchases with food-away-from-home purchases or obtain foods at no cost to themselves from other sources (for example, food pantries, friends or family, or school meals), and they did not specify how to identify household food purchases intended to meet a family’s dietary needs for one week using available data sources. Thus, when attempting to implement the purchase-based approach using observational data, we often needed to make additional decisions about how to obtain a reasonable TFP market basket and cost in alignment with Federal requirements based on transaction-level food purchase data. In each chapter, we highlight these decision points, describe our

[2] As discussed in greater detail in the Alternative Approaches report, HEI scores were identified by the expert panelists as an alternative method for determining alignment with current dietary guidance in lieu of the more comprehensive dietary requirements used in the TFP, 2021. Developed by USDA, HEI scores are a measure of diet quality that can be used to assess how well a set of foods, such as those included in food purchase transactions, aligns with key recommendations and dietary patterns. HEI scores range from 0 to 100 with a score of 100 indicating that a diet perfectly matches the Dietary Guidelines. Throughout the report we use the term “healthy” diet to refer to household food purchases with HEI-2020 scores that met or exceeded the thresholds identified by the expert panelists as being in sufficient conformance with the Dietary Guidelines.

rationale regarding specific decisions chosen, and, to the extent possible, discuss how the decisions influenced our assessment of the approach’s feasibility.

Our exploratory analyses using both FoodAPS and Circana Consumer Network data demonstrated that the **purchase-based approach was technically feasible to implement** insofar as it would be possible to construct a TFP market basket and generate an associated cost for that market basket. However, **inadequate sample sizes presented high barriers to conducting a sufficiently robust implementation to arrive at a reliable TFP market basket and cost**. As we discuss in greater detail in the conclusions of each chapter, few households in either data source met both the reference family household definition and purchased diets that were sufficiently aligned with current dietary guidance. Given these barriers, we were unable to determine how meaningfully the purchase-based approach’s TFP market basket and cost would differ from the current optimization model.

3. Reevaluating the TFP using a purchase-based approach with FoodAPS data

In this chapter, we focus on the first of two exploratory analyses we conducted to assess the feasibility of using a purchase-based approach to reevaluate the TFP. For this analysis, we used data from the National Household Food Acquisition and Purchase Survey (FoodAPS) to implement the purchase-based approach. We first describe the data we used to conduct the feasibility assessment and briefly discuss the rationale behind the expert panelists' selection of the given data source. We then outline the methods we used to calculate the TFP market basket and cost. We present results from each stage of the analysis that supported our conclusions about the feasibility of this approach.

3.1. Data source

FoodAPS is a nationally representative survey of U.S. households conducted by USDA that collected detailed information on food acquisitions. Conducted between April 2012 and January 2013, the survey captured comprehensive data from 4,826 households on all foods and beverages acquired for consumption both at home and away from home over a one-week period.

The FoodAPS datasets provide key elements needed for implementing a purchase-based approach, including:

- Demographic characteristics of household members—such as age and sex—used to identify households that meet the TFP reference family definition
- Detailed records of food purchases, encompassing both food-at-home and food-away-from-home acquisitions over the survey week
- Item-level characteristics for each food or beverage acquired, including product descriptions, prices, quantities, and nutrient profiles[3]

3.2. Rationale for using FoodAPS data

Although FoodAPS contains a relatively small sample size and these data were collected more than a decade ago, the expert panelists identified it as one of two preferred data sources for implementing the purchase-based approach. The panelists based their recommendation on the data set's distinct advantages—most notably, that it can be used to obtain nationally representative estimates and it reflects the most recent and most comprehensive data on household food acquisitions. Unlike other data sources that typically capture only food-at-home purchases, as described above, FoodAPS includes detailed information on both food-at-home and food-away-from-home acquisitions. As a result, FoodAPS offers the most complete picture of household food purchasing behavior available.

3.3. Identifying households that matched the TFP reference family definition

To identify households that meet the TFP reference family definition, we initially requested access to restricted-use FoodAPS data from the USDA, Economic Research Service (ERS). Unlike the public-use FoodAPS data that contain age ranges for household members, the restricted-use data contain detailed age information on each household member that can be used to determine whether a given household meets the

[3] Following the initial publication of the public-use FoodAPS data, USDA, Economic Research Service conducted further data processing of the food purchase data to impute missing information on food quantities in order to facilitate calculation of HEI scores (Mancino et al. 2018). We used these updated data files for our implementation.

TFP reference family definition. Upon reviewing our application, however, ERS determined that only 27 households met the TFP reference family definition. Given that the purchase-based approach requires further sample restrictions, as described in Chapter 2 and explored in more detail below, we ultimately rescinded our application for the restricted-use data; reporting restrictions for accessing these data would have prevented us from disclosing results from our analysis.[4] Instead, we used public-use FoodAPS data to identify households similar to the TFP reference family composition.[5] In total, we examined three TFP reference family definitions:

- **Pseudo-reference family + younger + older children:** Households comprising one male adult age 20 to 59 and one female adult age 20 to 59 with two children, one between the ages of 6 and 11 and one between the ages of either 4 and 5 or 12 and 15
- **Pseudo-reference family + younger children:** Households comprising one male adult age 20 to 59 and one female adult age 20 to 59 with two children, one between the ages of 6 and 11 and the other between the ages of 4 and 5
- **Pseudo-reference family:** Households comprising one male adult age 20 to 59 and one female adult age 20 to 59 with two children, one between the ages of 6 and 7 and the other between the ages of 8 and 11

Among the 4,826 households sampled by FoodAPS, only 50 households met the pseudo-reference family definition that most closely approximates the true reference family composition (Exhibit 1). Even when expanding the reference family definition to include children two to four years older or younger than the statutory requirements for the reference family, only 136 households met the broader definition.

Exhibit 1. Households meeting the three reference family definitions used in this analysis

Sample definition	Number	Percent
The overall sample of households		
All FoodAPS households	4,826	--
Households with food-at-home purchases	4,367	100
Households meeting reference family definitions		
Pseudo-reference family + younger + older children	136	3.1
Pseudo-reference family + younger children	85	1.9
Pseudo-reference family	50	1.1

Source: FoodAPS data, collected from April 2012 to January 2013.

Notes: Percentages use all households with food-at-home purchases as the denominator.

3.4. Scoring household food purchases according to their conformance with the Dietary Guidelines

Despite the small number of FoodAPS households that approximated the TFP reference family definition, we attempted to identify the subset of these households that also purchased a healthy diet. To determine the healthfulness of household food purchases, we calculated HEI-2020 scores for each household.

To compute HEI-2020 scores, we updated the code published by ERS to create HEI-2010 scores that used FoodAPS data to reflect the most recent version of the HEI. The updates included replacing the Empty

[4] Although this finding renders the purchase-based approach infeasible because of insufficient sample sizes, we decided to implement the approach by using public-use FoodAPS data to assess other potential limitations with the approach.

[5] When determining the household's composition, we excluded guests or others who did not normally live in the residential unit but were present at the time of data collection.

Calories moderation component (maximum 20 points) with components for Added Sugars and Saturated Fats (maximum 10 points each) and allocating legumes to both vegetable and protein components. To confirm the accuracy of our calculations, we computed the average food and nutrient densities as a percentage of the densities needed for the maximum HEI component scores and compared them with those reported by Mancino et al. (2018). Our averages for the food and nutrient densities for the HEI components were similar to the food and nutrient densities calculated by ERS, thereby confirming that we calculated HEI scores accurately. We also checked our HEI-2020 code against the HEI-2020 code published by the National Cancer Institute (NCI 2025).[6]

Given that the TFP assumes that a household's entire diet is purchased for consumption at home, we calculated HEI-2020 scores among food-at-home purchases only. Consistent with the expert panelists' preferences for defining a healthy diet, we used two HEI-based thresholds to identify households whose food purchases sufficiently conformed with the Dietary Guidelines. First, we used an HEI-2020 score of 80 or above.[7] Second, we used a relative threshold based on the top tercile (or 67th percentile) of households' HEI-2020 scores. We considered households whose food-at-home purchases achieved HEI-2020 scores in the top tercile to have purchased healthy diets. This relative threshold was viewed by the expert panelists as a way to mitigate the risk of too few households purchasing diets that approached (let alone achieved) alignment with current dietary guidance. By conceptualizing healthy diets as a relative measure as opposed to an absolute standard (for example, a score of 80 or above), this definition ensures that the diets purchased are attainable given current food shopping habits, preferences, and other factors.

In Exhibit 2, we show the distribution of HEI scores for food-at-home purchases for the three reference family household definitions. The maximum HEI-2020 score was less than 80 for two of the three reference family household definitions, and only one household achieved an HEI-2020 score of 80 or above among the broadest definition of TFP reference family households. These findings suggest that even when substantially relaxing the definition of a healthy diet far below what is required to be aligned with current dietary guidance, too few households achieve this level of healthfulness in their food purchases to feasibly obtain a TFP market basket. In fact, only 92 households within the full FoodAPS sample made food-at-home purchases with an overall HEI-2020 score at or above 80.

When examining the distribution of HEI-2020 scores across the three reference family household definitions, we observe that the top tercile of households included those with HEI-2020 scores of 58 or above. Most of these households had HEI-2020 scores between 58 and below 70, corresponding to a diet quality letter grade of D or F (Krebs-Smith et al. 2018). As a result, this alternative approach to identifying households with healthy food purchases reflects an even sharper departure from the legislative requirement that the TFP market basket must reflect current dietary guidance.

Exhibit 2. Distribution of HEI-2020 scores among reference families

Sample definition	N	Min	p10	p33	p50	p67	p90	Max	Mean	SE	% >=80
Pseudo-reference family + younger + older children	136	26.7	39.9	45.6	50.4	58.2	67.7	82.4	52.3	1.07	1%
Pseudo-reference family + younger children	85	26.7	39.9	48.4	50.6	58.4	69.3	79.4	52.8	1.74	0%
Pseudo-reference family	50	26.7	37.8	47.6	50.4	58.2	65.8	76.2	51.3	1.88	0%

[6] At the time of initial implementation, the HEI-2020 code had not been published by the National Cancer Institute.

[7] Although an HEI score of 80 is much lower than the HEI scores achieved by the current TFP market baskets (which range between 93 and 98, depending on the reference family member), the expert panel considered this score an achievable score that approaches a healthful diet in alignment with current dietary guidance.

Source: Analysis of FoodAPS data, collected from April 2012 to January 2013.

Note: The results use FoodAPS household weights. Sample sizes are unweighted. Units are HEI scores (on a 0–100 scale) unless otherwise noted. The rightmost column shows the percentage of households with an HEI score at or above 80.

HEI-2020 = Healthy Eating Index-2020; p = percentile; SE = standard error.

3.5. Amount of energy reflected in food-at-home purchases

An underlying assumption made by the expert panelists in prioritizing the purchase-based approach over other alternatives was the belief that household food purchases implicitly incorporate households' expectations around food waste among other hard-to-measure factors. For this assumption to be valid, the total amount of calories purchased by the household would need to be greater than the amount required to support a healthy diet.

In Exhibit 3, we show the distribution of total calories overall and among food-at-home purchases versus food-away-from home purchases among the three reference family household definitions. On average, TFP reference family households obtained roughly 65,000 calories from food purchases over the one-week data collection period, which is comparable to the roughly 67,000 calories per week reflected in the TFP, 2021 market basket.[8] However, only about 50,000 calories purchased by reference family households on average came from food-at-home purchases; the remainder came from food-away-from-home purchases. These findings may suggest that reference family households commonly supplemented their weekly food-at-home purchases with food-away-from-home purchases and did not on average purchase a sufficient quantity of energy from food-at-home purchases alone to support their weekly caloric needs. These findings may also be the result of underreporting by households in the FoodAPS sample. Research has shown that larger households reported fewer food acquisitions on a per-person basis than smaller households and that over the course of the reporting week, households reported fewer food items and food purchasing events (Yan and Maitland 2016; Hu et al. 2017). As such, basing the TFP market basket and costs solely on food-at-home purchases, as suggested by the expert panelists, is likely to underestimate the true amount and cost of foods and beverages needed to support a healthy diet.

A closer examination of the distribution of total calories purchased by reference family households further highlights additional complications involved with using these data as the basis for determining the TFP, namely the implicit assumption that food purchases are intended to be consumed over the course of one week. Although the average number of calories purchased by reference family households fell within the reasonable weekly caloric requirements for the reference family household, the minimum and maximum total calories purchased by reference family households did not meet these requirements. In particular, the bottom quartile of reference family households purchased roughly half the amount of calories needed to support a healthy diet. At the other extreme, reference family households–depending on how the reference family was defined–in some cases purchased three to four times as many calories required to support a healthy diet. These latter households likely purchased food items intended for consumption over a longer period, while households that purchased a smaller number of total calories may have supplemented their weekly consumption of foods with previously purchased food. The extremely low and extremely high values complicate the ability to obtain directly an accurate TFP market basket and cost reflecting the reference family's dietary needs for one week.

[8] The energy content of the TFP, 2021 market basket was 9,611.7 calories per day or 67,281.9 calories per week for the reference family.

Exhibit 3. Distribution of total calories purchased at-home versus away-from-home among reference families

Sample	Min	p25	p50	p75	Max	Mean	SE
Pseudo-reference family + younger + older children							
Food-at-home purchases	1,740	21,231	45,216	73,132	276,365	53,552	5,110
Food-away-from-home purchases	227	7,705	11,781	20,655	44,350	14,607	1,218
Total calories	8,898	38,828	64,936	88,129	281,838	68,002	5,130
Pseudo-reference family + younger children							
Food-at-home purchases	1,740	24,784	45,216	75,853	177,649	53,795	6,368
Food-away-from-home purchases	632	6,643	11,500	15,656	40,861	13,160	1,417
Total calories	9,479	38,828	64,936	93,387	185.507	66,763	6,403
Pseudo-reference family							
Food-at-home purchases	1,740	18,913	45,216	75,755	177,390	50,176	7,539
Food-away-from-home purchases	1,285	8,811	11,764	14,833	35,504	13,635	1,710
Total calories	13,945	33,414	64,936	93,387	180,708	63,567	7,803

Source: Analysis of FoodAPS data, collected from April 2012 to January 2013.

Note: The results use FoodAPS household weights. All values are presented in kcal units. A small number of households (N < 5) reported making zero food-away-from-home purchases during the data collection week. These households have been excluded from the analyses presented in Exhibit 3. For this reason, the mean values between food-at-home purchases and food-away-from-home purchases do not sum to the mean total calories purchased.

p = percentile; SE = standard error.

3.6. Using FoodAPS data to compute an alternative TFP market basket

Given that we were unable to identify an adequate number of households that both meet the TFP reference family definition and purchase a healthy diet, even after substantially relaxing the requirements for each of these criteria, we did not compute a TFP market basket or associated cost using FoodAPS. If we had continued with the implementation of our analysis, we would have next determined the costs of the market basket reflected by the households' food-at-home purchases. FoodAPS contains data needed to calculate costs before and after accounting for store savings (that is, savings from the use of store loyalty or rewards cards or store-specific sales and promotions) and coupons. We would have needed to decide which costs to use in our calculation. A valid argument could be made for using either version of costs. On the one hand, the actual price paid by the consumer reflects reduced prices made possible by store savings and coupons. Many food retailers, in particular, widely offer store savings.[9] On the other hand, not all consumers have the same access to store savings and coupons such that the exclusion of store savings and coupons might better reflect the costs charged to many consumers. In a small number of cases, households also reported that they received food items at no cost to themselves—for example, from a food bank. FoodAPS imputed cost values for these items whenever possible. Similar to store savings and coupons, there are justifiable reasons either to treat these items as having zero cost or to use imputed costs when calculating the TFP market basket cost, which would have required an additional determination regarding how to account for these items in the cost of the TFP market basket.

[9] Reflecting this, the number of food items in the FoodAPS item-level data with store savings was more than 15 times greater than the number of items with coupons.

4. Using a purchase-based approach with Circana Consumer Network data to reevaluate the TFP

In this chapter, we focus on the second implementation of the purchase-based approach, based on data from the Circana Consumer Network panel. As we did in Chapter 3, we first describe the data sources used for this analysis. We then discuss the methods we used to calculate the TFP market basket and cost, presenting results from each stage of the analysis that informed our conclusions about the feasibility of this approach.

4.1. Data source

4.1.1. 2015–2016 Circana Consumer Network panel

To facilitate comparisons with the published TFP, 2021 results, the primary dataset used in this analysis was the 2015–2016 Circana Consumer Network panel, which is a proprietary dataset containing detailed information on household food purchases. For the purposes of our feasibility assessment, we restricted our analysis to households included in the full static panel, which reflects a subset of households that consistently reported their food purchases over a 12-month period. By design, the Circana Consumer Network panel is unbalanced, meaning households could have participated in 2015, 2016, or in both years. The decision to restrict to respondents in the full static panel was informed by the preferences of the expert panelists, described in greater detail in the Alternative Approaches report. The full static panel included information on roughly 129,000 households as well as weights needed to obtain nationally representative estimates.[10] Importantly, several types of households are underrepresented in the static sample. These include households with one person, with a head of household younger than age 35, with Black and Hispanic members, with children, and with the lowest incomes. The static sample might differ from the U.S. population in other, unobservable ways that cannot be adjusted by weights and could affect purchasing behavior. For more information about the Circana Consumer Network panel, see Muth et al. (2016).

We used two data files from the Consumer Network panel: (1) a transaction-level data set and (2) a demographic data set.

The transaction-level data set included:

- All food-at-home purchases made by participating households between January 2015 and December 2016, including food item descriptions, Universal Product Codes (UPCs), prices paid, quantities purchased, and transaction dates
- Unique identifier for each household

The demographic data set included:

- Birthdates and sex for all members within each household, needed to determine which households met the TFP reference family definition
- Unique household ID, which was needed to link household demographics to their transactions

[10] For the purposes of this analysis, we used data on the full static panel which includes households that did not report the purchasing of random-weight products, such as fresh fruits and vegetables and deli items, that are typically sold by weight. This approach allowed us to maximize potential sample sizes for these analyses, however it also introduces bias in the estimates, as the items purchased and their associated costs do not reflect the full set of foods and beverages that were purchased by the household. Implications regarding this analytic decision are discussed in subsequent sections of this chapter.

4.1.2. 2015–2016 Purchase to Plate Crosswalk, Food and Nutrient Database for Dietary Studies, Food Patterns Equivalents Database, and Food Patterns Equivalents Ingredient Database

Because the Consumer Network panel does not include information on the full nutrient composition of items purchased (for example, micronutrient composition) or food pattern equivalents, which are needed to determine the healthfulness of each household's food purchases, we linked the transaction-level data with the Purchase to Plate Crosswalk (PPC) and subsequently to the Food and Nutrient Database for Dietary Studies (FNDDS), Food Patterns Equivalents Database (FPED) and Food Patterns Equivalents Ingredient Database (FPID). Developed by USDA, the PPC can be used to link UPCs from household food purchases with corresponding foods and ingredients in FNDDS. The PPC also provides conversion factors needed to convert purchased quantities to an edible ("as consumed") quantity, which was needed to calculate HEI-2020 scores corresponding to each household's food purchases. To obtain information on the full nutrient composition of each food item purchased by households and convert foods and beverages to their 37 USDA Food Patterns components, which was also needed to compute the HEI-2020 scores, we linked the corresponding FNDDS food code or Standard Reference code obtained from the PPC for each household's food purchases to the publicly available FPED 2015–2016 and FPID 2015–2016, respectively.

4.2. Identifying households that matched the TFP reference family definition

Consistent with the procedures used in the FoodAPS analysis, we first restricted the Consumer Network panel to households that met the TFP reference family definition. Because the demographic data contained birthdates rather than ages, we first had to link the demographic dataset with the transactions-level data to determine the age of each household member at the time of each transaction. To calculate age, we subtracted the month and year corresponding to each individual's birthdate from the month and year corresponding to each transaction. This meant that a single household could age in or out of the TFP reference family sample depending on the time of year in which the household's transactions occurred. For example, a child born in September 2009 would have been assigned the age of 5 for all household purchases made between January and August 2015 and the age of 6 for purchases made between September 2015 and August 2016.[11] In total, only 1,214 households (or 0.9 percent of those in the static sample) met the reference family definition at any point between 2015 and 2016 (Exhibit 4).

Exhibit 4. Sample sizes associated with identifying TFP reference family household

Sample definition	Number	Percent
Households in the static panel	128,803	100
Households meeting the reference family definition	1,214	0.9

Source: Analysis of Circana Consumer Network data, collected from January 2015 to December 2016.
Note: Numbers and percentages of households are unweighted. Households in the static sample are those who consistently report their purchases to Circana (see Muth et al. [2016] for details).

4.3. Scoring household food purchases according to their conformance with the Dietary Guidelines

Next, we identified the subset of reference family households that purchased healthy diets. Unlike the FoodAPS analysis, in which only one week of transaction-level data was available, the Consumer Network panel included all transactions reported over a two-year period. Given that the TFP market basket is designed to reflect weekly quantities of foods and beverages needed to support a healthy diet at home for the reference family, we needed to determine a procedure for identifying the set of transactions intended to meet

[11] As a sensitivity test, we also calculated age based on year alone to assess how this would affect our sample. This approach was less precise and yielded a smaller total sample of reference family households (n = 897).

the dietary needs of the household for one week only. For the purposes of this analysis, we decided to collapse individual transactions into daily, weekly, and monthly transactions.[12] When collapsing records to the weekly level, we defined the week based on the timing of January 1, 2015. As such, weekly transactions corresponded to purchases made between Thursday-Wednesday. For each sample (daily transactions, weekly transactions, and monthly transactions), we calculated HEI-2020 scores to determine the subset of healthy food purchases among households that matched the TFP reference family definition. As with the FoodAPS analysis described in Chapter 3, we defined "healthy" food purchases in two ways: (1) food purchases with HEI-2020 scores of 80 or above and (2) food purchases in the top tercile (67th percentile) of household transactions.

We were able to link 92 percent of the roughly 760,000 food items purchased by reference family households to the PPC. Items that could not be linked to the PPC were excluded from our analysis, as it was not possible to obtain information on their nutrient composition that is needed for computing an HEI score. Among the food items that could be linked to the PPC, about 11 percent were random-weight foods, such as fresh fruits and vegetables and deli items, that are typically sold by weight rather than by a fixed unit. Within the Consumer Network panel, the total price paid for random-weight foods is provided for each transaction but the quantity of each of these items that was purchased is missing.[13] To determine the edible weight of each item, the quantity purchased must be known. Therefore, we needed to impute missing quantities for random-weight items before calculating the HEI score corresponding to each daily, weekly, or monthly household transaction. To do this, we divided the price paid for each random-weight item by the average price per 100 grams of that item using the Supplement to the TFP, 2021 data set published by CNPP, which mapped average June 2021 prices per 100 grams for 3,072 FNDDS food codes. We then used the standard conversion factors provided in the PPC to estimate the proportion of each item that was edible. Using this approach, we were able to recover missing quantities for all random-weight items corresponding to an FNDDS food code, which represented roughly half of all random-weight items.[14] The remaining items were excluded from our analysis. However, additional sensitivity analyses showed that including these items would not have substantively altered our results.[15] In total, about 86 percent of food items purchased by reference family households were included in this analysis.

Exhibit 5 shows the sample sizes, mean, and median number of shopping trips for reference family households for daily, weekly, and monthly transactions that met either of the two criteria for healthfulness. Consistent with the findings from the FoodAPS analysis presented in Chapter 3, few households achieved the target level of healthfulness in their food purchases regardless of how the sample was defined. In total, only 40 unique households that met the TFP reference family definition had at least one set of monthly transactions with an HEI-2020 score of 80 or above, reflecting purchases across an average of six shopping trips. At most, only 143 households (or roughly 10 percent of all reference family households) had at least

[12] An alternative approach could have involved summing all transactions completed by the household over the entirety of the data collection period and then dividing by the number of weeks represented between the first and final transaction, which would have yielded an estimate of the average purchases in a week. We could have also taken an average of the food items and associated costs across all household transactions. We did not pursue either of these approaches, as we expected that estimating average purchases would reduce the variance in HEI-2020 scores, reducing the chances of identifying households with HEI-2020 scores of 80 or higher.

[13] Not all respondents in the full static panel provide the weight or quantity purchased for random-weight foods.

[14] The remaining items were linked to a Standard Reference (SR) code rather than FNDDS food code. Imputing missing quantities for these items would have required a substantially higher level of effort, involving crosswalking SR codes to a similar FNDDS food code based on similarity of item description.

[15] We conducted additional analyses that assigned all missing edible weights to the 25th percentile of non-missing edible weights in our data and separately to the 75th percentile of non-missing edible weights. Because the final samples remain essentially unchanged with this simplistic lower-and-upper bound approach, we concluded that the results were not sensitive to imputed edible weights.

one daily transaction with an HEI-2020 score of at least 80. These findings reinforce that few consumers purchase foods and beverages in alignment with current dietary guidance. Even when relaxing the definition of a healthy diet, only a miniscule number and proportion of households achieved this level of healthfulness on any given day let alone any week or month.

When examining households with food purchases in the top tercile of the HEI-2020 distribution for daily, weekly, or monthly transactions, we observed that the top tercile of reference family households included those with HEI-2020 scores in the 50s, a score indicating that even the top tercile of the HEI-2020 distribution included households whose diets did not align with the Dietary Guidelines for Americans (DGA). As with the FoodAPS analysis reported in Chapter 3, these findings demonstrate that using a relative threshold for defining the healthfulness of diets results in a significant departure from the legislative requirements that the TFP market basket align with current dietary guidance. For this reason, the rest of our analysis focused on reference family households with HEI-2020 scores of 80 or above (the primary definition of healthful food purchases).

Exhibit 5. Sample sizes for transactions collapsed by day, week, and month

Sample definition	Total sample	Unique households	Mean number of trips	Median number of trips
HEI-2020 of 80 or above				
All trips within a day	270	143	1.1	1
All trips within a week	231	127	1.8	2
All trips within a month	65	40	6	6
HEI-2020 in top tercile				
All trips within a day (HEI ≥ 50)	17,635	885	1.1	1
All trips within a week (HEI ≥ 53)	10,496	852	1.8	1
All trips within a month (HEI ≥ 54)	3,176	665	6.1	5

Source: Analysis of Circana Consumer Network data, collected from January 2015 to December 2016, linked to PPC, FPED, and FPID data

Notes: Numbers of households and trips are unweighted. A trip is defined as a single shopping trip to a retail outlet, which may consist of any number of purchased items. To be included in the sample, a single daily, weekly, or monthly transaction meeting the definition of healthy was required.

HEI-2020 = Healthy Eating Index-2020; FPED = Food Patterns Equivalents Database; FPID = Food Patterns Equivalents Ingredient Database: PPC = Purchase-to-Plate Crosswalk.

4.4. Amount of energy reflected in food-at-home purchases

Before calculating the TFP market basket and associated cost among the subset of reference family households with healthy daily, weekly, or monthly food purchases, we examined the distribution of calories purchased for each analytic sample to determine whether sufficient quantities of foods had been purchased to meet the household's dietary needs.

In Exhibit 6, we show the distribution of total calories purchased along with the number of calories needed per day, per week, and per month to achieve a healthy diet for the TFP reference family. In general, households in our sample that had HEI-2020 scores of 80 or above purchased substantially fewer calories than would be required to support a healthy diet for a family of four. For example, among weekly or monthly transactions with an HEI-2020 score of 80 or above, the total calories purchased by households on average was less than half of the total calories needed.[16] Although this sample includes households that did not report the purchases of random-weight products, which may partially account for the lower than expected

[16] Fewer than five reference family households had at least one weekly transaction that achieved an HEI-2020 score of 80 or above and purchased +/- 10 percent of total weekly calories needed (results not shown).

number of calories purchased, 88 percent of households in the weekly sample were part of the random-weight panel that did report these purchases. Thus, these findings suggest that households may have either supplemented their food-at-home purchases with food-away-from-home purchases (not observable within this data set) or point to potential underreporting of food purchases in the Circana Consumer Panel.

Notably, the distribution of calories among weekly transactions in Exhibit 6 is also substantially lower than the distribution observed in the FoodAPS analysis presented in Chapter 3. The FoodAPS analysis was restricted to reference family households with HEI scores in the top tercile due to the small number of households with HEI scores of 80 or above. The substantive differences between these two distributions could indicate that items included in food purchases with comparatively high HEI scores (those with HEI-2020 scores of 80 or above) are not reflective of typical foods purchased by households and are likely not intended to meet the complete dietary needs of the household.[17] This would suggest that these types of transactions would not be a good basis for determining the TFP market basket and cost.

Exhibit 6. Distribution of calories purchased among healthy food purchases

Sample	Calories needed for healthy diet[a]	N	p10	p25	p50	p75	p90	Mean	SE
All trips within a day	9,150	143	5,350	8,950	12,400	21,450	31,300	16,350	950
All trips within a week	64,000	127	10,850	15,500	25,200	38,150	48,500	27,950	1,400
All trips within a month	277,120	40	19,150	33,250	72,100	120,550	157,300	80,200	8,100

Source: Mathematica analysis of Circana Consumer Network data from 2015 – 2016 linked to PPC, FPED, and FPID data.

Notes: Distribution of calories is unweighted. Results only include one value per household. For households with more than one day of healthy purchases, we select the day that has the closest number of calories to the recommended amount of 9,100 per day, 64,000 per week, and 277,000 per month. In line with the requirements of our data use agreement, all calories are rounded to the nearest 50th to protect participant privacy (for example, 21,344 would be rounded to 21,350). We do not report minima or maxima for the same reason. All values are presented in kcal units.

[a] Calories needed for a healthy diet are based on dietary guidance at the time of TFP, 2021. To obtain a daily target, we divided the required 64,000 calories per week by 7 days per week. To obtain the monthly target, we multiplied the required 64,000 calories per week by 4.33 weeks per month.

HEI-2020 = Healthy Eating Index-2020; p = percentile.

4.5. Using Consumer Network panel data to compute an alternative TFP market basket

Despite the large number of households included in the Consumer Network panel, we were unable to identify an adequate sample of households that met the TFP reference family definition, purchased a healthy diet, and purchased a sufficient quantity of food to reasonably cover the household's dietary needs. For these reasons, we do not use these data to report a TFP market basket or associated cost. Had we continued with the implementation of our analysis, we would have had to make similar decisions about which prices to use when calculating costs as discussed in Section 3.6 of Chapter 3. In addition, we would have likely needed to scale the costs and quantities of items purchased to reflect the total calories needed to support a healthy

[17] To support this conclusion, we also examined the distribution of calories purchased among reference family households with HEI scores in the top tercile within the Consumer Network data. The distribution among weekly transactions was comparable to that observed in the FoodAPS analysis.

diet for the family of four for one week. Given that the average number of calories purchased among weekly transactions was substantially lower than those required, the approach used for scaling these costs and quantities would have a meaningful influence over the resulting cost and market basket composition. In addition, this scaling would need to consider how to account for likely food waste, given that not all foods that are purchased are ultimately consumed before they spoil. These types of considerations were not discussed by the expert panelists, given their strong assumption that households were likely to purchase more food than would be required to support a healthy diet at home—an assumption that is not borne out by the results of this analysis.

4.6. Conclusions about the purchase-based approach

Overall, the results from both the FoodAPS and Consumer Network analyses demonstrate that a miniscule proportion of households meet the narrow definition of the TFP reference family and purchase healthy diets. Because these households are comparatively rare across the full population, existing data sources—even those that are large and nationally representative—do not include adequate numbers of these households to support the full-scale implementation of a purchase-based approach for reevaluating the TFP.

Although it is well-documented that Americans' consumption patterns deviate substantially from nutritional guidance, our analyses underscore the difficulty in identifying households that purchase foods that even come close to approaching alignment with current dietary guidance. Therefore, even if CNPP were to collect new household food purchase data that oversampled reference family households, it is likely that most of these households would not purchase healthy diets to support implementation of this approach at scale. Moreover, although it would technically be possible to obtain a TFP market basket and associated cost by examining household food purchases, additional work would be needed to determine how best to translate food purchases into a market basket that reflected the household's dietary needs for one week.

However, given the recent changes to Federal legislation requiring that future TFP reevaluations be cost neutral, the expert panelists' basis for preferring this approach to the current optimization model is no longer supported. As described in the Alternative Approaches report, the expert panelists preference for this approach stemmed from the fact that deriving a TFP cost based on actual household food purchases would overcome several assumptions required in a model-based approach. However, when the TFP cost cannot exceed a fixed value, the focus of future reevaluations shifts toward determining whether a cost-neutral TFP market basket can be constructed, rather than determining the lowest cost of a market basket that meets the TFP requirements. It is entirely possible that no households in existing data sources purchase items that are both in alignment with the TFP requirements and also less than or equal to the cost of the TFP, 2021. However, this does not mean that such a market basket could not be constructed. For this reason, the purchase-based approach is not considered feasible under cost neutrality.

Feasibility Assessment of the Menu-Based Approach

5. Using a menu-based approach to reevaluate the TFP

In this chapter, we focus on a feasibility assessment of a menu-based approach to developing a TFP market basket and cost. We begin the chapter with a brief overview of the expert panelists' conceptualization of this alternative approach and then describe the procedures we used to conduct a small-scale feasibility assessment. We then present key findings from our implementation, including the resulting TFP market basket and associated costs. We conclude with a discussion on considerations about and barriers to future large-scale implementation.

5.1. The expert panelists' concept: Using a menu-based approach to reevaluate the TFP

A menu-based approach for reevaluating the TFP was the second most preferred approach among the alternatives identified by the expert panelists. The Alternative Approaches report (Jones et al. 2024) presents the concept of the menu-based approach as follows:

> *Under the menu-based option, nutritionists would develop healthy, lower-cost menus that meet current dietary guidance. The nutritionists would be asked to develop menus that include a complete list of meals and the ingredients and food items needed for each meal for a reference family of four. The frequency with which foods and beverages appear on the menus would be the basis for defining the market basket. To calculate the cost of the TFP, the menus would be linked to price databases to determine the cost of each menu. Ultimately, a TFP cost would be calculated by averaging the costs of the individual menus.*

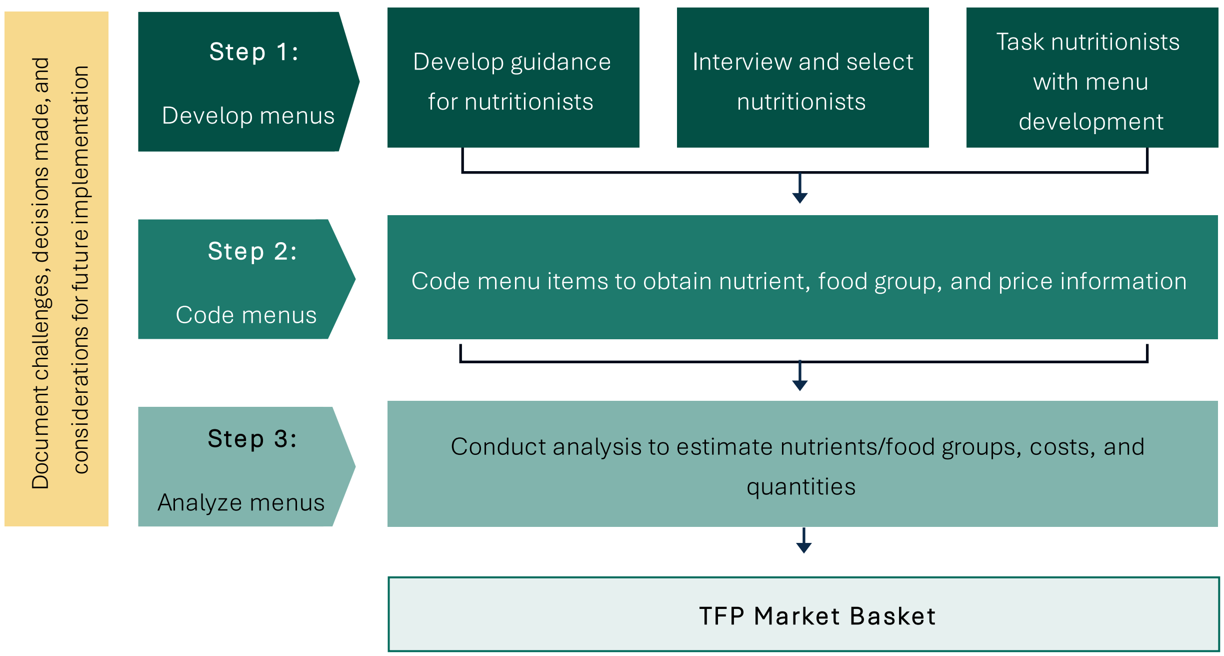
The expert panelists discussed some high-level considerations for implementing the menu-based approach, described in more detail in Chapter IV of the Alternative Approaches report. However, they did not consider several details required for implementing the approach. For instance, the panelists did not determine the number of menus needed to calculate the TFP market basket and its cost, how to set the nutritional targets for those menus at the family level (for the reference family as opposed to individuals within the reference family), or the assumptions regarding portion sizes or how food is likely to be shared among members of the reference family when the family prepares and consumes meals together. For these reasons, we implemented a small-scale assessment in order to determine the feasibility of the menu-based approach to identify issues, challenges, and considerations for a future, larger-scale implementation that would be needed if this initial assessment showed merit.

Recognizing that the approach was new, we first had to develop a process for implementing a menu-based approach that would define a market basket for the reference family of four and estimate the associated nutrients, costs, and quantities of foods included in the menus. When implementing the menu-based approach, we had to make certain decisions on how best to implement the steps when more than one option was available. In this chapter, we present the decisions that we ultimately made and present reasonable alternative decisions that we might have made instead, as applicable. To the extent possible, we discuss how these decisions influenced our assessment of the feasibility of the approach.

5.2. Overview of the methodology used to assess the feasibility of the menu-based approach

We documented our initial plans for executing the menu-based approach in an implementation plan for CNPP's review and approval. The plan established the main steps in the process, as summarized in Exhibit 7.

Exhibit 7. Steps in the menu-based approach feasibility assessment



For this small-scale feasibility assessment, two nutritionists each developed five weeks of menus, for a total of 10 weeks of menus. The first step involved three menu development activities: (1) developing standardized guidance and materials for nutritionists to use when formulating the menus, (2) selecting two nutritionists to develop the menus, and (3) tasking the nutritionists with developing menus and providing feedback on the process. We then compiled the menu data into an electronic format and cleaned and coded the data to obtain nutrient, food group, and price data for each weekly menu. The last step in the process involved estimating the amounts of selected nutrients/food groups, costs, and quantities of foods across the 10 weeks of menus. Throughout each step, we documented information to assess the feasibility of the menu-based approach, including issues and challenges that arose, decisions made, and considerations for a future, larger-scale assessment that would be needed before full implementation.

5.3. Menu development activities

Develop guidance and materials for nutritionists to use. We created a guidance document and Excel menu template for the nutritionists' use in developing the weekly menus. We worked with CNPP to establish the details in the guidance document, incorporating several considerations identified by the expert panelists. The box below (Box 1) summarizes the key guidance; Appendix A includes the full guidance document provided to the nutritionists.

Box 1. Key guidance provided to nutritionists

- Develop five weeks of distinct daily menus that include healthy, thrifty meals prepared at home for the specified members of the reference family of four
- Include breakfast, lunch, dinner, and one snack
- Account for several considerations, such as cost, availability, palatability, convenience, practicality, and variety
- Design the menus to meet the *combined* nutritional needs of the reference family of four (Exhibit A.1 in Appendix A outlines the nutritional goals provided to nutritionists) and ensure consistency with the Healthy U.S.-Style Dietary Patterns in the 2020-2025 Dietary Guidelines for Americans
- Include, for each menu item, the: food name and details, amount for the reference family to prepare, and detailed recipes for items prepared by combining two or more ingredients
- Use the Excel template to enter information for each week of menus (organized by day of the week, with a set of rows for recording foods for each meal—breakfast, lunch, dinner, and snack)

For the purposes of this feasibility assessment, we worked with CNPP to establish nutritional goals for planning menus. The TFP, 2021 reflects current dietary guidance specified in the Dietary Guidelines for Americans and the Dietary Reference Intakes (DRIs) and requires that each reference family member obtains the recommended intake levels from the defined market basket (Box 2).

Box 2. Overview of current dietary guidance

- The Dietary Reference Intakes (DRIs) establish reference values for energy, macronutrient, and micronutrient intakes, based on age, sex, and life stage.
- The 2020–2025 Dietary Guidelines for Americans provide dietary patterns with recommendations on daily or weekly amounts of food groups and subgroups to consume based on an appropriate daily calorie level, while limiting amounts of added sugars, refined starches, saturated fat, and sodium.

The DRIs and Dietary Guidelines establish recommended intake levels for an individual based on a variety of factors, including age, sex, life stage, physical activity level, and calorie level. Even though these recommendations pertain to the individual level, most families plan and prepare their meals for the family unit, sharing many of the same foods throughout the week. Therefore, we provided the nutritionists with guidance to develop menus that would align with nutritional goals at the family as opposed to the individual level.[18] To that end, we developed a simple, practical approach to establish family-based nutritional goals for the nutritionists' use in developing menus. This group-based approach is a departure from the existing individual-level approach used in the TFP optimization models for ensuring alignment with current nutritional guidance.

To establish the goals, we used the daily calorie level for each reference family member that the 2021 TFP reevaluation used (Box 3). We identified the corresponding, recommended daily or weekly minimum amounts of food groups and subgroups, aggregated the values across the reference family members, and

[18] In addition to the considerations presented in the text, tasking nutritionists with developing menus to meet four sets of nutritional goals (one for each reference family member) would be extremely challenging given the lack of existing technology to support such work. Implementation of such an approach would have been technically infeasible given the constraints of this feasibility assessment.

then multiplied the daily requirements by seven (days per week). Given that the calorie level can vary from the amount specified—by 0.5 percent in either direction—we included calorie ranges, which is also consist with how the TFP, 2021 was developed. The recommended limits on calories from saturated fat and from added sugars are expressed as a percentage of total calories (less than 10 percent for each) and thereby required no calculations. In Appendix A Exhibit A.1, we show the resulting nutritional goals for planning menus as provided to the nutritionists in the guidance. The guidance stated that the goal was to plan menus consistent with the collective needs of the reference family, as shown in the guidance document. However, the nutritionists were not required to verify that the menus met every nutritional goal.

Box 3. Calorie levels used to establish nutritional goals for reference family members

Male/Female ages 6 to 8	Male/Female ages 9 to 11	Male ages 20 to 50	Female ages 20 to 50
1,800	2,200	3,000	2,200

Source: U.S. Department of Agriculture. "Thrifty Food Plan, 2021." Food and Nutrition Service (FNS), FNS-916. Table A3.1. Energy requirement constraints for each Thrifty Food Plan age-sex group.

Select nutritionists. As suggested by the expert panelists, we focused on identifying a pool of nutritionists affiliated with SNAP-Ed programs across the country. We compiled a list of about 40 candidates through searches of websites for SNAP-Ed programs and Expanded Food and Nutrition Education Programs (EFNEP) and conducted initial outreach via email to gauge interest in and availability for participating in the menu development. We also asked the potential candidates to recommend other candidates in their program or professional network. We interviewed a total of seven candidates; after the interviews, two candidates indicated that they did not have time to participate. Of the remaining five candidates, we selected the two who had the most relevant experience and were available to participate during the required time frame. We asked the two nutritionists to disclose any potential conflicts of interest. Each nutritionist received a $1,000 honorarium for participating in the menu development activities. The nutritionists had the following experience and expertise:

- Nutritionist 1, a registered dietitian (RD) with more than 20 years of experience, is a professor in a State university's cooperative extension school and supervises the State's EFNEP. Nutritionist 1 has extensive experience in developing menus, recipes, and other resources for households with low incomes and teaches students about the TFP.
- Nutritionist 2 is a licensed dietitian/nutritionist (LDN) and certified nutrition specialist (CNS) who works as a nutrition education specialist at a regional food bank and has extensive experience in planning menus as part of individual and group-based nutrition education. Nutritionist 2 is also experienced in developing menus for athletes and in clinical settings for people with specific health conditions.

Develop menus and provide feedback on the process. We provided the two nutritionists with the guidance document and template for developing the menus and asked them to return the materials within two weeks. We also asked them to complete a questionnaire that allowed us to gather initial input on the process, including the amount of time spent on menu development, resources consulted, and questions or considerations that arose during the activity. We then conducted a 30-minute virtual debriefing call with each nutritionist to gather feedback on the activity, the guidance document provided, and considerations for future implementation. Below we summarize the input from the nutritionists on the menu development activities.

- **Time.** Nutritionist 1 spent 20 to 25 hours on the menu development activities and reported that the assignment took much longer than expected. Nutritionist 2 spent 48 hours and reported "burnout" after developing the first three weeks of menus along with challenges in finding time to complete the activity on time while working full time. The most time-consuming aspects of the process included selecting recipes, modifying recipes relative to nutritional goals, ensuring variety, and balancing the variety and cost of foods across the menus.
- **Approach and considerations.** Nutritionist 1 did not use menu or diet analysis software, noting that use of such software would have added another layer of complexity. They built menus each day based on potential meal choices, focusing first on specific components (seafood, legumes red/orange vegetables) and then repeated meals throughout the week for efficiency and consistency. Nutritionist 1 mostly used existing recipes available online from their SNAP-Ed program. Nutritionist 1 reported the following considerations when developing the menus: how they fed their own family (with children), foods that would typically be on hand for a family, availability of local foods (for example, less expensive fresh fish in their area); form of foods (initial attempt at seasonal alignment but later realization of practicality of frozen and canned foods); and preferences and palatability (children ate the same meals as the adults, and the family had no dietary restrictions and, would, for example, eat pork and dairy). After planning the menus, Nutritionist 1 was concerned about the significant amount of time the family would need to prepare and cook the planned meals. They also noted the exclusion of sweets or desserts from their planned menus but noted that their family and others would likely have included these items.

  Nutritionist 2 used diet analysis software to plan the menus and track macronutrient and micronutrient values across meals and days. They built the meals around a foundational list of ingredients (for example, berries, frozen vegetables, meats) and focused on overall calories and macronutrients (carbohydrate, fat, and protein). For a given day's menu, Nutritionist 2 planned the meals and then added fatty foods to meet calorie targets. Nutritionist 2 often selected frozen foods for convenience and cost and planned for the use of leftovers for two to three days within each week. Nutritionist 2 used recipes from a different state's SNAP-Ed program for inspiration but developed new recipes for the menus. This nutritionist reported the following considerations when developing the menus: palatability in terms of what a family of four would plan and what foods children would eat based on cooking classes they taught; use of snacks for variety and to enhance palatability; adjusting recipe yields for use of leftovers on other days; simple lunch preparation; adjusting foods or ingredients in response to cost; and basic kitchen equipment needed to prepare meals.

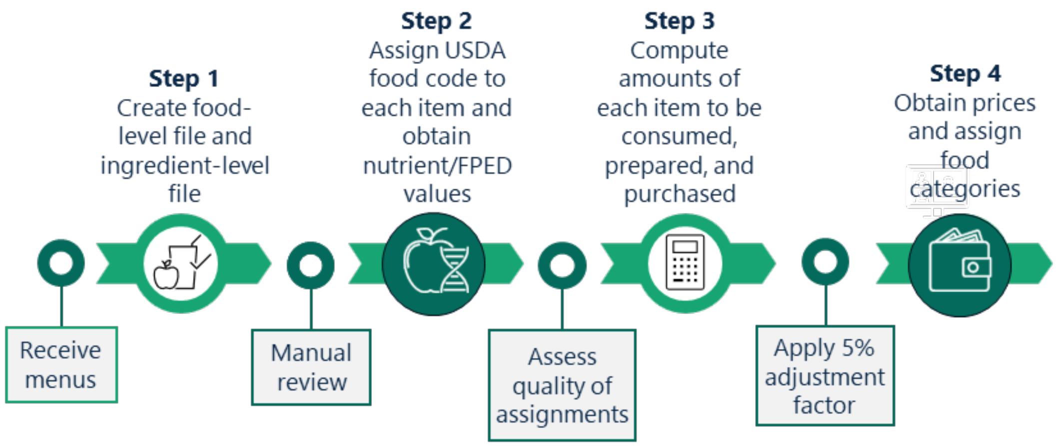
  Both nutritionists provided positive feedback on their experience in developing the menus. They also reported that developing menus was an iterative process for each day and week in order to accommodate the various aspects of the guidance. Nutritionist 1 compared the menu development process to doing a puzzle and said it pushed the limit on creativity given the constraints and considerations.
- **Feedback on guidance and materials provided.** Nutritionist 1 noted that the guidance had varying levels of specificity, suggesting a degree of inconsistency that required independent decision-making in the absence of detailed direction. Both nutritionists had questions about portion sizes for each reference family member, and Nutritionist 2 wanted information on the protein requirements for the reference family to guide better meal planning. They also had questions about the food groups specified in the nutritional guidance, especially for vegetable subgroups (for example, which subgroup includes yellow vegetables, and whether beans could be counted as both vegetables and proteins). For the Excel menu template, Nutritionist 1 did not like that the menu template started on Monday, which is not the first day of the week for their approach to weekly menu planning.

Nutritionist 2 used a diet analysis software and found it burdensome to enter menu information into the Excel template.

5.4. Processing the menus to obtain data on nutrition, food group, and price

We processed the menus for analysis by creating a food-level data file with all food items and portion sizes, along with their associated USDA food code, nutrient and food group amounts, quantity to purchase, and price. We developed data processing procedures based on our knowledge of the data sources and ultimate goals of the analysis. We present the main steps in Exhibit 8.

Exhibit 8. Overview of steps for menu items and recipes



5.4.1. Create food-level and ingredient-level files

The nutritionists submitted ten Excel files (five each) listing foods and portion sizes for each food item specified in the weekly menus, along with an indicator for items prepared from recipes. They also submitted recipes in various formats, including Word and PDF formats and website links. The two nutritionists submitted a total of 90 unique recipes (72 and 18 recipes, respectively).[19]

Transforming the information in the Excel files and recipes into a data file was labor-intensive. We used a combination of manual coding and programming to clean the Excel menu data. For each recipe, we used OpenAI's ChatGPT Enterprise o3 model, a type of generative artificial intelligence (AI), to transcribe image files and html text to create a raw data file containing a list of ingredients and their associated quantities and units of measurement (OpenAI 2025). A study team member reviewed each recipe transcription for accuracy before finalizing the raw data file.

We were able to implement some processing steps based on unique item names and portion sizes instead of having to code each individual food item and ingredient. However, the degree of standardization in the information provided by the nutritionists limited the extent to which we could do so. For example, the nutritionists listed the same food items in different formats that resulted in variation in spelling or how units of measure were reported across menus. We also had to disaggregate food items reported as a single item into more than one item to facilitate matching to a single USDA food code (for example, we converted fresh carrots and broccoli served with a dip into three items). Some individual food items and ingredients in

[19] There was some variation in how the nutritionists recorded items that included few ingredients. The nutritionist who submitted 18 recipes often reported ingredients as individual items rather than providing a recipe.

recipes lacked volume or weight-related units of measure (for example, four bananas, eight slices of bread, salt and pepper to taste).

The recipes were the most challenging to process. One nutritionist used mostly existing recipes from SNAP-Ed. Although such an approach was likely efficient for the nutritionist, it necessitated additional coding and required the study team to make several assumptions. Some of the issues and associated decisions included the following:

- Recipe not scaled to the correct yield for the reference family
  - We had to apply a recipe scale factor and assume the suggested serving size was relevant for each reference family member. For example, for a recipe that made eight servings (yield of eight cups) and had a suggested serving size of one cup, we assumed the one cup serving size for each family member and scaled the recipe (and its ingredients) to yield four cups (instead of eight).
- Recipe included choices of ingredients (for example, American or cheddar cheese; butter or oil; choice of protein—chicken, beef, or pork) or optional ingredients (for example, cilantro, jalapeno)
  - For ingredient choices, we randomly selected one.
  - For optional ingredients, we included them in the recipes.
- Ingredient portion sizes listed as a range (for example, two to three garlic cloves), for which we selected either the lower bound of the range or the mid-point

5.4.2. Assign USDA food code and obtain nutrient and food group values

To obtain nutrient and food group values on a per 100-gram basis, we used the following USDA databases (Chapter 4 provides detailed descriptions of each data source)[20]:

- 2015-2016 Food and Nutrient Database for Dietary Studies (FNDDS)
- 2015-2016 Food Patterns Equivalents Database (FPED)
- 2015-2016 Food Patterns Equivalents Ingredients Database (FPID)

We selected the best matching USDA food code (from FNDDS or an ingredient code from the National Nutrient Database for Standard Reference (SR)) based on the food or ingredient description provided by the nutritionists. The main challenge was the lack of specificity in the food or ingredient name provided by the nutritionists relative to the details included in the USDA food code descriptions.[21] For example, it was not uncommon for the nutritionists to list “chicken” as a menu item without specifying cooking method, whether skin was included, or the part of chicken; “peppers” did not always specify form (fresh, frozen, and so forth), color, or whether fat was added during cooking; “rice” did not specify type (white, brown, wild) and whether fat was added during cooking. When feasible, we made decisions on which USDA food code to select by using other information provided by that nutritionist for similar foods (for example, rice was specified as brown rice on another day and fat was not typically included in recipes for grains). In Exhibit 9, we provide a summary of the total number of food items, recipe items, and ingredients within the recipe items that we coded.

[20] The 2015-2016 versions of the databases are consistent with those used in the 2021 TFP reevaluation.

[21] Other decisions could be made when matching foods to a USDA food code and could ultimately influence the nutrient and food group estimates for the menus. Although the nutritionists received guidance on providing details, they did not always provide the requested details. In addition, FNDDS captured other characteristics that were not specifically requested (for example, whether skin was on chicken).

Exhibit 9. Number of food items, recipe items, and ingredients included in menus

Characteristic	Number
Total number of items	
Total number of food items and recipe items	1,258
Total number of food items	1,086
Total number of recipe items	172
Total number of ingredients	1,257
Unique number of items	
Number of unique food items and recipe items	418
Number of unique food items	328
Number of unique recipe items	90
Number of unique ingredients	442
Number of matched items	
Number of unique food items and ingredients matched to FNDDS	684
Number of unique food items and ingredients matched to SR	63
Number of unique food items and ingredients flagged for not matching well to food in FNDDS or SR	74

Note: A food item is defined as an item that did not have a recipe provided by the nutritionist.
FNDDS = Food and Nutrient Database for Dietary Studies; SR = Standard Reference

Matching reported food items and recipe items to FNDDS food codes was preferable to using SR codes because we used FNDDS food codes in the price file in a later step. We were able to match the majority of unique items to an FNDDS food code; about 8 percent of unique items were matched to a food code in SR (mostly for herbs and spices and for baking ingredients such as baking soda and flour). About 10 percent of items were flagged during the coding process as not matching well to an available FNDDS or SR code, including herbs and seasonings and foods included by nutritionists with specific nutritional characteristics not available in FNDDS or SR (for example, low-sodium mayonnaise, low-fat feta cheese, and sodium-free broth).

5.4.3. Compute amounts of each food item and ingredient

For the menu analysis, we needed to compute various amount variables (or gram weights) for each food item and ingredient, including (1) the amount to be consumed by the reference family, (2) the amount to be prepared by the family after accounting for waste during preparation and eating, and (3) the amount to be purchased after accounting for changes in the weight of a food because of refuse or cooking.

We first converted various units of measure reported by the nutritionists to grams, which is the unit of measure used in the USDA nutrient/food group databases. We used the Portions and Weights file from FNDDS for conversions for volume or nondescript units. This file provided the gram weights associated with the edible portion of the food (that is, after refuse is removed such as the stem and core of an apple or a bone in chicken). For each FNDDS food code, the file provides various options for the unit of measure or portion sizes—for example, the gram weight for one cup, tablespoon, slice, or item. We used other standard conversions for units reported in weight measures (for example, ounces and pounds) to convert to grams.

Some of the issues encountered and decisions included the following:

- The Portions and Weights file included various options based on the form or size of the food such as the gram weight associated with one cup chopped, diced, mashed, sliced, or grated or one small, medium, or large item. The nutritionists often did not specify this level of detail. In such cases, we had to select an option to generate a gram weight.
- For foods or ingredients reported as items, we assigned the “1 medium” option.
- For foods or ingredients reported in volume measures that do not specify the form (for example, chopped, diced, mashed, sliced), we selected the “not further specified” option if available or randomly selected another option from the ones available for a given food code.

After computing the gram weight associated with the portion size reported by the nutritionists, we scaled the nutrient and FPED amounts per 100 grams to reflect the portion sizes reported by the nutritionists. Consistent with procedures used in the 2021 TFP reevaluation, we then applied a 5 percent adjustment factor to the amounts to account for plate waste and/or foods that may go uneaten before they spoil. Finally, by applying a yield factor, we adjusted the quantity of some items to reflect the amount to be purchased. This accounted for foods that have refuse—that is, inedible parts—or dry or unprepared foods that undergo changes in weight during cooking (for example, dry rice or pasta). We obtained yield factors from the Purchase to Plate resources (file named ECFormRules2015_2016.xlsx). The file did not include all the food codes that we used. In addition, there were often several yields for a food based on the form purchased and the form that was reflected in the USDA food code. Given that the nutritionists did not consistently specify the form of food to purchase (for example, whether fruits, vegetables, and meats were purchased ready to eat or had refuse), we had to make decisions about which form to select, thus influencing the yield factor we applied.

5.4.4. Obtain prices and assign food categories

After we assigned a USDA food code to all foods and ingredients, we then obtained a price for each item and assigned a modeling category. To assign prices, we used the Supplement to the TFP, 2021 data set published by CNPP, which mapped average June 2021 prices per 100 grams for 3,072 FNDDS food codes. We determined that 27 percent of unique food codes (N = 87 unique food codes) or 16 percent of total menu items (N = 2,343 total food items) lacked a known price. For missing values observed in the econometric-based approach presented in Chapter 6 (N = 50 unique food codes; N = 224 items overall), we imputed the price by using the average price of items within the same TFP modeling category (Chapter 6 provides additional details). For the remaining 37 food codes (and N = 406 menu items overall), which were mostly water, spices, and baking ingredients (such as baking soda, baking powder, flour), we assigned a food code and price that were generally in the same food category. After obtaining a price for each item, we computed the price for the amount of food to be purchased for each food item.

We assigned each food item and ingredient to one of 10 food and beverage categories that consolidates the 95 TFP modeling categories into higher-level categories. About 11 percent of unique food codes (N = 36 unique food codes) or 12 percent of total menu items (N = 276 total food items) did not match to a category. For these items (mostly spices and condiments), we assigned them to the most relevant category. We assigned water to the “beverage” category rather than omitting it.

5.5. Analysis and estimates of nutrients/food groups, costs, and quantities

For the analysis, we constructed a data file that contained week-level sums of nutrient and food group amounts and costs as well as the quantities of foods to purchase. We estimated the mean and distribution of weekly costs and calories across the 10 weeks of menus (market baskets) developed by the nutritionists,

(Exhibit 10). We also estimated mean distributions of the food groups, subgroups, and dietary components, along with the goal specified in the guidance provided to the nutritionists. In Exhibit 11, we provide some insights into the degree to which the nutritionists' menus aligned with targets. In Exhibit 12, we show the mean quantity, cost, and cost share of weekly menus by food categories.

As presented in Exhibit 10, the average weekly cost of menus was about $312, with considerable variation across the 10 menus ($225 to $383). By comparison, this average cost is about 60 percent higher than the TFP, 2021 cost of $192.97. The weekly menus would provide the reference family with an average of 53,573 calories per week, with a range of 38,482 to 67,208.

Exhibit 10. Menu-based approach: Distribution of weekly menu costs and calorie content

Outcome	Min	p25	p50	p75	Max	Mean	SE
Weekly cost ($)	$224.91	$233.87	$323.80	$380.25	$383.07	$312.37	$22.22
Weekly calories (kcal)	38,482	41,069	55,126	65,082	67,208	53,573	3,862

Notes: Estimates are based on 10 sets of weekly menus developed by two nutritionists.
SE = standard error; p = percentile.

Based on the distribution of weekly amounts of calories, food groups, subgroups, and dietary components (Exhibit 11), many weekly menus did not meet nutritional goals.[22] For instance, slightly more than 25 percent of the weekly menus did not include enough calories to meet the combined needs of the reference family (the 75th percentile was just over 65,000 calories compared to the target of 64,000 calories). The one exception to meeting the goals was added sugars, for which all weekly menus fell below the limit on calories from added sugars (maximum value of 8 percent relative to a limit of 10 percent). Most menus exceeded the targeted minimum amounts for the majority of food groups. However, none of the menus achieved the minimum amount of starchy vegetables, and roughly 25 percent of weekly menus fell below the food group goals for vegetables, dairy, protein foods, and oils.

Exhibit 11. Menu-based approach: Distribution of weekly amounts of calories, food groups, and subgroups

Outcome	Unit	Weekly nutritional goal for planning menus	Min	p25	p50	p75	Max	Mean	SE
Calories	kcal	64,000	38,482	41,069	55,126	65,082	67,208	53,573	3,862
Saturated fat	% of kcal	< 10%	4.77	7.44	8.28	8.79	11.01	8.12	0.54
Added sugars	% of kcal	< 10%	1.74	3.40	3.62	4.55	7.97	4.12	0.54
Food groups (minimum amounts)									
Vegetables	cup eq	87.5	59.65	84.99	94.38	100.07	109.79	91.48	4.40
Dark green	cup eq	8	3.11	7.45	9.00	25.78	33.47	15.61	3.55
Red and orange	cup eq	25	21.21	25.69	33.74	34.52	39.93	31.29	2.08
Beans, peas, legumes	cup eq	8.5	2.28	3.38	6.56	9.45	14.56	6.86	1.23

[22] The goals for food groups and subgroups are minimum amounts.

Outcome	Unit	Weekly nutritional goal for planning menus	Min	p25	p50	p75	Max	Mean	SE
Starchy	cup eq	25	2.08	8.85	14.08	17.28	22.36	13.14	1.87
Other	cup eq	21	16.38	20.84	25.96	26.88	34.58	24.59	1.71
Fruits	cup eq	56	55.06	63.49	66.82	69.81	83.91	66.88	2.57
Grains	oz eq	210	106.39	137.23	156.03	165.09	178.02	149.85	7.40
Whole grains	oz eq	105	58.58	71.66	80.76	94.51	115.04	83.39	5.36
Refined grains	oz eq	105	22.19	59.76	75.67	77.53	101.51	66.47	8.12
Dairy	cup eq	80.5	54.91	57.93	75.93	111.97	124.68	83.84	9.24
Protein foods	oz eq	168	99.15	131.90	194.18	251.98	284.13	189.67	21.83
Meats, poultry, eggs	oz eq	112	54.98	81.82	137.75	156.39	183.51	126.57	14.64
Seafood	oz eq	36	18.22	25.45	30.31	45.25	58.96	33.85	4.08
Nuts, seeds, soy products	oz eq	20	1.83	13.76	25.15	51.43	58.21	29.26	6.76
Oils	g	882	345.32	426.57	792.35	1,380.04	1,733.50	900.28	172.21

Notes: Estimates are based on 10 sets of weekly menus developed by two nutritionists. Nutritional goals were provided in the guidance for nutritionists. See Appendix 0.

As shown in Exhibit 12, the largest cost shares across the food categories were for vegetables (27 percent); meat, poultry, seafood, and eggs (24 percent); and fruits and fruit juice (18 percent). The low share for mixed dishes (2.5 percent) likely reflects the approach we took to assign food categories at the ingredient level. The nutritionists did not consistently include beverages in each meal, likely influencing the small share of costs from this category (< 1 percent).

Exhibit 12. Menu-based approach: Mean quantity, cost, and cost share of weekly menus, by food categories

Food category	Weekly quantity (pounds)	Weekly cost ($)	Expenditure share (%)
Dairy	33	$39.89	12.2%
Meat, poultry, seafood, eggs	11	$75.25	23.5%
Nuts and seeds, soy products	1	$3.98	1.2%
Mixed dishes	3	$6.97	2.5%
Grains and cereals	12	$24.08	8.0%
Snack foods and sweets	2	$9.43	2.8%
Fruits and fruit juice	25	$55.46	18.1%
Vegetables	29	$82.25	27.4%
Beverages	54	$2.77	0.7%
Fats, oils, and condiments	3	$12.97	3.9%

Notes: Estimates are based on 10 sets of weekly menus developed by the two nutritionists. For items prepared from a recipe, each ingredient is represented in the associated food category.

5.6. Key findings and considerations for the future

In this section, we summarize key findings for implementing each step in the menu-based approach in this small-scale feasibility assessment. We also note barriers to implementation that are important to consider in a future, larger-scale effort.

5.6.1. Conduct menu development activities

For this feasibility assessment, we established family-based nutritional goals for two nutritionists to use in developing menus. The family-based approach is a departure from the existing individual-level approach used in the TFP optimization models for ensuring alignment with current nutritional guidance. Thus, additional efforts are needed to develop family-based nutrient and food group targets for use in the context of a menu-based approach.

The nutritionists found that developing five weeks of menus was an iterative and time-consuming process. Going forward, it might be advisable to require nutritionists to develop fewer weeks of menus and give them more time to complete them. It is important to recognize that the guidance provided to the nutritionists directed them to meet the combined nutritional needs of the reference family; however, the guidance did not require the nutritionists to verify that the weekly menus met all the nutrient and food group requirements that were specified in the TFP, 2021. Requiring menus to meet all nutrient and food group requirements that have historically been used to ensure alignment with current dietary guidance would have required even more iteration and more time.

The nutritionists' feedback on the most time-consuming aspects of menu development stressed the modification of recipes relative to nutritional goals and the iterative nature of the work—that is, having to balance the various considerations and constraints (described as being similar to completing a puzzle. This could imply that the number or combination of constraints and considerations that they were asked to account for, including calorie requirements and the need to be budget friendly, was beyond what they typically do as nutritionists when planning meals for individuals or households. This feedback raises important considerations for the use of customized or new menu planning software. The design and functionality of such software would need to be driven by the specific criteria that need to be satisfied as part of the menu development process. For example, new technology could include nutrient and food group values for foods and ingredients, prices of foods and ingredients, recipe development and modification at the ingredient level, and daily and weekly reports to compare planned menus to nutritional goals (at the family or individual level). Other constraints could also be built into the technology, such as palatability ratings, preparation time estimates, or needed equipment.

Even with the use of custom technology, the menu development process for nutritionists would need to be iterative and would be time-consuming in view of the need to meet a potentially large number of nutrient and/or food group-based targets and other constraints. We are not aware of a currently available menu/diet technology with the required functionality that could be used by nutritionists. The development of a new system would therefore require a significant investment and involve additional decisions and considerations during the design and testing phase—for example, underlying nutrient or food group databases, a recipe bank for users, required data elements, and user experience.

Additional procedures, criteria, and guidance would be needed to ensure that menu development activities are transparent and standardized for a larger-scale implementation of the menu-based approach. Such considerations include:

- How many weeks of menus are needed?
- How many nutritionists are needed?

- What is the time commitment per nutritionist?
- Should nutritionists receive compensation for their time, and, if so, what is an appropriate amount?
- How should a pool of nutritionist candidates be identified?
- What professional experience and expertise should be required of nutritionists, and what characteristics should nutritionists demonstrate (for example, geographic location, lived experience, clientele served)?
- What nutritional goals should be the basis for the menus, and how should those goals be denominated (for example, calories, macronutrients, micronutrients, and/or food groups and subgroups in the Dietary Patterns)?
- Is there an acceptable range for meeting each nutritional goal?
- If nutritionists plan menus around food groups and subgroups from Dietary Patterns, what guidance is needed to ensure an understanding of how foods are categorized and credited?
- What guidance is appropriate to establish portion sizes for the reference family? What approach should be used to develop portion size guidance?
- Should terms such as thrifty, lower cost, or budget friendly be defined, and, if so, how?
- Should nutritionists use actual prices when planning the menus? If so, what guidance is needed and from what source?
- Should additional criteria or guidance be established for the following considerations, and, if so, what approach is appropriate?
  - Number of meals and snacks, palatability, individual preferences or dietary restrictions for each family member, level of convenience and preparation time, available kitchen equipment, use of food on hand, use of leftovers, use of strategies to reduce food waste, and variety within a day and across the week
- How do specific criteria ultimately influence the selection of foods in the market basket and their associated nutrient, food group, and quantity values?
- How should nutritionists prioritize various considerations such as nutritional goals, cost, convenience, and so forth?
- How should data be collected to ensure standardization and reflect all required data elements?

If a technology solution were to be developed to support menu development activities by nutritionists, final decisions on the above criteria would be needed early in the process to ensure their incorporation into the technology (for example, nutritional goals).

5.6.2. Processing the menus to obtain nutrient, food group, and price data

As part of this feasibility assessment, we needed to develop a method to process the data that would yield nutrient, food group, quantity, and price values. The small sample size of menus (10 weekly menus, or 70 daily menus) and the many unknowns about the process influenced our method. One major problem was the lack of standardization in the menus and recipes provided by the nutritionists. When feasible, we tried to implement some processing steps based on unique food data elements (rather than for each observation in the data), but inconsistencies in the data provided by the nutritionists undermined this approach. As a result, processing the data required a high level of effort to construct a usable data file for both coding and use in the ultimate analysis. A larger sample size of menus would increase the associated level of effort needed for data processing.

The lack of specificity in the data provided by the nutritionists also contributed to the complexity of implementing the menu-based approach—specifically, we lacked the details included in USDA food code descriptions that are needed to accurately estimate the nutrient and food group content of foods as well as the foods' actual gram weights. As a result, we had to make many assumptions and decisions about how or which values to assign to food items in the information provided by the nutritionists and the available data we used in the nutrient, food group, and price databases. Even if we had made other decisions, we would have introduced factors potentially affecting market basket quantities, nutrients/food groups, and costs included in the analysis. Each decision point warrants careful consideration and a methodology to test the sensitivity of applying different decisions–a time- and labor-intensive undertaking.

Technology could provide a solution to the menus' lack of standardization and specificity. A system that prompts users to specify all required data elements (for example, all details specified in USDA food code descriptions, the form purchased, and a unit of measure converted to grams) would improve data quality and reduce the number of assumptions or decisions to be made during data processing. The sensitivity analyses mentioned above could determine whether specific assumptions could be applied with little effect on the estimates or whether the nutritionist must provide specific information for a given food. As described, the development of a new technology would involve high costs and a long lead time and require many methodological decisions. One potential way, however, to overcome such a challenge would be to direct nutritionists involved in menu development to use technology that encompasses standardized food and ingredient descriptions linked to nutrient/food group values.

5.6.3. Conducting the analysis to estimate nutrients/food groups, costs, and quantities

In terms of implementation, the analysis was straightforward and would be feasible on a larger scale. The estimates presented in Exhibit 10 and Exhibit 11 demonstrate the ability to generate a TFP market basket and cost; however, the decisions we made throughout the processing of the menus to obtain nutrient, food group, and price data influenced the point estimates. The estimates in Exhibit 12 show that the menus developed by the nutritionists were high in cost relative to the TFP, 2021 and did not meet the majority of the nutritional goals for calories, food groups, and subgroups. The only exception pertained to added sugars, with all 10 weekly menus falling below the recommended limit for calories from added sugars. Most notably, many menus did not include an adequate level of calories to meet a healthy diet. An assumption underlying the panelists' concept of the menu-based approach is that the expertise of nutritionists is essential in planning menus to meet specific goals. However, this feasibility assessment demonstrates that the panel's assumption does not hold. It further indicates that nutritionists involved in menu development must use the same nutrient and food group databases that would be used for the menu analysis so they can accurately see the nutrient and food group values associated with their foods, recipes, and menus.

With respect to higher costs, it is unclear to what extent nutritionists heeded the guidance to develop budget-friendly menus. It is possible that in the absence of having access to food prices, the nutritionists were unable to adequately account for relative costs of items when constructing menus. It is also possible, as noted above, that decisions regarding how to match menu items to FNDDS food codes influenced the estimated costs associated with the menus. Given the relatively high degree of variability in the distribution of costs, it is also possible that had more menus been developed, a subset of those may have yielded lower costs than what was observed in this small-scale assessment.

5.7. Conclusion

From a technical standpoint, a **menu-based approach is feasible to implement**. However, this small-scale feasibility assessment identified **several significant barriers to implementation** that influence the advisability of using the menu-based approach to develop a TFP market basket and cost. One major barrier is the technology nutritionists need to develop menus that satisfy all nutritional requirements and account for various constraints (for example, price and variety) is lacking. Developing a new, custom technology for the menu development process would require substantial resources and time. In addition, a menu-based approach involves many assumptions or decision points, which could result in higher degrees of error or bias in the estimated TFP market basket and costs, resulting in greater uncertainty. Each of these assumptions and decision points requires further consideration and testing, along with significant time and resource investments and a larger-scale feasibility assessment, contributing to higher barriers to implementation.

Although it would be **feasible to implement a menu-based approach that is cost neutral** to the TFP, 2021 level, findings from this initial assessment suggest that adding this requirement would substantially increase the complexity of the menu development task. None of the menus developed by the two nutritionists as part of this feasibility assessment were cost neutral to the TFP, 2021; the lowest-cost menu was roughly $30 more than the TFP, 2021. To obtain a set of cost-neutral menus, CNPP could pursue a couple different approaches. One option would involve updating the guidance to the nutritionists to include a new requirement that menu costs not exceed a fixed value. This option would require that nutritionists have access to food price data while developing their menus, so they could both verify the cost of each menu they develop and identify less expensive foods and beverages in situations where menus exceeded the threshold. The nutritionists would also need access to the nutrient and food group databases, as well as adjustment factors to compute the amount of food to purchase, so they could use this information when selecting foods and recipes to include in the menus. Given the complexity of these calculations, this option would almost certainly require new, custom technology to implement. Rather than placing the burden on the nutritionists to ensure cost neutrality of the menus, a second option could involve pricing each menu developed by the nutritionists and then excluding any menus that exceeded the cost threshold when determining the market basket. As noted, none of the menus from this small-scale feasibility assessment would have qualified for inclusion in determining the market basket under this option. Therefore, if CNPP were to pursue this approach, the nutritionists may need to develop a much larger number of candidate menus to ensure that a cost neutral menu could be identified among the set.

Another option CNPP could explore is the use of AI to develop or modify menus that meet the various TFP constraints, rather than using nutritionists. Researchers are currently exploring the use of AI to develop individualized meal plans (Papastratis et al. 2024) that meet selected dietary requirements. However, additional investments would be needed to develop and test an AI methodology that could be applied in the context of the TFP requirements.

Feasibility Assessment of the Econometric-Based Approach

6. Overview of the econometric-based approach

Among the three alternative options identified by the expert panel for reevaluating the TFP were two implementations of an alternative **econometric**-based approach: a **demand model** and a **stochastic production frontier** model. The concept underlying the demand model was for CNPP to continue solving an optimization problem to compute the TFP market basket while modifying the objective function (for optimization) to maximize consumers' utility based on preferences for food items (rather than minimize the distance of the TFP market basket to current consumption). Accordingly, a demand model would describe consumer preferences (utility) and still specify various constraints in the optimization problem that require the TFP market basket to meet dietary requirements.[23] The stochastic production frontier model concept involves the development of an econometric model to describe the relationship between the composition of a market basket (quantities for each food and beverage modeling category) and its "healthfulness"—a production function. After using econometric modeling to relate food and beverage *inputs* to healthful diet *production*, one could calculate the most cost-efficient way to construct a TFP market basket that achieves a minimum healthfulness score.

Both econometric-based approaches are complex, and neither has been previously used to identify the lowest cost needed to acquire a practical and nutritious diet for the reference family. Although Chapter III of the Alternative Approaches report describes the two modeling approaches at a conceptual level (Jones et al. 2024), both approaches warranted additional research to assess whether either approach would lead to a feasible solution or whether existing modeling implementations could be adapted for the purpose of revaluating the TFP. For instance, the report did not recommend the class of demand models to use and did not provide other details, such as which data sources to use, whether to model the demands for individual foods or the demands for food composites, how to solve for a TFP market basket after estimating the econometric models, or how to require a healthy diet. Thus, to better understand the approaches and identify feasible options for the demand model and stochastic production frontier (henceforth SPF) model, we (1) reviewed the literature on estimating demand model systems and SPF models, (2) identified available programming packages for estimating the identified models, and (3) assessed the advantages and disadvantages of existing data sources.

We summarized the results of our initial assessment of potential econometric-based approaches in an implementation plan for CNPP's review and approval (Kranker 2024). We identified feasible and tractable demand and SPF approaches that aligned closely with the expert panelists' concept and could be implemented empirically with real datasets. We hypothesized that the demand system approach would be feasible to implement but would produce a TFP market basket similar to the basket CNPP previously produced with an optimization-based approach for the TFP, 2021 (CNPP 2021a). We also identified an approach for implementing an SPF model but raised concerns about using a log-linear SPF model to approximate the HEI score function—a function known to be nonlinear (CNPP 2023)—and substituting the HEI-2020 score for the age- and sex-specific nutritional guidance previously used to identify the TFP.

After conducting the initial assessment, we implemented both econometric-based approaches to reevaluate the TFP according to the plan. We also replicated the optimization-based approach that CNPP used to compute the TFP, 2021 (CNPP 2021a) and implemented a few alternatives and then conducted sensitivity analysis. Chapters 7 and 8 document the data and methods we used for implementing both econometric-

[23] A utility function expresses the relationship between consumers' utility and the quantities of each good they acquire, while an indirect utility function gives the consumers' maximum attainable utility when faced with a vector of goods' prices and fixed level of income (Mas-Colell, Whinston, and Green 1995, 50–57). Utility is a theoretical measure of consumer satisfaction. Market baskets that yield higher utility to a consumer would be chosen over baskets that yield lower utility, all else equal.

based approaches and our results. Appendix B provides results related to our replication and Appendix C through Appendix E present supplemental results.

As we mentioned in Chapter 1, we retained, to the extent possible, the same data sources and assumptions that had been used in the TFP, 2021 (CNPP 2021a; 2021b). Specifically, we (1) based food and beverage consumption data on the National Health and Nutrition Examination Survey (NHANES), What We Eat in America (WWEIA) Day-1 dietary recall data; (2) categorized foods and beverages into the same 95 TFP modeling categories and 45 combined modeling categories used in the TFP, 2021;[24] (3) re-used average food price data from the TFP, 2021 optimization model and used the same underlying data source for food code–level prices; and (4) reused the same nutritional and food group and practicality requirements when applicable. Use of a consistent set of data and assumptions enabled us to focus our feasibility assessment on the methodological aspects of revaluating the TFP. In other words, we were able to interpret differences in TFP market baskets as resulting from the new methods without confounding due to different data sources or assumptions. Of course, CNPP could consider using alternative data sources or assumptions if it decides to pursue using econometric approaches to reevaluate the TFP.

Another way that the econometric-based methods followed the TFP, 2021 approach was that we solved for a TFP market basket for each age-sex group, then aggregated the results for four age-sex groups together to obtain an alternative TFP market basket for the reference family of four. We fit the econometric models using data for a pooled sample of NHANES, WWEIA respondents in all age-sex groups, since the sample sizes in the NHANES, WWEIA data did not support estimation of the econometric models separately for each age-sex group. This is similar to the way that current U.S. consumption was calculated among the pooled NHANES, WWEIA sample in TFP, 2021 when determining the relative importance of food codes within each of the 95 modeling categories.

Among the econometric-based methods, we found that it **was feasible to implement the demand system-based approach** to reevaluate the TFP market basket (Chapter 7). However, the approach proved more complicated than the approach CNPP used for the 2021 TFP revaluation, and the differences between the two market baskets were modest overall. We found that the **SPF-based approach was not technically feasible**, in that it produced an empty market basket (quantities of foods and beverages and costs approached zero). As discussed in greater detail in Chapter 8, these results largely stem from the SPF model's failure to estimate (that is, predict) HEI scores accurately and precisely.

[24] The 45 combined modeling categories combine higher- and lower-nutrient density and higher- and lower-priced TFP modeling categories into aggregate categories (CNPP 2021a, app. 1).

7. Reevaluating the TFP using a demand system approach

In this chapter, we focus on the first of two econometric-based approaches for reevaluating the TFP—the demand system approach. We briefly discuss how the expert panelists originally conceived of using demand modeling to reevaluate the TFP and introduce demand system modeling in the context of this feasibility assessment. We then describe the data and methods used for estimating various demand systems and present the estimated demand systems. Finally, we discuss how we used the demand system model output to calculate a TFP market basket and present the results. Three appendices (Appendix C, Appendix D, and Appendix E) provide additional results for the reference family of four.

7.1. The expert panelists' concept: Using demand models to reevaluate the TFP

Chapter V of the Alternative Approaches report (Jones et al. 2024) reports how the expert panelists conceived of using demand models to reevaluate the TFP:

> *The expert panel discussed a demand model that maximizes utility based on preferences for food items subject to cost and nutrition constraints... Results from the demand model would be the diet that maximizes utility subject to constraints. The resulting as-purchased diet from [the model] would be used as the basis for the TFP market basket and associated cost... Using purchasing data, a demand model would have a utility function with parameters to translate food items purchased into utility, and a cost function based on prices of the purchased food items. The model could include constraints around nutrition, such as a minimum healthy eating index (HEI) score. Food items could be treated individually or combined into categories. The demand model assumes the consumer will maximize utility within any constraints. For example, if the food purchase data show that certain food items are frequently purchased, the model would assume these items provide a large amount of utility, and it would include them in the diets produced by the model. The nutrition constraints would prevent the model from selecting only commonly purchased items that collectively would not support a healthy diet. With these parameters in place, the model could determine what diets the consumer would choose, and then calculate the costs of those diets.*

We focused on turning the above conceptual plan into a tractable method for reevaluating the TFP. As mentioned in Chapter 6, development of the plan required identification of a specific demand modeling approach and formulation for computing an alternative TFP market basket (Kranker 2024).

7.2. Introduction to demand system modeling

Economists have a long history of estimating the demand for goods in markets. In a market with a variety of goods available to consumers, a **demand system** estimates the quantity of each good that each consumer chooses to purchase given the prices of each good, the person's level of income or expenditures, conditioning variables capturing the characteristics of the consumer (or region or time period), and an unobserved term that introduces heterogeneity across consumers.[25] Many demand system models include a utility function with parameters to translate the quantity of each good acquired into a utility and a cost function based on the prices of the acquired goods; consumers maximize their utility subject to a budget

[25] The inclusion of a variety of goods in the model distinguishes demand *system* models from single-good demand models. For example, in discrete choice demand models, consumers select exactly one of the goods available in the market (for example, Berry et al. 1995). We focus on demand system models because the TFP market basket must determine specific quantities for several food items or food groups.

constraint. (See footnote 23.) Demand estimation can pose a challenge because the prices of goods in a market can be affected by consumers' choices (endogenous) and the demand for an individual good depends on the prices of all goods in the market (Berry and Haile 2021).

For purposes of this feasibility assessment, we focus on two basic, readily available demand system modeling approaches: the **Cobb–Douglas demand system** and the **linear expenditure system (LES)**. Both models solve for the quantities of each good that the consumer acquires (or consumes), conditional on the prices faced by the consumer and total expenditures. The LES begins with consumers maximizing the following utility function:[26]

$$\max_{\boldsymbol{q}_i} u(\boldsymbol{q};\boldsymbol{\beta},\boldsymbol{\mu},\boldsymbol{\nu}) = \prod_{j=1}^{J}\left(q_{ij} - \left(\mu_j + \boldsymbol{\nu}_j\, \boldsymbol{z_i}\right)\right)^{\beta_j} \qquad 1$$

subject to

$$\sum_{j=1}^{J} p_j\, q_{ij} \le y_i \qquad \text{C.1.1}$$

$$0 \le q_{ig} \quad \forall\, g \qquad \text{C.1.2}$$

$$\sum_{j=1}^{J} \beta_j = 1 \qquad \text{C.1.3}$$

where q_{ig} is the quantity of good g acquired by consumer *i*, *j* indexes goods ($j = 1, 2, 3, \dots J$), p_g is the price of good g, y_i is the consumer's total expenditures on all the goods in the system being modeled, and $\boldsymbol{z}_i$ is a vector of consumer characteristics (such as consumer age and sex). The constraints require the total cost of the goods acquired to be non-negative and sum to total expenditures. The vectors $\boldsymbol{\beta}$ and $\boldsymbol{\mu}$ represent parameters to be estimated.[27] The $\boldsymbol{\beta}$ vector determines the consumer's preferences for each good—on the margin, goods with higher values of β_g increase the consumer's utility more than goods with lower values for β_g. Utility is unbounded, in that consumers receive ever-increasing utility as quantities q_{ig} approach infinity; the budget constraint (C.1.1) make large quantities infeasible and thus plays an important role in the LES approach. The consumer does not receive any utility from a good g unless the quantity acquired (q_{ig}) exceeds the value $\mu_g + \boldsymbol{\nu}_g\, \boldsymbol{z}_i$, which is usually called the subsistence (or committed) quantity that a consumer *must* purchase. The model captures heterogeneity across consumers by letting subsistence quantities vary based on consumer characteristics ($\boldsymbol{z}$) through the vector of coefficients $\boldsymbol{\nu}$. We estimate a Cobb–Douglas demand system (rather than an LES demand system) by setting $\boldsymbol{\mu}$ equal to zero in Equation 1. Setting $\boldsymbol{\nu}$ to zero results in demand system models without demographic adjustments.

With this demand system functional form, it is convenient to focus on the share of expenditures that consumers allocate to each good. We define the consumer's expenditure share for good g as $w_{ig} = q_{ig}\, p_g / y_i$. Solving the maximization problem analytically and assuming that utility is subject to random shocks (ε_i), yields the following expenditure-share function for each good:

$$w_{ig}(\boldsymbol{p}, y_i, \boldsymbol{z}_i; \boldsymbol{\beta}, \boldsymbol{\mu}, \boldsymbol{\nu}) = \frac{p_g\left(\mu_g + \nu_g\, \boldsymbol{z}_i\right)}{y_i} + \beta_g\left(1 - \sum_{j=1}^{J} \frac{p_j\left(\mu_j + \boldsymbol{\nu}_j\, \boldsymbol{z}_i\right)}{y_i}\right) + \varepsilon_{ig} \qquad 2$$

The term on the left captures the share of spending required to achieve the subsistence level. The term to the right (in parentheses) represents the proportion of expenditure that remains after meeting the subsistence

[26] This presentation of the LES and Cobb-Douglas demand systems closely follows documentation from StataCorp (2023a). The methods are attributed to Stone (1954).

[27] This report uses **bold** text to identify quantities that are vectors or matrices and non-bold text for scalars.

level for all other goods; allocating a share of β_g of this remaining expenditure on good g maximizes utility. The model proceeds by estimating a system of nonlinear equations, with one equation for each good, to solve for parameters $\boldsymbol{\beta}$, $\boldsymbol{\mu}$, and $\boldsymbol{\nu}$.[28] After estimating model parameters, we can predict budget shares ($\boldsymbol{w}_i$) and quantities ($\boldsymbol{q_i}$) for each good and the utility for any consumer $\left(u(\boldsymbol{q_i})\right)$, conditional on consumer's total expenditures (y_i), the consumer's characteristics ($\boldsymbol{z}_i$), and prices ($\boldsymbol{p}$).

Although a variety of more complex demand system models are available in the literature, we focused on the Cobb–Douglas and LES demand system approaches for two reasons. First, both approaches provide closed-form functional forms for calculating consumer's utility. Second, the assumed prices are exogenous. It is relatively uncommon to estimate demand systems with such a large number of goods. (In this context, J equals 95 or 45, depending on whether we use TFP modeling categories or combined modeling categories as inputs, respectively.) Given computational concerns about estimating the demand system, we selected a method that is more likely to be feasible to implement and less likely to produce unusual results. Other approaches that use different functional forms are possible but present greater feasibility challenges. The almost ideal demand system (AIDS) is used widely, but its functional form for computing consumers' utility and TFP market baskets is less convenient (Deaton and Muellbauer 1980). The Exact Affine Stone Index (EASI) demand system allows for endogenous total expenditures and prices by using an instrumental variables approach (Lewbel and Pendakur 2009). As discussed in Chapter 6, we aimed to align our data inputs closely with the TFP, 2021 (CNPP 2021a), which used national average food prices as an input, rather than the actual prices faced by each consumer. With national prices as the input, demand system modeling approaches with exogenous prices are a better fit for this analysis. If CNPP extends this work, it might consider more complex demand systems, such as EASI, that allow prices to vary across consumers and use instrumental variables to account for price endogeneity.[29]

7.3. Data sources

We briefly describe the data sources we used to implement the econometric-based approaches to reevaluate the TFP. As discussed in Chapter 6, we retained the same data sources that CNPP had used in the most recent revaluation of the TFP, 2021 to the extent possible.

7.3.1. TFP, 2021 optimization model input and output data

Along with the TFP, 2021 (2021a), CNPP published the input data and programming code that it used to implement the optimization-based approach for reevaluating the TFP (CNPP 2021b). These input files included:

1. Average prices for each of 95 TFP modeling categories and 45 combined modeling categories based on the USDA Purchase to Plate Price Tool, Information Resources Inc. (IRI) Retail Scanner (InfoScan) data (CNPP 2021a, p. 12-14),[30]

[28] Greene (1993, sec. 14.3) discusses the process for estimating the system of equations and computing standard errors. Imposing the constraint that the beta terms sum to one $\left(\sum_g \beta_g = 1\right)$ ensures that budget shares sum to 100 percent $\left(\sum_g w_g(\boldsymbol{p}, y_i) = 1\right)$.

[29] Extensions of EASI have been used to measure the demand for foods using large data sources (Zhen et al. 2014; Ferrier and Zhen 2017; Zhen et al. 2024)

[30] For more details about the food modeling categories, see Appendix 1 in the TFP, 2021 report (CNPP 2021a). CNPP assigned FNDDS food codes to 45 combined modeling categories, such as "cheese" or "dark green vegetables" or "mixed dishes-pizza." They subdivided food codes in some of the 45 combined modeling categories into higher- and lower- nutritional density groups, creating 65 intermediate categories. They also subdivided food codes in some of the 65 intermediate categories into higher- and lower-cost groups, creating the 95 TFP modeling categories.

2. Current consumption (means and standard deviations [SD]) for each age-sex group for each combined modeling category based on the 2015–2016 wave of the National Health and Nutrition Examination Survey (NHANES), What We Eat in America (WWEIA) Day 1 recall data (more details about the data below),
3. The nutrient composition of each TFP modeling category,[31]
4. Nutrient-specific lower and upper bounds for the minimum and maximum recommended consumption amounts of nutrients for each age-sex group,
5. Usual intake distributions for select FPED food groups and sodium for each age-sex group,
6. A starting value to use as a cost constraint for each age-sex group, which was set at $0.01 less than the cost of the TFP, 2021 market basket,
7. The Supplement to the TFP, 2021 data set published by CNPP, which mapped 3,072 individual FNDDS food codes into 65 intermediate categories (combined modeling categories separated by nutritional density) and provided an average price for each food code. The Purchase to Plate Price Tool does not provide price information for all FNDDS food codes reported in the NHANES, WWEIA Day 1 food recalls; this caused some issues with classifying food codes that we describe later in this section.

We used all these data files in our analyses and replicated several data processing steps from the TFP, 2021 GAMS programming code (for example, to build matrices with the nutrient and food group lower- and upper-bound requirements). Appendix B demonstrates that we successfully acquired the data to reproduce the TFP, 2021 market basket by benchmarking our results against the output data published in the TFP, 2021 supplemental files (CNPP 2021b), including:

1. The amount of food in the market basket solution for each TFP modeling category for each age-sex group
2. The cost of the market basket solution for each age-sex group
3. The nutrient composition of the market basket solution for each age-sex group

7.3.2. NHANES, WWEIA

We used the 2015–2016 wave of NHANES, WWEIA (NCHS 2020; 2021) dietary recall food intake data that CNPP previously used to create some of the input data files for the TFP, 2021 reevaluation. NHANES survey respondents are a nationally representative sample of individuals of all ages who reside in households. NHANES, WWEIA respondents reported the quantities of each food and beverage they consumed throughout a day, with foods and beverages recorded using FNDDS food codes. In the 2021 TFP reevaluation, food codes reported in the Day 1 recall data were classified into 95 TFP modeling categories and NHANES, WWEIA data were used to compute average, current consumption patterns (average quantities consumed in each category) among low-income respondents to the survey (CNPP 2021a, pp. 17–23).[32] Given that demand system modeling involves analyzing the choices of many consumers in a market, we were unable to use the aggregate data to implement the demand system modeling approach. We needed consumer-level food consumption data for this step. However, we still aimed to use the same underlying data from TFP, 2021 for the reasons discussed in Chapter 6.

[31] CNPP derived these data from the FNDDS (BHNRC 2024a) and Food Patterns Equivalents Database (FPED) (BHNRC 2024a; 2024b). The data for a TFP modeling category or combined modeling category was a weighted average of FNDDS codes assigned to the category.

[32] As we mentioned earlier, CNPP was unable to provide price information for FNDDS food codes reported in the Day 1 recalls. As a result, these items could not be matched to higher or lower cost categories. See Footnote 33 for more details.

Using the TFP, 2021 as a guide, we prepared the NHANES, WWEIA analysis as follows:

1. We subset the NHANES, WWEIA respondents who completed the WWEIA Day 1 food recall questionnaires, who were at least age 2 at the time of the survey, who did not report consuming human milk, were a member of a household with incomes less than or equal to 350 percent of the federal poverty level (FPL), and reported consuming at least one food or beverage in the 95 TFP modeling categories. Some NHANES, WWEIA respondents provided recalls for two days, but we only used the data corresponding to Day 1. The analyses in this report excluded children under 24 months to align with other analyses conducted for this project. A total of 6,105 out of 8,505 NHANES, WWEIA respondents met these criteria (Exhibit 13).

Exhibit 13. NHANES, WWEIA sample sizes before and after applying inclusion criteria

Step	Number of respondents	Number of respondent recall entries	Number of unique food codes	Number of unique respondent-food code combinations	Number of unique respondent-TFP modeling category combinations	Number of unique respondent-combined modeling category combinations
All NHANES respondents	9,971	—	—	—	—	—
Restrict to WWEIA Day 1 respondents	8,505	121,481	5,085	103,428	77,561	85,172
Restrict to overall analysis population[a]	6,106	84,901	4,476	73,792	56,411	61,825
Remove excluded FNDDS food codes[b]	6,105	74,011	4,366	67,443	56,411	56,763
Remove price outlier FNDDS food codes[c]	6,105	72,117	4,187	65,668	56,411	55,527
Final food recall-level dataset	6,105	72,117	4,187	65,668	58,896	55,527

Source: Mathematica tabulations of data from NHANES, WWEIA data, 2015-2016 wave.

[a] We required respondents be at least age 2 at the time of the survey, not report consuming human milk, and be a member of a household with incomes less than or equal to 350 percent of the federal poverty level (FPL).

[b] Human milk, baby food, formula, alcohol, powder mixes, and water (CNPP 2021a, 15).

[c] Food codes that were price outliers within their TFP modeling category were identified in TFP, 2021 (CNPP 2021a, 21).

FNDDS = Food and Nutrient Database for Dietary Studies; NHANES = National Health and Nutrition Examination Survey; WWEIA = What We Eat in America.

2. We mapped the FNDDS food codes that respondents reported in the Day 1 recall data to the 95 TFP modeling categories and 45 combined modeling categories.[33]

3. We computed the total quantity of food and beverages (in grams) in each TFP modeling category and each combined modeling category that each respondent consumed on Day 1.

[33] Data files provided by CNPP classified FNDDS food codes into one of the 65 intermediate modeling categories described in footnote 30. If the TFP modeling category (which identifies whether the food code was higher- or lower-price) was not available, we assigned the food code to the higher-cost of the two possible food TFP modeling categories. The WWEIA, NHANES respondents reported consuming food codes with known TFP modeling categories (that is, food codes with prices) more frequently than food codes for which we had to make this imputation; food codes with TFP modeling categories represented about 90.6 percent of the average respondent's estimated food expenditures. In sensitivity analyses, not presented here, we found that demand system modeling results were generally similar if we excluded food codes without prices from the dataset before analysis.

4. We computed an estimate of the total expenditure on each TFP modeling category and each combined modeling category for each respondent. The NHANES, WWEIA data do not capture the cost of acquiring foods and beverages for respondents, so we computed expenditure amounts by multiplying the quantity (in 100g) of each FNDDS food code reported in the Day 1 food recall data by the average price ($ per 100g) for the corresponding TFP modeling category. CNPP compiled these average prices for the TFP, 2021 analyses (see Section 7.3.1). Next, we calculated the sum of costs across FNDDS food codes that each respondent had reported eating on Day 1.
5. We computed the share of total expenditures allocated to each TFP modeling category and each combined modeling category for each respondent. The expenditure share for a category was defined as the expenditures for the category divided by total expenditures.

For the second and fourth steps, CNPP provided Mathematica with two intermediate data files that it had used to create the input files (Section 7.3.1). One file mapped 8,950 FNDDS food codes to 65 intermediate modeling categories (the 45 combined modeling categories subdivided into high- and low-nutrient density categories when applicable) and identified 291 food codes that CNPP had excluded from previous analyses (price outliers plus human milk, baby food, formula, alcohol, powder mixes, and water). A second file provided analytic weights that CNPP used to aggregate FNDDS food code prices to the TFP modeling category level.[34]

7.4. Demand system estimation

We estimated the demand system models with the "`demandsys`" command in Stata (StataCorp 2023a). The input data for estimation were a single analytic file with one observation per respondent in our analytic population and variables for each respondent's (1) total food expenditures in Day 1, y_i; (2) budget share allocated to each TFP modeling category (95 columns) or combined modeling category (45 columns), $\boldsymbol{w}_i$; (3) age-sex group, age (in years), and sex, $\boldsymbol{z}_i$; and (4) survey weights, sampling strata, and primary sampling units to account for NHANES' complex survey design. It also included the average price for each TFP modeling category, $\boldsymbol{p}$.[35]

We estimated several alternative demand systems:[36]

1. LES and Cobb-Douglas demand systems (Section 7.2)
2. With TFP modeling categories (95 goods) or with combined modeling categories (45 goods)
3. With or without demographic adjustments for age and sex

After estimating the demand systems, we stored the estimated model coefficients $(\hat{\boldsymbol{\beta}}, \hat{\boldsymbol{\mu}}, \hat{\boldsymbol{\nu}})$ and other model output (such as standard errors). We also computed the utility for each respondent by using the respondent's reported food and beverage consumption $(u(\boldsymbol{q_i}))$ and predicted food and beverage consumption $(u(\boldsymbol{q}_i^*))$. For the latter, we computed the optimal quantities $(\boldsymbol{q}_i^*)$ conditional on each

[34] We confirmed that NHANES, WWEIA Day 1 respondent-level data aligned with the input files (listed in Section 7.3.1) when we applied the FNDDS food code weights that CNPP provided for the respondent-level data.

[35] Using the same prices for respondents—that is, prices that are neither heterogeneous nor endogenous—is consistent with the approach taken in the 2021 TFP reevaluation. In sensitivity analyses, not presented here, we used average FNDDS food-code level prices for each food code reported by a respondent to compute expenditure shares for each modeling category. With this approach, the average price for each food code remained constant across respondents but the average price "paid" by respondents for a modeling category can vary across respondents because they report consuming different FNDDS food codes. These prices were strongly correlated with the prices in the main approach but we preferred using average prices to estimate the demand system because those are the prices that would be used to compute TFP market baskets by using the steps outlined in Section 7.6.

[36] We also conduced sensitivity analyses focused on missing prices, discussed previously in footnotes 33 and 35.

respondent's total daily food expenditures (y_i) and demographics ($\boldsymbol{z}_i$), given the estimated coefficients from the demand system.

7.5. Estimated demand system coefficients

After estimating the demand systems and reviewing the results, we found that some of the demand systems produced reasonable and plausible coefficients while others did not.

1. **Unadjusted Cobb-Douglas demand systems.** The Cobb-Douglas demand system without demographic adjustments was the simplest demand system that we estimated. It was feasible to estimate the demand system with the 95 TFP modeling categories or the 45 combined modeling categories, and in both cases the values of $\hat{\beta}_g$ fell within the expected range and demonstrated plausible variation in preferences across food categories (Exhibit 14). In a Cobb-Douglas demand system without demographic adjustments, the subsistence quantities were zero for all food categories (Exhibit 15), so consumers could begin receiving positive (rather than zero) utility from a good as soon as they allocate positive (non-zero) shares of their budget to that category (Exhibit 16, right panel). In models without demographic adjustment, all age-sex groups had the same preferences, and the utility-maximizing bundle of goods differed across consumers only because they had different total food expenditures (y_i). We tried to use the model coefficients to calculate the utility for all NHANES, WWEIA respondents; however, none of the respondents consumed foods and beverages in all 95 modeling categories (in a single day); therefore, the utility we calculated for them was zero (Exhibit 16, left panel).
2. **Unadjusted LES demand systems.** Estimating the LES without demographic adjustments inexplicably resulted in some food categories exhibiting very large values of $\hat{\mu}_g$, which governs the subsistence quantities for each food category (Exhibit 14).[37] We did not consider these large coefficients to be plausible. With these large values for μ_g, daily total expenditures needed to achieve subsistence for respondents in our sample could be no less than $40.91 in models with the 95 TFP modeling categories or $130.36 in models with the 45 combined modeling categories (Exhibit 15). Average daily total expenditures fell below $7 among NHANES, WWEIA respondents in our sample, and no respondents had sufficient daily total expenditures to afford subsistence quantities. As a result, all NHANES, WWEIA respondents would fail to meet the subsistence quantities and receive positive (non-zero) utility with unadjusted LES demand system (Exhibit 16).
3. **Adjusted Cobb-Douglas demand systems with combined modeling categories.** It was feasible to estimate the adjusted Cobb-Douglas demand system with 45 combined modeling categories. The estimated $\hat{\beta}_g$ coefficients for this demand system fell within the expected range, with plausible variation across food categories (Exhibit 14). The daily expenditure level required to achieve the subsistence quantity levels varied across age-sex groups but never exceeded $0.05 per day. The expenditure levels needed to acquire the subsistence quantities also fell below the total food and beverage expenditures for all NHANES, WWEIA respondents (Exhibit 15). Therefore, all respondents could have allocated sufficient shares of their budget to each combined modeling category to achieve the subsistence level for all food categories and thus receive positive utility according to this demand system (Exhibit 16). The predicted utility levels across respondents exhibited substantial variation, resulting from differences in expenditures (which determine the quantities affordable given the budget constraint) and demographics (which determine preferences).

[37] For both models, Stata's model convergence criteria were met at both stages of model estimation (nonlinear least squares and feasible generalized nonlinear least square). However, the standard errors for some coefficients were missing, which can sometimes indicate that the iterative estimation procedure ran into numerical issues.

4. **Other adjusted demand systems.** We originally intended to adjust for respondents' age-sex groups by using 14 binary variables indicating the age-sex group of each respondent (as in the above discussion). Such a demographic adjustment proved infeasible with the TFP modeling categories.[38] We tried adjusting for age (in years) and sex (binary variable) as an alternative and did obtain estimated coefficients for the demand system model. However, the estimated coefficients from the other demand systems (similar to the unadjusted LES models) involved subsistence quantities that were infeasible to purchase with realistic levels of daily total expenditures. All or two-thirds of respondents could not obtain positive utility with the other demand systems when we estimated the demand systems with TFP modeling categories or combined modeling categories, respectively (Exhibit 16 and Exhibit 15), because the daily total expenditures required to purchase the subsistence quantities exceeded respondents' daily total expenditures. The Cobb-Douglas demand system with demographic adjustments for age (in years) and sex ran into numerical issues and unexpectedly returned negative β_g coefficients, implying that the consumer receives positive utility even if they have zero consumption of an item.[39]

After reviewing the above results, we determined that **the Cobb-Douglas models with combined modeling categories and demographic adjustments for age- sex group produced the best demand system for reevaluating the TFP**. We selected this adjusted Cobb-Douglas model for the next step of our analyses, which used the demand system's utility function to compute the TFP market basket (Section 7.6). The adjusted Cobb-Douglas model was the only model that (1) allowed preferences to vary (plausibly) across age-sex groups and (2) had subsistence quantities that were feasible for consumers to achieve at plausible levels of daily total expenditures. In Exhibit 17, we present the estimated coefficients from this demand system, namely the values of $\hat{\boldsymbol{\beta}}$ and the values of $\hat{\boldsymbol{\mu}} + \hat{\boldsymbol{\nu}}\, \boldsymbol{z}$ for the four age-sex groups comprising the reference family of four. We can use these coefficients and Equation 1 to compute utility for any age-sex group given a set of combined modeling group quantities ($\boldsymbol{q}$).

[38] As we mentioned above, estimating these adjusted demand systems with 95 goods introduced computational challenges. In addition to simply being computationally intensive, the estimation procedure exceeded the maximum limit on the number of allowed variables by Stata. If J is the number of goods and K is the number of demographic covariates, the LES estimation requires $J \times 2 + 1 + K$ variables as inputs (not including any respondent identifiers and weights) and temporarily creates an additional $J \times \left((J - 1) + J + J \times K\right)$ variables during estimation. A model for 95 goods with 15 demographic exceeds Stata MP 18.5's hard limit of 120,000 variables in memory.

[39] Future work could attempt to estimate a separate LES demand system model for each age-sex group, rather than including age-sex groups as covariates in the model. This approach would let all model parameters vary across age-sex groups. Further, subsistence levels would be non-negative in Cobb-Douglas models without demographic adjustments ($\boldsymbol{\mu} = \boldsymbol{\nu} = \mathbf{0}$). However, it could prove difficult to estimate with sample sizes ranging from 128 to 1,029 respondents, depending on the age-sex group.

Exhibit 14. Minimum, median, and maximum coefficients using alternative demand systems.

Demand system	Demographic adjustment	β_g			μ_g			ν_{gk}		
		Min.	Median	Max.	Min.	Median	Max.	Min.	Median	Max.
95 TFP modeling categories										
Cobb-Douglas	Without demographic adjustment	0.000205	0.00753	0.0451	0	0	0	—	—	—
Cobb-Douglas	Adjusted for sex and age (in years)[a]	−0.00447	0.00624	0.0613	0	0	0	−0.0341	≈ 0	0.0456
Linear expenditure system	Without demographic adjustment	−0.00224	0.00707	0.0591	−0.495	0.476	13.3	—	—	—
Linear expenditure system	Adjusted for sex and age (in years) [a]	−0.00224	0.00708	0.0590	−1.08	−0.00271	1.35	−1.18	0.00926	1.26
45 combined modeling categories										
Cobb-Douglas	Without demographic adjustment	0.000969	0.0130	0.0932	0	0	0	—	—	—
Cobb-Douglas	Adjusted for age-sex groups	0.00107	0.0171	0.0905	0	0	0	−0.0547	0	0.0925
Linear expenditure system	Without demographic adjustment	0.00107	0.0126	0.106	0.157	3.01	69.1	—	—	—
Linear expenditure system	Adjusted for age-sex groups	0.000919	0.0126	0.105	−35.9	−1.68	−0.0585	−50.4	1.06	122

[a] Demographic adjustment by age-sex group was infeasible. See the text for more information.

Exhibit 15. Expenditures required to achieve subsistence quantities for NHANES, WWEIA respondents using alternative demand systems

Demand system	Demographic adjustment	Mean	Standard deviation	Min.	Median	Max.
95 TFP modeling categories						
Cobb-Douglas	Without demographic adjustment	$0.00	$0.00	$0.00	$0.00	$0.00
Cobb-Douglas	Adjusted for sex and age (in years)[a]	−$0.03	$0.04	−$0.08	−$0.03	$0.03
Linear expenditure system	Without demographic adjustment	$40.91	$0.00	$40.91	$40.91	$40.91
Linear expenditure system	Adjusted for sex and age (in years)[a]	$79.44	$55.83	$4.60	$69.07	$184.77
45 combined modeling categories						
Cobb-Douglas	Without demographic adjustment	$0.00	$0.00	$0.00	$0.00	$0.00
Cobb-Douglas	Adjusted for age-sex groups	$0.02	$0.02	−$0.05	$0.02	$0.05
Linear expenditure system	Without demographic adjustment	$130.36	$0.00	$130.36	$130.36	$130.36
Linear expenditure system	Adjusted for age-sex groups	−$16.50	$70.43	−$171.90	−$10.50	$171.15

Note: In Cobb-Douglas and linear expenditure demand systems, the consumer does not receive any utility from a good unless the quantity acquired exceeds a minimum value, which is usually called the subsistence (or committed) quantity that a consumer must purchase. (Negative values are feasible in the model due to the demographic adjustments; the negative values imply that the consumer can obtain positive utility with zero or positive quantities of the good.) We then multiplied the subsistence quantities by average prices and then, for each respondent, calculated the sum of these subsistence expenditures across all goods in the system. Then we summarized the distribution of the total expenditures to achieve the subsistence quantities across all NHANES, WWEIA respondents.

[a] Demographic adjustment by age-sex group was infeasible. See the text for more information.

NHANES = National Health and Nutrition Examination Survey; WWEIA = What We Eat in America.

Exhibit 16. Calculated and predicted utility levels for NHANES, WWEIA respondents using alternative demand systems

Demand system	Demographic adjustment	Utility calculated using reported consumption (Day 1)			Utility calculated using predicted consumption		
		Mean	Standard deviation	Percentage nonmissing	Mean	Standard deviation	Percentage nonmissing
95 TFP modeling categories							
Cobb-Douglas	Without demographic adjustment	0	0	100	0.0934	0.0655	100
Cobb-Douglas	Adjusted for sex and age (in years)[a]	—	—	0	—	—	0
Linear expenditure system	Without demographic adjustment	—	—	0	—	—	0
Linear expenditure system	Adjusted for sex and age (in years)[a]	—	—	0	—	—	0
45 combined modeling categories							
Cobb-Douglas	Without demographic adjustment	0	0	100	0.235	0.197	100
Cobb-Douglas	Adjusted for age-sex groups	0	0	5.21	0.229	0.178	100
Linear expenditure system	Without demographic adjustment	—	—	0	—	—	0
Linear expenditure system	Adjusted for age-sex groups	4.25	11.2	57.0	1.57	2.30	67.8

[a] Demographic adjustment by age-sex group was infeasible. See the text for more information.

Exhibit 17. Demand system coefficients for the selected demand system

Combined modeling category	β_g	$\mu_g + \nu_g z_i$			
		Child 6–8	Child 9–11	Male 20–50	Female 20–50
Dairy					
Cheese	0.0172	0.00335	0.00650	0.00536	0.00588
Milk and yogurt	0.0320	0.0527	0.0280	−0.00878	−0.00548
Meat, poultry, seafood, eggs					
Meat	0.0491	−0.0203	−0.00999	0.0121	−0.00519
Poultry	0.0266	0.0231	0.0204	0.0313	0.0257
Seafood	0.0205	−0.0115	−0.00720	0.00439	0.00839
Eggs	0.00968	−0.00534	−0.00224	−0.00177	−0.000544
Cured meat	0.0287	0.00683	0.00892	0.0102	0.00151
Nuts and seeds, soy products					
Nuts and Seeds	0.0114	−0.00123	−0.00766	−0.00283	0.0000797
Nut and seed butters	0.00107	−0.0000368	−0.000603	−0.000116	0.0000847
Processed soy products	0.00242	−0.00200	−0.00103	−0.000206	−0.000440
Mixed dishes					
Mixed Dishes - Eggs	0.00586	−0.00228	0.000737	0.000243	0.00295
Mixed Dishes - Vegetables	0.0285	−0.0155	−0.00831	−0.0100	−0.00424
Mixed Dishes - Meat-Poultry-Seafood	0.0691	−0.0295	−0.0245	−0.0150	−0.0136
Mixed Dishes - Grain based	0.0607	0.0329	0.0424	0.0567	0.0389
Mixed Dishes - Pizza	0.0212	0.0265	0.0330	0.0229	0.00843
Mixed Dishes - Sandwiches	0.0372	0.0374	0.0277	0.0607	0.0276
Mixed Dishes - Soups	0.0373	−0.0193	−0.0177	−0.0196	−0.0137
Mixed Dishes - Beans-peas-lentils	0.00212	−0.000000881	−0.000697	0.000996	0.000809
Grains and cereals					
Grains - rice pasta cooked grains breads	0.0500	−0.00529	−0.0151	−0.00626	−0.00940
Biscuits-muffins-quick breads	0.0146	0.00821	0.00731	−0.00602	−0.00408
Breakfast cereals	0.0197	0.00653	0.00659	−0.00446	−0.00471
Snack foods and sweets					
Tortilla-corn-other chips	0.00360	0.0130	0.0178	0.00501	0.00640
Popcorn	0.00165	0.00187	0.00373	0.00108	0.00132
Pretzels-snack mix	0.00442	−0.00144	0.000493	−0.00220	−0.00237
Crackers	0.00492	0.00800	0.00678	−0.000954	−0.0000648
Snack-Meal Bars	0.00197	0.00368	0.00453	0.00480	0.00580
Sweet bakery products	0.0736	−0.0188	−0.0242	−0.0458	−0.0347
Candy	0.0151	0.00720	−0.000294	−0.00712	−0.00350
Other Desserts	0.0303	−0.00894	−0.00682	−0.0213	−0.0171
Sugars	0.00526	0.00267	0.000389	−0.00137	−0.00193

Combined modeling category	β_g	$\mu_g + v_g z_i$			
		Child 6–8	Child 9–11	Male 20–50	Female 20–50
Fruits and fruit juice					
Fruit	0.0905	−0.0198	−0.0296	−0.0547	−0.0420
100 percent fruit juice	0.0210	0.00239	−0.00268	−0.00482	−0.00797
Vegetables					
Red orange vegetables	0.0239	−0.0164	−0.0170	−0.0165	−0.00824
Dark green vegetables	0.00975	−0.00552	−0.00351	−0.00227	0.00788
Other vegetables and vegetable combinations	0.0226	−0.0161	−0.0154	−0.00529	0.00459
Starchy vegetables	0.00741	−0.00102	−0.000782	−0.00278	0.000680
Potatoes	0.0144	0.00951	0.00636	0.00566	0.00518
Beans - peas - lentils	0.00463	−0.00271	−0.00228	−0.00147	0.000578
Beverages					
Fruit drinks	0.00622	0.0167	0.0119	0.00293	0.00190
Other beverages	0.0171	−0.0142	−0.00757	−0.00850	−0.00664
Soft drinks	0.0213	0.00917	0.0134	0.0462	0.0358
Coffee and Tea	0.0506	−0.0452	−0.0401	−0.0173	−0.00929
Fats, oils and condiments					
Butter and animal fats	0.00350	−0.00242	−0.00263	−0.00269	−0.00233
Margarine and oils	0.0146	−0.00895	−0.00812	−0.00549	0.000393
Condiments and Sauces	0.00679	0.00212	0.00890	0.00518	0.00651

Note: These results are based on a Cobb-Douglas demand system model with combined modeling categories and demographic adjustments for age- sex group. Ten other age-sex groups were included in the demand system, but the values of $\mu_g + v_g z_i$ are not presented in this table for those groups.

7.6. Using the demand system to compute an alternative TFP market basket

The expert panelists envisioned that the estimated parameters of the demand system could identify combinations of food items that maximize utility, conditional on any constraints imposed by the research team—for example, meeting nutrient, food group, and practicality constraints or achieving a minimum HEI score. Following this conceptualization, the natural step was to modify the consumer's problem (Equation 1) to require the consumer to acquire a healthy diet according to the nutrition and food group and practicality constraints required for the TFP, 2021 market basket (CNPP 2021a, app. 3).[40] Using the estimated coefficients from Exhibit 17 ($\widehat{\boldsymbol{\beta}}$ and $\widehat{\boldsymbol{\mu}}$) and adding these additional constraints results in the following consumer choice problem:

$$\max_{\boldsymbol{q}_i} u(\boldsymbol{q};\boldsymbol{\beta},\boldsymbol{\mu},\boldsymbol{\nu}) = \prod_{j=1}^{J}\left(q_{ij} - \left(\hat{\mu}_j + \hat{\boldsymbol{\nu}}_j\, \boldsymbol{z_i}\right)\right)^{\hat{\beta}_j} \qquad 3$$

$$\text{subject to} \qquad \sum_{j=1}^{J} p_j q_j \le y_i^* \qquad \text{C.3.1}$$

$$0 \le q_g \quad \forall\, g \qquad \text{C.3.2}$$

$$D_k^{LB} \le \sum_{j}^{J} q_j d_{j,k} \qquad \text{C.3.3}$$

$$F_l = \sum_{j=1}^{J} q_j f_{j,l} \quad \forall\, l \qquad \text{C.3.4}$$

$$Q_g^{LB} \le q_g \le Q_g^{UB} \quad \forall\, g \qquad \text{C.3.5}$$

Here we define the parameters identically to those in Equation 1; $d_{g,k}$ is the amount of nutrient k in one unit of modeling category (good) g; $f_{g,l}$ is the amount that one unit of food in modeling category g contributes to a food pattern modeling food group or subgroup l (for example, Dark-green vegetables); D_k^{LB} and D_k^{UB} are nutrient recommendation lower and upper bounds for nutrient k, respectively; F_l is the recommended food group or subgroup consumption in the Dietary Guidelines for Americans (USDA and DHHS 2020) Healthy U.S.-Style (HUSS) Dietary Pattern (for example, two cup equivalents per week of Dark-green vegetables); and Q_g^{LB} and Q_g^{UB} are minimum and maximum amounts imposed on the market basket for practicality.[41] In these equations, y_i^* represents the cost of the TFP market basket for the respective age-sex group. The data to implement these constraints come from CNPP (2021b), as described in Section 7.3.1.

As far as we understand, the approach outlined above is consistent with the expert panelists' conceptualization of this alternative approach. The one remaining question was how to compute the cost of the market basket, represented by y_i^* in Constraint C.3.1. The consumer's problem is infeasible at low expenditure levels. Our main approach to determining y_i^* was to attempt to solve Equation 3 at $y = \$0.01$, then incrementally increase y by \$0.01 until we arrived at the lowest-cost feasible solution. We also found it

[40] When implementing the demand system-based approach, we followed the expert panelists' proposed approach. We did not attempt to address any conceptual concerns arising from (1) estimating the demand system coefficients among consumers who were *not* constrained to eat healthy diets and (2) adding the nutrient, food group, and practicality constraints to the consumer's problem without re-estimating the demand system coefficients. Extrapolating the utility function coefficients estimated with unconstrained consumers to constrained consumers implicitly assumes that the two types of consumers have the same utility functions.

[41] The HUSS Dietary Pattern food-group and -subgroup limits can alternatively be introduced as upper and lower bounds (CNPP 2021a, app. 2). Q_g^{LB} and Q_g^{UB} can be set to zero or infinity, respectively, when a TFP modeling category does not have practically constraints.

more convenient to maximize the logarithm of utility than to maximize utility directly, which does not affect maximization. With these two additions, we can rewrite Equation 3 as follows:

$$\min_{\boldsymbol{q}_i} \sum_g p_g \, q_g \qquad 4$$

where

$$\boldsymbol{q}_i = \operatorname{argmax} \log u(\boldsymbol{q_i}; \hat{\boldsymbol{\beta}}, \hat{\boldsymbol{\mu}}, \hat{\boldsymbol{\nu}}) = \operatorname{argmax} \sum_{j=1}^{J} \hat{\beta}_j \left(q_{ij} - \left(\hat{\mu}_j + \hat{\boldsymbol{\nu}}_j \, \boldsymbol{z_i} \right) \right) \qquad \text{C.4.1}$$

and subject to constraints C.3.2 through C.3.5

and

$$100 \sum_{j=1}^{J} p_j \, q_j \in \mathbb{Z} \qquad \text{C.4.2}$$

where the last row imposes a requirement that the market basket cost, in cents, is an integer ($\mathbb{Z}$ is the set of real integers).

We solved Equation 4 analytically by using disciplined convex programming (DCP), specifically the `cvxr` package for the R programming language (Fu et al. 2017; Fu, Narasimhan, and Boyd 2020). DCP is an approach for solving least squares, linear, and quadratic programming problems (Boyd and Vandenberghe 2004; Diamond 2013) with the following advantages: (1) DCP makes it is easy to write an optimization problem in a natural, mathematical syntax; (2) writing the problem with DCP ensures that a problem is convex, or DCP-compliant; (3) the packages convert the convex problem to a standard form that can be solved with a variety of open-source and commercial solvers;[42] (4) solutions are obtained efficiently; and (5) DCP is implemented in several modern, widely used, accessible, open-source programming languages (including R).[43] When we solved Equation 4, we computed the consumers' optimal quantities, $\boldsymbol{q}^*$, conditional on the constraints—a TFP market basket—and TFP market basket cost (y^*) separately for each age-sex group. We computed the sum of the quantities and costs across the four age-sex groups corresponding to the reference family (as CNPP did to compute the TFP, 2021 market basket). After solving for the alternative TFP market basket, we also computed other quantities of interest, such as the HEI-2020 score, and compared our solution to the TFP, 2021 market basket.

Equation 4 closely resembles the optimization problem CNPP solved to compute the TFP, 2021 market basket (CNPP 2021a, app. 2; 2021b). Using the notation from above, we can write the optimization problem from TFP, 2021 as follows:

[42] We used the open-source solvers CLARABEL, ECOS, and SCS in CVXR. These solvers are from the `clarabel`, `ECOSolveR`, `scs`, and `Rglpk` packages for the R programming language (Domahidi et al. 2013; Fu and Narasimhan 2015; O'Donoghue et al. 2016; Schwendinger, O'Donoghue, and Narasimhan 2016; Fu et al. 2017; Narasimhan et al. 2023; Goulart and Chen 2024).

[43] The TFP, 2021 optimization problem was solved by using GAMS (GAMS Software GmbH 2024a; CNPP 2021b). However, GAMS could be a barrier to the public's use of CNPP's published code and data to reproduce the TFP, given it is a specialized programming language and costs $3,500 to $7,000 (GAMS Software GmbH 2024b). CNPP preferred the R programming language, but we alternatively could have solved Equation 3 by using Julia (Udell et al. 2014) or Python (Diamond and Boyd 2016).

$$\min_{\boldsymbol{q}_i} \sum_g p_g \, q_g \qquad 5$$

where
$$\begin{aligned}\boldsymbol{q}_i &= \operatorname{argmin} d(\boldsymbol{q_i}) \\ &= \operatorname{argmin} \sum_{j=1}^{J} \frac{p_j \, \bar{q}_j}{\sum_k p_k \bar{q}_k} \left(q_j - \bar{q}_j\right)^2 \end{aligned} \qquad \text{C.5.1}$$

and subject to constraints C.3.2 through C.3.5

and
$$100 \sum_{j=1}^{J} p_j \, q_j \in \mathbb{Z} \qquad \text{C.5.2}$$

where $\bar{q}_j$ is the average observed consumption of combined modeling category g from WWEIA, NHANES Day 1 dietary recall data for respective age-sex groups. We refer to $d(\boldsymbol{q}_i)$ as the distance between the TFP market basket and current consumption.

In Appendix B, we demonstrate that we correctly implemented the nutrient, food group, and practicality constraints by reproducing the TFP, 2021 market basket—that is, by independently solving Equation 5 with DCP methods.

A comparison of Equations 4 and 5 readily demonstrates the similarity between the two approaches. Both impose the same set of nutrient, food group, and practicality constraints on the consumer (constraints C.3.2 through C.3.5) and minimize the cost of the market basket to the nearest $0.01. Further, both equations use the 45 combined modeling categories as the key variable in the objective function, rather than the 95 TFP modeling categories (another factor that contributed to our choice of demand systems in Section 7.5). The main difference lies in the "inner" optimization step, which functionally allows the model to converge on an integer solution.[44] Equation 4 achieves convergence by maximizing consumer utility, while Equation 5 does so by minimizing the distance from the market basket to current consumption. Both objective functions are based on the same data source (NHANES, WWEIA Day 1 recall data), and the demand system's utility function—$u\left(\boldsymbol{q_i}; \widehat{\boldsymbol{\beta}}, \widehat{\boldsymbol{\mu}}, \widehat{\boldsymbol{v}}\right)$ in Equation 4—was designed to model consumer preferences as revealed through the food and beverage consumption reported by respondents—$\bar{\boldsymbol{q}}$ in Equation 5.

Recognizing the similarity of the two approaches, and that the nutrient, food group, and practicality constraints (C.3.3 through C.3.5) govern the solution to both problems we hypothesized that the demand system approach would produce a TFP market basket cost (y^*) and quantities (q_i) similar to the TFP, 2021 market basket (Chapter 6 and Kranker 2024). However, some modest differences could arise for two reasons. First, the requirement that the market basket cost must be an integer (in cents) allows for some minor differences in market basket quantities. If the lowest feasible market basket cost that meets the nutrient, food group, and practicality constraints lies in the interval $(y_i^* - 0.01, y_i^*]$, then use of different objective functions—that is, maximizing utility versus minimizing the distance to current consumption—will cause a small amount of food expenditure (less than $0.01 per day) to be allocated differently under the two approaches. Second, the numerical solver will allocate expenditures to each combined modeling category slightly larger than $\left(\hat{\mu}_j + \hat{v}_j \, \boldsymbol{z_i}\right)$ to avoid solutions whereby the logarithm of utility equals minus infinity. The subsistence quantities in the demand system equation could be higher than the quantities from the TFP, 2021 market basket solution, in turn increasing the cost of the demand system–based TFP market basket.

[44] Without C.4.1 or C.5.1, the models would not converge, because the minimum feasible market basket cost (subject to constraints C.3.3 through C.3.5) is rarely, if ever, an integer (in cents).

7.7. The demand system–based TFP market basket

As we hypothesized, the demand system–based TFP market basket for the reference family was fairly similar to the TFP, 2021 market basket, although there were some modest differences in the quantities of foods and costs allocated to specific TFP modeling categories. Compared to the previous TFP, 2021 market basket, the demand system-based basket allocated an additional $0.21 to mixed dishes and $0.14 to snack foods, while allocating $0.06 to $0.08 less to each of dairy; meat, poultry, seafood, eggs; and grains and cereals (Exhibit 18). The total quantity of eggs decreased by 6 percent while soy products increased by 13 percent. More detailed results can be found in Appendix C (Appendix Exhibit C.1 and Appendix Exhibit C.2). These small tradeoffs in the composition of the market basket were expected. The demand system approach is designed to avoid solutions wherein a combined modeling category has a quantity of zero (or below the subsistence quantity). Increasing the quantities of some categories from zero to a positive amount would require small decreases in other combined modeling categories' quantities because the nutrient, food group, and practicality constraints bounded the total energy of the market basket and other measures of nutrient content.

At $27.66 per day for the reference family, the cost of the TFP market basket was $0.06 higher than that of the TFP, 2021 market basket (Exhibit 19).[45] This small increase was in line with expected levels based on the coefficients in the demand system model governing subsistence quantities as reported in Section 7.5.

Our summary statistics reveal some additional small changes in the composition of the market basket. The aggregate measure of distance from current consumption ($d(\boldsymbol{q})$) increased by about 5 percent (from 5.857 to 6.141), indicating that the demand system–based market basket was less similar to current consumption than to the TFP, 2021 market basket. The average HEI-2020 score for the market basket across the four age-sex groups in the reference family increased slightly (from 94.0 to 94.7). By two measures (Gini impurity and entropy), there was not a meaningful change in the concentration of expenditure shares in specific modeling categories. In both approaches, the resulting market baskets exhibit similar degrees of heterogeneity across modeling categories; that is, expenditure shares are diversely spread across modeling categories, and no single modeling category dominates the market basket.[46]

Unsurprisingly, given that the nutrient and food group constraints govern the nutritional content of the market basket, the market baskets produced by the two approaches had generally similar nutritional content (Exhibit 20). The total energy content of the diet (kcal), dietary fiber, vitamin D, and potassium were all similar in the two market baskets. The demand system–based market basket exhibited modestly lower levels of calcium, iron, folate, sodium, and saturated fats than did the TFP, 2021 market basket, while calories from added sugars were modestly higher with the demand system–based approach.

[45] Appendix D isolates the effect of the demand system's subsistence quantities have on the cost of the market basket. These quantities increase total expenditures by about $0.0609 in total for the reference family of four.

[46] The Gini impurity and entropy measures are defined as $1 - \sum_g w_g^2$ and $-\sum_g w_g \log(w_g)$, respectively. The lowest possible score (0) is given to market baskets where only one food modeling category has nonzero expenditures. Higher scores (up to 1) are awarded as expenditure shares are spread more equally across the food modeling categories.

Exhibit 18. The demand system–based TFP market basket: Aggregate modeling categories

Category	Quantities (100-gram units)		Costs ($ per day)		Expenditure shares (%)	
	TFP, 2021 (reproduce results)	Demand system approach	TFP, 2021 (reproduce results)	Demand system approach	TFP, 2021 (reproduce results)	Demand system approach
Dairy	26.95601	27.72002	$3.98	$3.90	14.4%	14.1%
Meat, poultry, seafood, eggs	7.64502	7.49240	$6.05	$5.96	21.9%	21.5%
Nuts and seeds, soy products	1.27399	1.25688	$0.72	$0.71	2.6%	2.6%
Mixed dishes	5.45692	5.86925	$1.57	$1.78	5.7%	6.4%
Grains and cereals	11.81321	11.52590	$3.93	$3.87	14.2%	14.0%
Snack foods and sweets	0.72123	0.88788	$0.46	$0.60	1.7%	2.2%
Fruits and fruit juice	14.44422	14.38828	$3.85	$3.84	13.9%	13.9%
Vegetables	16.80054	16.70441	$6.37	$6.34	23.1%	22.9%
Beverages	4.80000	5.01638	$0.32	$0.32	1.2%	1.2%
Fats, oils and condiments	0.65079	0.62141	$0.36	$0.34	1.3%	1.2%

Note: These results are based on a Cobb-Douglas demand system model with combined modeling categories and demographic adjustments for age- sex group. After computing the alternative TFP market basket quantities for all 95 food modeling categories, we calculated total quantities (in 100-gram units), costs ($ per day), and expenditure shares (a percentage) for the 10 categories shown in this table.

TFP = Thrifty Food Plan.

Exhibit 19. The demand system–based TFP market basket: Summary statistics using alternative demand systems

Result	TFP, 2021 (reproduce results)	Demand system approach
Successfully solved for the reference family's four age-sex groups?	✓	✓
Market basket cost ($ per day)[a]	$27.60	$27.66
Distance of combined modeling categories from current consumption (in 10,000 gram^2 units)[a]	5.857	6.141
Distance of combined modeling categories from the published TFP, 2021 solution (10,000 gram^2 units)[a]	2.185 × 10−11	0.022
Mean squared error distance of TFP modeling categories from the TFP, 2021 solution (100 gram units)[a]	8.050 × 10−12	0.011
Energy (kcal)[a]	9,611.7	9,611.7
Calculated HEI-2020 score (0-100)[b]	94.0	94.7
SPF-predicted HEI-2020 score (average inefficiency)[b]	—	1.8
SPF-predicted HEI-2020 score (no inefficiency)[b]	—	2.1
Any combined modeling categories with zero quantity?	✓	✗
Number of combined modeling categories with zero quantity?[a]	29	0
Any combined modeling categories with near-zero (< 1e-9) quantity?	✓	✓
Number of combined modeling categories with near-zero (< 1e-9) quantity?[a]	71	26
Demand system-predicted utility[a]	0	—
Demand system-predicted log(utility)[a]	−Inf	—
All TFP, 2021 nutrient constraints met?	✓	✓
Number of TFP, 2021 nutrient and food group constraints met[a]	376	376
All TFP, 2021 practicality constraints met?	✓	✓
Number of TFP, 2021 practicality constraints met[a]	112	112
Gini impurity of the TFP modeling category expenditure shares (0-1)	0.946	0.947
Gini impurity of the combined modeling category expenditure shares (0-1)	0.929	0.929
Entropy of the TFP modeling category expenditure shares (0-1)	0.230	0.230
Entropy of the combined modeling category expenditure shares (0-1)	0.268	0.272

Note: These results are based on a Cobb-Douglas demand system model with combined modeling categories and demographic adjustments for age- sex group.

[a] Sum across the reference family's age-sex groups.

[b] Average across the reference family's age-sex groups.

HEI = Healthy Eating Index; TFP = Thrifty Food Plan.

Exhibit 20. The demand system–based TFP market basket: Nutrient and food group content

Nutrient	TFP, 2021 (reproduce results)	Demand system approach
Food energy		
Energy (kcal)	9,611.7	9,611.7
Macro-nutrients		
Carbohydrates (g)	1,237.5	1,245.2
Protein (g)	455.8	454.6
18:02 (linoleic acid) (g)	77.9	78.0
18:03 (linolenic acid) (g)	6.8	6.8
Fatty acids total monounsaturated (g)	122.5	122.0
Fatty acids total polyunsaturated (g)	86.8	86.9
Saturated fat (g)	97.8	96.0
Total Fat (g)	336.9	334.2
Fiber total dietary (g)	135.2	135.2
Micro-nutrient		
Calcium (mg)	6,296.7	6,219.7
Cholesterol (mg)	1,249.2	1,209.6
Choline total (mg)	1,843.6	1,836.4
Copper (mg)	6.4	6.4
Iron (mg)	73.3	72.8
Folic acid (µg)	716.0	709.1
Folate (µg DFE)	2,876.2	2,861.7
Potassium (mg)	17,782.2	17,877.6
Magnesium (mg)	1,950.0	1,954.5
Sodium (mg)	11,149.2	11,106.5
Niacin (mg)	132.0	132.0
Phosphorus (mg)	8,215.6	8,172.9
Riboflavin (mg)	11.6	11.7
Selenium (µg)	632.9	628.3
Thiamin (mg)	9.0	9.0
Vitamin E (alpha-tocopherol) (mg)	49.8	49.9
Vitamin A RAE	6,293.4	6,269.6
Vitamin B-12 (µg)	24.5	24.7
Vitamin B-6 (mg)	11.9	11.9
Vitamin C (mg)	497.2	496.5
Vitamin D (D2 + D3) (µg)	44.4	44.5
Vitamin K (phylloquinone) (µg)	668.0	667.8
Zinc (mg)	55.0	54.9
Calories from macro-nutrients		
Kcal from protein	1,823.3	1,818.4
Kcal from carbohydrates	4,950.1	4,980.8
Kcal from fat	3,031.9	3,007.4
Kcal from saturated fat	879.9	863.8

Nutrient	TFP, 2021 (reproduce results)	Demand system approach
FPED food groups		
Fruit juices - citrus and non citrus (cup eq.)	2.4	2.4
Total intact or cut fruits and fruit juices (cup eq.)	8.4	8.4
Dark green vegetables (cup eq.)	1.2	1.2
Total red and orange vegetables (tomatoes + other red and orange) (cup eq.)	3.8	3.8
Total starchy vegetables (white potatoes + other starchy) (cup eq.)	3.9	3.9
Other vegetables not in the vegetable components listed above (cup eq.)	3.1	3.1
Legumes computed as vegetables (cup eq.)	1.5	1.5
Total dark green red and orange starchy and other vegetables; excludes legumes (cup eq.)	13.5	13.5
Whole grains (oz. eq.)	17.9	17.9
Refined or non-whole grains (oz. eq.)	17.9	17.9
Total whole and refined grains (oz. eq.)	35.8	35.8
Beef veal pork lamb game meat; excludes organ meats and cured meat (oz. eq.)	3.9	3.8
Chicken turkey Cornish hens and game birds; excludes organ meats and cured meat (oz. eq.)	9.7	9.7
Eggs (chicken duck goose quail) and egg substitutes (oz. eq.)	2.7	2.5
Soy products excluding calcium fortified soy milk and immature soybeans (oz. eq.)	0.1	0.1
Peanuts tree nuts and seeds excludes coconut (oz. eq.)	8.0	8.0
Total meat poultry seafood organ meats cured meat eggs soy and nuts and seeds; excludes legumes (oz. eq.)	30.4	30.3
Total milk yogurt cheese and whey (cup eq.)	12.1	12.1
Oils (g)	141.0	142.1
Meat poultry egg aggregate (oz. eq.)	16.9	16.9
Seafood aggregate (oz. eq.)	5.4	5.4
Nut seed soy aggregate (oz. eq.)	8.1	8.1
Kcal from added sugars	384.8	399.6
Calories by eating occasion		
Kcal from breakfast	2,210.7	2,210.7
Kcal from lunch	2,690.6	2,690.5
Kcal from dinner	3,283.8	3,254.0
Kcal from snacks	1,241.6	1,270.0
Kcal from drinks	109.9	111.3
Kcal from extended consumption	75.1	75.2

Note: These results are based on a Cobb-Douglas demand system model with combined modeling categories and demographic adjustments for age- sex group.

TFP = Thrifty Food Plan; DFE = dietary folate equivalent; eq. = equivalent; g = gram; kcal = kilocalorie; oz = ounce; mg = milligram; µg = microgram; RAE = retinol activity equivalent.

7.8. Conclusions about the demand system-based approach

Altogether, we found that it **was technically feasible** to implement a demand system–based approach to reevaluate the TFP market basket. However, the **approach proved more complicated than the optimization approach** used by CNPP for TFP, 2021 and the **differences between the two market baskets were modest overall**. Both approaches minimize market basket costs subject to many nutrition, food group, and practicality constraints. Given that the market basket costs are an increasing, linear function of the TFP modeling category quantities, the optimization routine produces a market basket with one or more binding constraints. In other words, the model constraints (rather than the objective function) govern which foods and beverages are ultimately included in the TFP, 2021 market basket and in what amounts; those same constraints continue to govern the solution in the demand system–based approach that we developed above. In Appendix C, we explore this idea further and show that CNPP could obtain similar market baskets without using a second, inner objective function in Equations 4 or 5. In other words, we calculated the lowest-cost market basket that satisfied all the nutrient, food group, and practicality constraints, where the market basket cost was not necessarily an integer (in cents). If we can directly obtain the corner solution by directly minimizing the market basket costs (as long as the cost of the market basket, in cents, is not required to be an integer), there seems to be little advantage in adding the second level of objective functions and choosing the exact functional form (either minimizing distance to current consumption or maximizing utility). This complication determines only how the consumer spends less than $0.01. The modest differences between the TFP, 2021 and demand system–based market baskets arise mostly because the demand system–based market basket requires a token amount of costs to be allocated to each of the combined modeling categories. Otherwise, there is little room for the alternative objective function to make much difference.

If CNPP modified its optimization approach to obtain cost-neutral market baskets, rather than cost-minimizing market baskets, the demand system-based utility function could be used in the objective function. Thus, it could be feasible to implement a cost neutrality requirement when using a demand system-based approach. An important caveat is needed, however, because we found the total cost of the TFP market basket using the demand system approach to be slightly higher than the TFP, 2021 solution. For this reason, it would not be possible to obtain a TFP market basket using the demand system approach that meets all nutrient, food group, and practicality constraints used in TFP, 2021 and costs the same or less than the TFP, 2021 solution. However, because future reevaluations would likely have different nutrient, food group, and practicality constraints and food prices than those used in TFP, 2021, we consider this approach to be feasible under cost neutrality.

This work demonstrates that it is possible to use NHANES, WWEIA data to model the demand for foods and beverages—to estimate the utility function—for a representative sample of individuals in the United States. This finding could be useful in other contexts, where the consumer problem is less constrained. For example, the differences in the distance- and utility-based objective functions could be quite important in research settings that do not try to minizine the cost of the market basket or that relax the nutrition and food group and practicality constraints. Minimizing distance to current consumption would converge on solutions that are neither below nor above current consumption, while maximizing consumers' utility could avoid solutions with zero dollars allocated to any modeling category and, if left unbounded, converge on solutions with quantities and expenditure levels exceeding current consumption. Utility functions based on demand systems offer different insights that could support various USDA goals and potentially become a basis for modeling consumer preferences; future research on consumer utility could account for other aspects of a diet, such as its convenience or variety, that are important to consumers but have not been directly included in previous TFP revaluation optimization problems.

8. Using a stochastic production frontier approach to reevaluate the TFP

This chapter focuses on the second econometric-based approach for reevaluating the TFP—the stochastic production frontier (SPF) approach. We briefly discuss how the expert panelists originally conceived of using SPF models to reevaluate the TFP and describe the SPF models. We then describe the data and methods we used to estimate an SPF in this application and present results from the modeling step. Finally, we discuss how we used the SPF model output to calculate a TFP market basket and present those results. Two appendices (Appendix C and Appendix E) provide additional results for the reference family of four.

8.1. The expert panelists' concept: Using SPF models to reevaluate the TFP

Chapter V of the Alternative Approaches report (Jones et al. 2024) describes how the expert panelists conceived of using SPF models to reevaluate the TFP:

> *The expert panel discussed a SPF model that minimizes the cost needed to produce a diet of a certain level of healthfulness... Results from the stochastic frontier model would be the most cost-efficient way to achieve a sufficiently healthy diet or related goal. The resulting as-purchased diet from [the model] would be used as the basis for the TFP market basket and associated cost... The SPF model would consist of a parameterized "diet quality production function," using observed HEI as the output from the production process and purchase data as the inputs to the production process. As with the demand model, food items could be incorporated individually or combined into broader food categories. The model would include two error terms: One term would reflect random variation, and a one-sided term would reflect inefficiency in the process of using the model inputs (purchase data) to produce the model output (a diet with an HEI score). Maximum likelihood or similar techniques would estimate the parameterized production function and the inefficiency error term. This approach would result in a parameterized frontier that reflects the lowest-cost solution for producing diets of varying healthfulness and also notes how far each household in the data is from the frontier—in other words, how "inefficient" they are.*

We focused on turning this conceptual plan into a tractable method for reevaluating the TFP. As noted in Chapter 6, this required identifying a specific SPF modeling approach and developing a plan to compute an alternative TFP market basket (Kranker 2024). We were skeptical about using SPF modeling as a feasible or useful alternative for computing a TFP market basket because the SPF approach requires diets to be scored with a single number, which we viewed as incompatible with the multitude of criteria CNPP used to define a healthy diet for TFP, 2021.

8.2. Introduction to SPF models

An SPF model has a production function, $f(.)$, that relates an array of inputs ($\boldsymbol{z_i}$) for producer i into a scalar measure of the maximum output (O_i) achievable, with a multiplier ε_i capturing the degree of inefficiency ($0 < \varepsilon_i \leq 1$):

$$O_i = f(\boldsymbol{z_i}, \boldsymbol{\beta})\varepsilon_i \qquad 6$$

The term ε_i must be in the interval (0, 1]. The producer is not making the most of the inputs ($\boldsymbol{z}$) given the technology described by the production function if ε_i is in the interval (0, 1). The producer is at full, or maximum, production if ε_i equals 1. For example, the production function could be a Cobb-Douglas production function:

$$O_i = \varepsilon_i \sum_{j=1}^{J} \left(z_{ij}\right)^{\beta_j} \qquad 6'$$

where z_{ig} is the amount of input g used by producer i, there are J inputs, and β_g is an elasticity parameter for good g (Mas-Colell et al. 1995, p. 130). Defining $u_i \equiv -\ln(\varepsilon_i) \geq 0$ and assuming output is linear in logarithms and subject to random shocks (υ_i) leads to the reformulation:

$$\ln(O_i) = \beta_0 + \sum_{j=1}^{J} \beta_j \ \ln\left(z_{ij}\right) + u_i \ + \upsilon_\mathrm{i} \qquad 7$$

$$H_i = \beta_0 + \sum_{j=1}^{J} \beta_j \, x_{ij} + u_i \ + \upsilon_\mathrm{i} \qquad 8$$

We obtained the second line by taking the logarithm of the data before estimating the model (for example, $H_i \equiv \ln O_i$ and $x_{ig} \equiv \ln z_{ig}$). The error terms in this model (u_i and υ_i) are parameterized by their combined variance ($\sigma_S^2 = \sigma_u^2 + \sigma_v^2$) and the proportion of the total variance from u_i ($\gamma = \sigma_u^2/\sigma_S^2$). The model resembles a regular ordinary least squares linear regression model except for the error terms, one of which is bounded at zero.[47] Different specifications for the two error terms (u_i and υ_i) leads to different models, but in many formulations, Equation 8 can be estimated by maximum likelihood or nonlinear least squares.[48] In the economic literature, estimating the distribution of u_i is the principal reason for estimating SPF models. (Researchers only interested in estimating the β parameters can estimate simpler production functions that have only one error term.) In the food and nutrition literature, a few papers have used SPF models with food groups used as inputs for producing energy (Yu and Jaenicke 2020) or weight outcomes (Li and Lopez 2016) in humans and farm milk output from cows in dairy herds (Moreira and Bravo-Ureta 2010).

The expert panelists intended to use the SPF modeling approach to predict HEI scores (H_i) as a function of the TFP modeling categories' costs (in dollars), accounting for technical inefficiency. However, using costs (in dollars) or quantities (in grams) for food categories would lead to essentially the same results because we assume all consumers face the same, average food prices (for the reasons described in Chapters 1 and 7). Because using quantities (rather than costs) would be more convenient for calculating a TFP market basket (in the steps described in Section 8.6 below), we recommended computing quantities of foods from NHANES, WWEIA Day 1 dietary recall data and then using those *quantities* in the SPF model in place of dollars (that is, using $x_i = q_i$ rather than $x_i = p * q_i$).

This SPF model (Equation 8) helpfully estimates the distribution of inefficiencies across respondents ($\hat{u}$), but is otherwise essentially an attempt to "rediscover" the formula for calculating HEI scores. In other words, the SPF model coefficients and functional form are intended to return the HEI score when provided a vector of quantities for each modeling, q_i. Rediscovering this widely published formula is obviously unnecessary. (This point was raised by one of the experts during the expert panelists' discussions.) The SPF model also assumes log-linear relationships between predicted HEI scores and TFP modeling category quantities, but we know the formula for calculating HEI-2020 scores is a complicated function based on the nutritional content of the foods and beverages that make up a diet. Specifically, the HEI-2020 score is mainly driven by a diet's FPED food group quantities and its energy (Shams-White et al. 2023, 1285; CNPP 2023; NCI and CNPP 2024). For

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[47] Defining $u_i = -\log \varepsilon_i$ with $\varepsilon_i \in (0, 1]$ implies that $u_i \geq 0$.

[48] For more details, see Aigner et al. (1977), Greene (1993, sec. 17.6.3) and Kumbhakar et al. (2015, chaps. 2–3).

these reasons, we **hypothesized the SPF model would inaccurately estimate the relationship between prices (or quantities) of food and HEI scores** (Kranker 2024).

8.3. Data sources

As discussed in Chapter 6, we retained the same data sources that CNPP had used in the most recent revaluation of the TFP, 2021 to the extent possible. To implement the SPF-based approach, we used the same data sources we described in Chapter 7, Section 7.3—the input data and programming code that were used to implement the optimization-based approach for evaluating the TFP (CNPP 2021b) and the 2015-2016 wave of NHANES, WWEIA Day 1 recall data. We used the data processing steps described above to compute the total amount of each modeling category acquired (q_{ig}) in gram equivalents for each respondent in our analytic population. We also calculated an HEI-2020 score, H_i, for each respondent using published formulas (Shams-White et al. 2023). This required calculating the FPED equivalent amounts for each food and beverage reported by each respondent at the quantities they reported, calculating the total amounts for each FPED food group in Day 1 for each respondent, and using these totals in the HEI-2020 formulas. The average HEI-2020 score for respondents in our analytic sample was 48.5 (SD = 13.9).

8.4. SPF model estimation

We next estimated the SPF model using Stata's "`frontier`" command (StataCorp 2023b). The input data for SPF estimation was a single analytic file with one observation per respondent in our analytic population and variables for each respondent's (1) logarithm of their HEI-2020 score, $\log H_i$; (2) vector of the logarithm of total amounts, in grams, for each TFP modeling category (95 columns) or combined modeling category (45 columns), $\log\ q_i$; (3) age group and sex, $\boldsymbol{z}_i$; and (4) survey weights, sampling strata, and primary sampling units to account for NHANES' complex survey design.[49]

We estimated several SPF models:[50]

1. Models with the 95 TFP modeling categories and separately with the 45 combined modeling categories.
2. Models with and without demographic adjustments for age and sex. We used the truncated-normal error distribution for estimation, which can accommodate models with demographic adjustment and without adjustment. [51]

After estimating the SPF models, we stored the estimated model coefficients $(\widehat{\boldsymbol{\beta}})$, the components of the error terms (for example, the variance of u_i and υ_i), and other model output (such as standard errors). We also calculated a predicted HEI-2020 score for each respondent ($\widehat{H}_i$) in our analysis sample along with the corresponding estimated inefficiency term $\left(f(\widehat{u}_i|\boldsymbol{\upsilon}, \widehat{\boldsymbol{\beta}})\right)$. The distribution of the $\hat{u}$ indicates the range of levels of efficiency among respondents in the data. We also computed a population weighted mean of our estimate of the technical efficiency, $E_i = \mathrm{E}(\exp(-u_i)|\hat{\varepsilon}_i)$, for each age-sex group to use in steps that we describe later. The estimated frontier, where there is no inefficiency ($u = 0$ or $\varepsilon = 1$), can be interpreted as the most efficient (least expensive or lowest cost) way for a consumer to achieve a given HEI-2020 score.

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[49] Because $q_{ig} = 0$ for many observations, we set $\log q_i$ to a floor of -2 for SPF estimation in Stata.

[50] We also estimated models that used modeling category costs (in dollars) as an input rather than modeling category quantities (in grams), estimated unadjusted half-normal models (rather than truncated-normal models), and conducted sensitivity analyses focused on missing prices (discussed in footnotes 33 and 35). Those results are not included in this report for the sake of brevity.

[51] Stata's "`frontier`" command can estimate SPF models that assume u_i error terms are independently exponentially distributed, independently half-normally distributed, or independently truncated-normally distributed.

8.5. Estimated SPF model coefficients

We found that it was feasible to estimate these SPF models. However, after reviewing the results, we found that all four SPF models produced large β_0 coefficients and relatively smaller positive and negative β_g coefficients for the modeling categories (Exhibit 21). The predicted values from all four SPF models were fairly well calibrated among NHANES, WWEIA respondents in our sample—that is, the means and SDs of predicted HEI-2020 scores were similar in magnitude to the mean and SD of actual HEI-2020 scores (Exhibit 22). For example, the SPF model with 95 TFP modeling categories with demographic adjustments for age-sex groups predicted HEI-2020 scores with an average of 48.1 (SD = 12.2) which was similar to the observed HEI-2020 score average 48.5 (SD = 13.9).

Although the SPF models were reasonably well-calibrated on average, the mean squared error for this model was 28.5. This relatively large error indicates that **the SPF model does not precisely predict HEI-2020 scores for specific respondents' diets**—a confirmation of our hypothesis in Section 8.2. The predicted HEI-2020 scores from models with combined modeling categories had significantly larger mean squared errors (39.0 to 39.4). Demographic adjustment (for age-sex groups) did not meaningfully improve mean squared errors but did allow the technical efficiency to vary across age-sex groups, which we viewed to be a helpful addition conceptually and one that also led to lower mean squared errors for some of the age-sex groups (results not shown).

Based on these results, we determined **the SPF models with the TFP modeling categories with demographic adjustments for age-sex groups produced the best SPF for revaluating the TFP**. We selected this model for the next step of our analysis, which used the SPF model to compute the TFP market basket (Section 8.6).

Exhibit 23 presents the estimated coefficients for this specific SPF model, namely the estimated values of $\hat{\boldsymbol{\beta}}$. Exhibit 24 provides a population weighted mean of our estimate of the technical efficiency, $\hat{E}_i$, for the four age-sex groups that make up the reference family of four. We can interpret this table as suggesting the technical inefficiency lowers HEI-2020 scores by 10.8 to 14.5 percent, depending on the age-sex group. We can use these estimates with Equation 7 to compute the predicted HEI-2020 score for any age-sex group for a given set of TFP modeling category quantities ($\boldsymbol{q}$).

The coefficients returned by the SPF model raise immediate concerns. The $\hat{\beta}_0$ coefficient is 4.63 (Exhibit 23), which is quite large. For example, even if the TFP modeling category quantities ($\boldsymbol{q}$) were set to zero, the predicted HEI-2020 score from the SPF model would be 87.52, 92.67, or 102.97 with technical efficiency at 85, 90, and 100 percent, respectively. Increasing the quantities ($\boldsymbol{q}$) can further increase or decrease the HEI score, but only to a limited degree, because the other $\hat{\beta}_g$ terms are relatively small and have both negative and positive signs.[52] With a mix of negative and positive coefficients in $\hat{\boldsymbol{\beta}}$, the SPF-predicted HEI-2020 scores are not a DCP-compliant function of the quantities when quantities are specified in levels ($\boldsymbol{q}$); DCP problems that use SPF-predicted HEI-2020 scores as an objective or constraint use logarithms of quantities ($\log \boldsymbol{q}$) as variables, which introduces some limitations.

[52] For example, given the signs of the coefficients in Exhibit 23, adding eggs or candy to the market basket would *decrease* the predicted HEI-2020 score, whereas adding beans, peas, and lentils or fried potato products would *increase* the predicted HEI-2020 score.

Exhibit 21. Minimum, median, and maximum coefficients using alternative SPF models

Demographic adjustment	β_0	β_g Min.	β_g Median	β_g Max.	$\log(\sigma^2)$	logit(¥)
95 TFP modeling categories						
Without demographic adjustment	4.64	−0.0215	0.00350	0.0314	3.19	7.24
Adjusted for age-sex groups	4.63	−0.0210	0.00370	0.0313	2.86	6.91
45 combined modeling categories						
Without demographic adjustment	4.22	−0.0193	0.00316	0.0316	3.20	6.97
Adjusted for age-sex groups	4.22	−0.0186	0.00274	0.0315	2.86	6.62

SPF = stochastic production frontier.

Exhibit 22. Observed and predicted HEI-2020 scores for NHANES, WWEIA respondents using alternative SPF models

Demographic adjustment	HEI-2020 score with reported consumption (Day 1)		SPF-predicted HEI-2020 score (estimated inefficiency)			SPF-predicted HEI-2020 score (no inefficiency)		
	Mean	Standard deviation	Mean	Standard deviation	Mean squared error	Mean	Standard deviation	Mean squared error
95 TFP modeling categories								
Without demographic adjustment	48.5	13.9	48.1	12.2	28.3	54.4	13.2	116.1
Adjusted for age-sex groups	48.5	13.9	48.1	12.2	28.5	54.4	13.1	115.3
45 combined modeling categories								
Without demographic adjustment	48.5	13.9	48.1	11.6	39.0	54.5	12.3	127.1
Adjusted for age-sex groups	48.5	13.9	48.1	11.6	39.4	54.4	12.2	125.9

SPF = stochastic production frontier.

Exhibit 23. Coefficients for the selected SPF model

TFP modeling category	β_g
Constant term, β_0	4.63
Dairy	
Cheese - higher cost	−0.00265
Cheese - lower cost	−0.00424
Milk and yogurt - higher nutrient density	0.0101
Milk and yogurt - lower nutrient density	0.00931
Meat, poultry, seafood, eggs	
Meat - higher nutrient density - higher cost	0.000395
Meat - higher nutrient density - lower cost	0.00395
Meat - lower nutrient density - higher cost	−0.00384
Meat - lower nutrient density - lower cost	0.00186
Poultry - higher nutrient density - higher cost	0.00623
Poultry - higher nutrient density - lower cost	0.00370
Poultry - lower nutrient density - higher cost	−0.000232
Poultry - lower nutrient density - lower cost	0.000773
Seafood - higher cost	0.0188
Seafood - lower cost	0.00797
Eggs	−0.000273
Cured meat	−0.00590
Nuts and seeds, soy products	
Nuts and Seeds - higher nutrient density	0.0273
Nuts and Seeds - lower nutrient density	0.0228
Nut and seed butters	0.0166
Processed soy products	0.0116
Mixed dishes	
Mixed Dishes - Eggs - higher nutrient density	0.00452
Mixed Dishes - Eggs - lower nutrient density	0.00111
Mixed Dishes - Vegetables - higher nutrient density - higher cost	0.00377
Mixed Dishes - Vegetables - higher nutrient density - lower cost	0.000884
Mixed Dishes - Vegetables - lower nutrient density - higher cost	0.00316
Mixed Dishes - Vegetables - lower nutrient density - lower cost	0.00234
Mixed Dishes - Meat-Poultry-Seafood - higher nutrient density - higher cost	0.0134
Mixed Dishes - Meat-Poultry-Seafood - higher nutrient density - lower cost	0.00717
Mixed Dishes - Meat-Poultry-Seafood - lower nutrient density - higher cost	0.00598
Mixed Dishes - Meat-Poultry-Seafood - lower nutrient density - lower cost	0.00640
Mixed Dishes - Grain based - higher nutrient density - higher cost	0.00231
Mixed Dishes - Grain based - higher nutrient density - lower cost	0.00399
Mixed Dishes - Grain based - lower nutrient density - higher cost	−0.00438
Mixed Dishes - Grain based - lower nutrient density - lower cost	−0.00795

TFP modeling category	β_g
Mixed Dishes - Pizza - higher nutrient density - higher cost	−0.00921
Mixed Dishes - Pizza - higher nutrient density - lower cost	−0.0175
Mixed Dishes - Pizza - lower nutrient density - higher cost	−0.0210
Mixed Dishes - Pizza - lower nutrient density - lower cost	−0.0193
Mixed Dishes - Sandwiches - higher nutrient density - higher cost	−0.000874
Mixed Dishes - Sandwiches - higher nutrient density - lower cost	0.00748
Mixed Dishes - Sandwiches - lower nutrient density - higher cost	−0.0119
Mixed Dishes - Sandwiches - lower nutrient density - lower cost	−0.0163
Mixed Dishes - Soups - higher nutrient density - higher cost	0.00459
Mixed Dishes - Soups - higher nutrient density - lower cost	−0.0141
Mixed Dishes - Soups - lower nutrient density - higher cost	0.00103
Mixed Dishes - Soups - lower nutrient density - lower cost	−0.00435
Mixed Dishes - Beans-peas-lentils - higher nutrient density - higher cost	0.0313
Mixed Dishes - Beans-peas-lentils - higher nutrient density - lower cost	0.0180
Mixed Dishes - Beans-peas-lentils - lower nutrient density - higher cost	0.0297
Mixed Dishes - Beans-peas-lentils - lower nutrient density - lower cost	0.0154
Grains and cereals	
Grains - higher nutrient density - higher cost	0.0180
Grains - higher nutrient density - lower cost	0.0229
Grains - lower nutrient density - higher cost	−0.00532
Grains - lower nutrient density - lower cost	−0.00555
Biscuits-muffins-quick breads	−0.00448
Breakfast cereals - higher nutrient density	0.0189
Breakfast cereals - lower nutrient density	0.00558
Snack foods and sweets	
Tortilla-corn-other chips	0.00743
Popcorn - higher nutrient density	0.0176
Popcorn - lower nutrient density	0.00383
Pretzels-snack mix	−0.00686
Crackers - higher nutrient density	0.0204
Crackers - lower nutrient density	−0.000376
Snack-Meal Bars	0.0151
Sweet bakery products	−0.00817
Candy	−0.00400
Other Desserts	−0.00756
Sugars	−0.00310
Fruits and fruit juice	
Fruit - higher nutrient density - higher cost	0.0157
Fruit - higher nutrient density - lower cost	0.0240
Fruit - lower nutrient density - higher cost	0.00779

TFP modeling category	β_g
Fruit - lower nutrient density - lower cost	0.0147
100 percent fruit juice - higher cost	0.00741
100 percent fruit juice - lower cost	0.0125
Vegetables	
Red orange vegetables - higher cost	0.00640
Red orange vegetables - lower cost	0.0000631
Dark green vegetables - higher cost	0.0133
Dark green vegetables - lower cost	0.0124
Other vegetables and vegetable combinations - higher cost	0.00424
Other vegetables and vegetable combinations - lower cost	0.00587
Starchy vegetables - higher cost	0.00296
Starchy vegetables - lower cost	0.00263
Beans - peas – lentils	0.0313
Other fried potato products	0.0147
Beverages	
Fruit drinks - higher nutrient density	0.00376
Fruit drinks - lower nutrient density	−0.00140
Soft drinks	−0.00557
Diet beverages	0.00130
Coffee and Tea - higher nutrient density	0.0000264
Coffee and Tea - lower nutrient density	−0.000728
Other beverages - smoothies grain-based milk substitutes nutritional beverages	0.0164
Fats, oils and condiments	
Butter and animal fats	−0.0175
Margarine and oils	−0.00125
Condiments and Sauces - higher cost	−0.00221
Condiments and Sauces - lower cost	−0.00694

Note: These results are based on the SPF model with the 95 TFP modeling categories with demographic adjustments for age- sex groups.

SPF = stochastic production frontier; TFP = Thrifty Food Plan.

Exhibit 24. Population-weighted mean of the estimated technical inefficiency by age-sex group using the selected SPF model

Age-sex group	Mean	Standard error
Child 6–8	0.888	0.005
Child 9–11	0.855	0.007
Female 20–50	0.892	0.003
Male 20–50	0.881	0.003

Note: These results are based on the SPF model with the 95 TFP modeling categories with demographic adjustments for age- sex groups. Ten other age-sex groups were included in the SPF model, but are not included in this table.

SPF = stochastic production frontier; TFP = Thrifty Food Plan.

8.6. Using the SPF model to compute an alternative TFP market basket

Following the expert panelists' concept (Section 8.1), we employed the SPF model estimates (Exhibit 23 and Exhibit 24) as a "parameterized frontier" to determine the lowest-cost solution for producing diets of set levels of healthfulness. Specifically, we used DCP methods (described on page 50) to solve for the lowest-cost combination of quantities ($\boldsymbol{q}$) that yield a predicted HEI-2020 score at least as high as a lower bound value set by the researcher, $\underline{H_i}$. Besides the estimated SPF model coefficients ($\widehat{\boldsymbol{\beta}}$) and technical efficiency corresponding to an age-sex group ($\hat{E}_i$), the only other data needed were the average TFP modeling category prices ($\boldsymbol{p}$). In the end, the consumer optimization problem simply minimizes the cost of the market basket, subject to the constant for the HEI-2020 scores:

$$\min_{\boldsymbol{q}} \sum_{j=1}^{J} p_j \, q_j \qquad 9$$

$$\text{subject to} \qquad \log \underline{H_i} \leq \hat{\beta}_0 + \sum_{j=1}^{J} \hat{\beta}_j \log(q_j) + \log(\hat{E}_i) \qquad \text{C.9.1}$$

As a benchmark, we set the lower-bound HEI-2020 score, $\underline{H_i}$, to be the HEI-2020 score of the TFP, 2021 market basket for the age-sex group.[53] The value of the objective function at the optimal solution $\left(\sum_{j=1}^{J} p_j \, q_j^*\right)$ is the TFP market basket cost. We also solved Equation 9 with $\hat{E}_i$ set to zero. This alternative result could be interpreted as the lowest-cost market basket that could achieve the HEI-2020 score of $\underline{H}$ under a hypothetical in which consumers have no technical inefficiency in their production function.

When writing the implementation plan, we were concerned about whether this SPF-based approach could produce reasonable TFP market baskets. When the SPF model estimated a large coefficient for $\hat{\beta}_0$ and small coefficients for $\hat{\beta}_g$ (see p. 61), it appeared that the predicted HEI-2020 scores would remain within a narrow range even when the TFP market basket quantities varied substantially. In addition, we had concerns about the nutritional composition of the market basket, previewed earlier in the discussion on the concerns about low precision when the SPF model is used to predict HEI scores (see p. 59 and p. 61). Although the expert panelists *assumed* the HEI score would provide a useful dependent variable for the production frontier function, the HEI score is only a summary "measure of overall diet quality, independent of quantity, that can be used to assess alignment with the DGA" (Shams-White et al. 2023, p. 1280). As a one-dimensional measure, the HEI score does not encapsulate alignment with *all* clinical guidelines (which variety by age, sex, and other factors). Meanwhile, the statutory guidelines require the TFP market basket to be "based on current dietary guidance." Because the SPF approach outlined above does not *require* the market basket to meet clinical guidelines or align with the DGA, it was important to assess the nutritional content of the market basket produced through this method.

8.7. The SPF-based TFP market basket

We were able to compute the SPF-based TFP market basket using the method described above, but the resulting market basket assigned near-zero quantities for all TFP modeling categories. With this approach the TFP modeling categories all have miniscule quantities (less than 0.001 grams) and low costs (less than $0.005). For this reason, the quantities and costs for each modeling category appears as "0" after rounding in

[53] $\underline{H_i}$ ranged from 92.94 to 96.38 for the reference family. The expert panelists discussed using $\underline{H_i} = 80$, but an HEI-2020 score of 80 represents a substantial departure from the Federal requirement that the TFP market basket reflect current dietary guidance. Furthermore, a criterion that sets the HEI-2020 score as low as 80 would represent a major relaxation from the TFP, 2021 criteria for defining a healthful diet.

Exhibit 25.[54] The total cost of the SPF-based TFP market basket was less than a penny ($0.0000000045) when assuming average technical efficiency (Exhibit 26), implying that the reference family theoretically could purchase a healthy diet, as defined by a high HEI score, at effectively zero cost. No NHANES, WWEIA respondents had daily food expenditures close to $0. However, because the modeling category quantities were near-zero, the market basket's nutritional content was also close to zero (Appendix Exhibit C.3). There is no indication that the DCP solver failed to optimize the model. For example, the solver achieved all convergence criteria without returning any error messages, and the SPF-predicted HEI-2020 scores of both market baskets were above the minimum score that we required. Given the estimated SPF model coefficients (Exhibit 23 and Exhibit 24), it is feasible to achieve a market basket that has near-zero quantities ($\boldsymbol{q} \cong \mathbf{0}$) for all modeling categories and an SPF-predicted HEI-2020 score above the lower bound ($H_i \geq \underline{H_i}$). We do not put too much stock in the *exact* quantities returned by the solver for the SPF-based TFP market basket, however; the quantities are so small that numerical precision of R and Stata and the solver convergence criteria could have small effects on the results. (For example, the *actual* HEI-2020 scores of these SPF-based market baskets were above 85, but that calculation is based on near-zero quantities of the TFP modeling categories and could be inaccurate.)

Exhibit 25. The SPF-based TFP market basket: Aggregate modeling categories

	Quantities (100 gram units)			Costs ($ per day)			Expenditure shares (%)		
Category	TFP, 2021 (reproduce results)	SPF approach (average ineff.)	SPF approach (no ineff.)	TFP, 2021 (reproduce results)	SPF approach (average ineff.)	SPF approach (no ineff.)	TFP, 2021 (reproduce results)	SPF approach (average ineff.)	SPF approach (no ineff.)
Dairy	26.95601	0.00000	0.00000	$3.98	$0.00	$0.00	14.4%	1.0%	1.0%
Meat, poultry, seafood, eggs	7.64502	0.00000	0.00000	$6.05	$0.00	$0.00	21.9%	1.9%	3.1%
Nuts and seeds, soy products	1.27399	0.00000	0.00000	$0.72	$0.00	$0.00	2.6%	11.5%	12.0%
Mixed dishes	5.45692	0.00000	0.00000	$1.57	$0.00	$0.00	5.7%	34.9%	35.4%
Grains and cereals	11.81321	0.00000	0.00000	$3.93	$0.00	$0.00	14.2%	12.0%	11.5%
Snack foods and sweets	0.72123	0.00000	0.00000	$0.46	$0.00	$0.00	1.7%	5.3%	4.8%
Fruits and fruit juice	14.44422	0.00000	0.00000	$3.85	$0.00	$0.00	13.9%	11.7%	11.4%
Vegetables	16.80054	0.00000	0.00000	$6.37	$0.00	$0.00	23.1%	18.8%	18.4%
Beverages	4.80000	0.00000	0.00000	$0.32	$0.00	$0.00	1.2%	2.7%	2.4%
Fats, oils and condiments	0.65079	0.00000	0.00000	$0.36	$0.00	$0.00	1.3%	0.0%	0.0%

Note: Quantities and costs may be reported as zero due to rounding. After computing the alternative TFP market basket quantities for all 95 food modeling categories, we calculated total quantities (in 100-gram units), costs ($ per day), and expenditure shares (a percentage) for the 10 categories shown in this table.

ineff. = inefficiency; SPF = stochastic production frontier; TFP = Thrifty Food Plan.

[54] We provide detailed results in Appendix Exhibit C.4, and Appendix Exhibit C.5.

Exhibit 26. The SPF-based TFP market basket: Summary statistics

Result	TFP, 2021 (reproduce results)	SPF approach (average inefficiency)	SPF approach (no inefficiency)
Successfully solved for the reference family's four age-sex groups?	✓	✓	✓
Market basket cost ($ per day)[a]	$27.60	$0.0000000045	$0.0000000037
Distance of combined modeling categories from current consumption (10,000 $gram^2$ units)[a]	5.857	0.902	0.902
Distance of combined modeling categories from the published TFP, 2021 solution (10,000 $gram^2$ units)[a]	2.185×10^{-11}	8.91	8.91
Mean squared error distance of TFP modeling categories from the TFP, 2021 solution (100 gram units)[a]	8.050×10^{-12}	1.932	1.932
Energy (kcal)[a]	9,611.7	0.0	0.0
Calculated HEI-2020 score (0-100)[b]	94.0	85.8	85.7
SPF-predicted HEI-2020 score (average inefficiency)[b]	—	104.2	91.4
SPF-predicted HEI-2020 score (no inefficiency)[b]	—	118.5	103.9
Any combined modeling categories with zero quantity?	✓	✗	✗
Number of combined modeling categories with zero quantity?[a]	29	0	0
Any combined modeling categories with near-zero (< 1e-9) quantity?	✓	✓	✓
Number of combined modeling categories with near-zero (< 1e-9) quantity?[a]	71	176	179
Demand system-predicted utility[a]	0	—	—
Demand system-predicted log(utility)[a]	−Inf	—	—
All TFP, 2021 nutrient constraints met?	✓	✗	✗
Number of TFP, 2021 nutrient and food group constraints met[a]	376	200	200
All TFP, 2021 practicality constraints met?	✓	✗	✗
Number of TFP, 2021 practicality constraints met[a]	112	110	110
Gini impurity of the TFP modeling category expenditure shares (0-1)	0.946	0.925	0.921
Gini impurity of the combined modeling category expenditure shares (0-1)	0.929	0.848	0.843
Entropy of the TFP modeling category expenditure shares (0-1)	0.230	0.280	0.283
Entropy of the combined modeling category expenditure shares (0-1)	0.268	0.364	0.365

[a] Sum across the reference family's age-sex groups.

[b] Average across the reference family's age-sex groups.

HEI = Healthy Eating Index; SPF = stochastic production frontier; TFP = Thrifty Food Plan.

8.8. Conclusions about the SPF-based approach

This project found that implementing the stochastic production frontier approach was **not technically feasible**, given the currently available data and methods used in this assessment. With these methods, we did not obtain meaningful cost estimates or a market basket. As noted, the issues probably stem from the SPF models' failure to accurately and precisely estimate the HEI scores. These SPF models used a log-linear regression functional form to estimate HEI scores based on TFP modeling category quantities. However, the actual HEI score formula uses different data inputs and is nonlinear. The degree of imprecision of the SPF model might be a surprise; perhaps the SPF approach would be more useful if it modeled HEI scores more accurately. Model fit could potentially be improved by estimating the SPF models with a data set in which more respondents have higher HEI scores. With NHANES, WWEIA data, the SPF-based approach extrapolates extensively because the HEI scores used to fit the SPF model are considerably lower than the minimum HEI-2020 score we required when computing the TFP market basket. Using alternative regression modeling frameworks (with or without the technical inefficiency parameters) could also potentially improve the model's fit.

In Appendix E, we explore the limit of what CNPP could expect to achieve from improving the SPF models (or other econometric models) to the point where they *perfectly* predict HEI-2020 scores. Specifically, we used the *actual* formula for computing HEI-2020 scores in place of SPF model's formula for predicting HEI-2020 scores. Then we used DCP methods to compute the lowest-cost TFP market baskets that had an HEI-2020 score of 100 (the highest possible score) and had sufficient energy content at the age-sex group's Recommended Energy Intake (REI).[55] This approach therefore removes *all* error that resulted from using econometric modeling to "rediscover" the HEI score formulas. With this approach, we obtained a more reasonable TFP market basket than we did with the SPF-based approach—the market basket quantities and costs were no longer zero. However, requiring a high HEI score for a market basket did not functionally guarantee that the market basket would comply with current dietary guidance, aside from having sufficient energy (kcal). Thus, we found many of the nutrient, food group, and practicality constraints from TFP, 2021 were violated even though we had required the market basket to have an HEI-2020 score of 100. The expert panelists raised the compelling idea of substituting HEI scores for the nutritional and food group constraints that were used in the 2021 TFP reevaluation. However, CNPP will need to do more than imposing a requirement that market baskets have high HEI-2020 scores to ensure the market baskets fully comply with current dietary guidance on recommended levels of food groups, nutrients, and caloric intakes. It does not appear that the (single- dimensional) HEI-2020 score is sufficient to guarantee all the multi-dimensional requirements embodied in constraints C.3.2 through C.3.5 are met.

[55] Requiring HEI scores to be 100 would produce TFP market baskets with near-zero modeling category quantities and costs without additional constraints such as a minimum energy (kcal) amount.

Summary of Feasibility Assessments

9. Summary of feasibility assessments

Based on the three sets of feasibility assessments we completed, only two alternative approaches could be used to determine a TFP market basket and associated cost: 1) the menu-based approach and 2) the demand-system implementation of the econometric-based approach. The other approaches, including the purchase-based approach and the stochastic production frontier implementation of the econometric-based approach, either lacked adequate sample sizes to calculate the TFP market basket and cost or were determined to be technically infeasible to implement. Below we summarize our findings from the feasibility assessments across the four criteria of interest: (1) technical feasibility; (2) barriers to implementation; (3) meaningful differences from the TFP, 2021; and (4) feasibility under cost neutrality. We conclude with a brief discussion of considerations for future work.

9.1. Technical feasibility

Each of the alternative approaches was determined to be technically feasible to implement except for the stochastic production frontier implementation of the econometric-based approach. In terms of the purchase-based approach, both the FoodAPS and Circana Consumer Network exploratory analyses showed that it was possible to use these data sources to identify the subset of households that met the TFP reference family definition, made healthy food purchases, and purchased sufficient amounts of foods and beverages to reasonably cover the family's caloric needs for a week. Our small-scale assessment of the menu-based approach showed that manual implementation of this approach was also feasible, although it was labor-intensive and required several assumptions to determine the TFP market basket and cost. Among the two implementations of the econometric-based approach, only the demand system-based approach proved feasible. Even so, among the multiple demand systems we explored for this implementation, only a subset produced reasonable and plausible coefficients. None of our attempts at implementing an SPF-based approach resulted in sensical results, which we hypothesized was due to the SPF models' failure to accurately and precisely estimate the HEI scores.

9.2. Barriers to implementation

Aside from the demand system implementation of the econometric-based approach, we identified several substantial barriers to future implementation for both the purchase-based and menu-based approaches. With respect to the purchase-based approach, current data sources do not include large enough samples of reference family households to precisely determine a TFP market basket and cost in accordance with statutory requirements. Even if such a data source were to be collected, implementation of this approach would still require further consideration regarding how to translate transaction-level data into purchases intended to meet the dietary requirements of the reference family for one week as well as other decisions regarding whether to include store savings and other discounts when calculating costs. Alternatively, future implementation of this approach could explore modifying the approach to use synthetic households. As discussed in the Alternative Approaches report, these synthetic households could either be constructed by combining households whose food purchases achieve greater conformance to the DGA along a particular food category or could be constructed by weighting households of varying sizes and compositions to better reflect the demographic composition of reference family households. Although such modifications could help to overcome the small sample sizes that result from restricting the analysis to households that match the reference family composition, the expert panelists did not favor these types of modifications as they moved away from observed households' purchasing behavior and introduced additional assumptions into the approach.

Although we were able to implement a small-scale implementation of the menu-based approach manually, a larger-scale effort would almost certainly necessitate the development of new menu planning software. In addition, this approach requires a high degree of iteration to obtain menus that satisfy the numerous TFP requirements. Even with new technology, this approach is likely to be time-intensive to complete. There are also a number of assumptions and decisions required throughout the implementation process that are likely to influence the resulting TFP market basket cost and composition. For instance, the market basket nutrient composition and cost is sensitive to the specific FNDDS food codes chosen to align with menu item descriptions. These layers of assumptions contribute to a high degree of variability and potential for error and uncertainty in the estimates derived from this approach.

9.3. Meaningful differences from TFP, 2021

Only one of the two alternative approaches that yielded a TFP market basket resulted in meaningful differences from the TFP, 2021 (Exhibit 27). The menu-based approach resulted in a substantially higher cost TFP market basket, which was 60 percent more expensive than the TFP, 2021. As noted elsewhere in the report, the higher costs may have been driven by a number of factors, including the guidance provided to nutritionists, the assumptions required to link menu items to FNDDS food codes, or the fact that nutritionists did not have access to price information when developing their menus. Despite the higher cost, however, expenditure shares were comparable between the menu-based approach and the TFP, 2021 for several food and beverage categories, including dairy; meat, poultry, seafood, eggs; nuts and seeds, soy products; and beverages. In contrast, the share of expenditures was much higher in the fruits and fruit juices; vegetables; and fats, oils, and condiments categories for the menu-based approach compared to the TFP, 2021.

The demand-system-based econometric approach was practically equivalent to the TFP, 2021 with only minor variations in expenditure shares across food and beverage categories. Given the similarities between the market baskets obtained from the demand system approach and the TFP, 2021, it is not surprising that the TFP cost between the two approaches were also essentially the same with the demand system resulting in a TFP cost that was only $0.06 per day higher than the TFP, 2021.

Exhibit 27. Side-by-side comparison of TFP market baskets by approach: Aggregate modeling categories

	Costs ($ per day)			Expenditure shares (%)		
Category	TFP, 2021 (reproduce results)	Menu-based approach	Demand system econometric-based approach	TFP, 2021 (reproduce results)	Menu-based approach	Demand system econometric-based approach
Dairy	$3.98	$5.70	$3.90	14.4%	12.2%	14.1%
Meat, poultry, seafood, eggs	$6.05	$10.75	$5.96	21.9%	23.5%	21.5%
Nuts and seeds, soy products	$0.72	$0.57	$0.71	2.6%	1.2%	2.6%
Mixed dishes	$1.57	$1.00	$1.78	5.7%	2.5%	6.4%
Grains and cereals	$3.93	$3.44	$3.87	14.2%	8.0%	14.0%
Snack foods and sweets	$0.46	$1.35	$0.60	1.7%	2.8%	2.2%
Fruits and fruit juice	$3.85	$7.92	$3.84	13.9%	18.1%	13.9%
Vegetables	$6.37	$11.75	$6.34	23.1%	27.4%	22.9%
Beverages	$0.32	$0.40	$0.32	1.2%	0.7%	1.2%
Fats, oils and condiments	$0.36	$1.85	$0.34	1.3%	12.2%	1.2%

Note: To obtain the daily costs for the menu-based approach, weekly costs were divided by seven.

TFP = Thrifty Food Plan.

9.4. Feasibility under cost neutrality

For an approach to be feasible under cost neutrality, it must be able to demonstrate *whether* a cost-neutral market basket exists given current food prices, dietary guidance, food composition data, and consumption patterns. This means that the approach must be able to determine the composition of the cost-neutral market basket should one exist and also positively determine that no such market basket could be constructed in the event that one does not exist. Given these requirements, both the menu-based approach and the demand system approach are technically feasible under cost neutrality. Although neither the demand system econometric-based approach nor the menu-based approach yielded a market basket that was cost neutral to the TFP, 2021 (Exhibit 27), we expect both approaches could be technically feasible under cost neutrality. In terms of the menu-based approach, we examined two potential options that CNPP could pursue to obtain a menu-based market basket that is cost neutral. One option would substantially increase the burden placed on nutritionists developing these menus by asking them to account for cost in the development of the weekly menus, whereas the second option would use the cost-neutral threshold to exclude menus that exceeded the acceptable cost prior to computing the market basket composition. In terms of the demand system model, it is possible to incorporate a cost neutrality constraint when identifying the market basket that maximizes utility similar to the procedures that would be used to impose cost neutrality under the current optimization-based approach.

In contrast, the purchase-based approach is not feasible under cost neutrality. Setting aside the practical difficulties in identifying reference family households that purchase foods in accordance with the statutory requirements of the TFP, it is entirely possible that no households ever make food purchases that conform to the TFP requirements and are cost neutral to the TFP, 2021. However, such a finding would not be sufficient to conclude that no such market basket could be purchased. That is, even if there are no observations in existing food purchase data that meet the TFP requirements and is also cost neutral to the TFP, 2021, this would be insufficient evidence to conclude that such a market basket does not exist. For this reason, under cost neutrality, the purchase-based approach is no longer conceptually in alignment with the goals of the TFP reevaluation, rendering this approach an infeasible alternative to the current optimization-based approach.

9.5. Considerations for future work

Overall, the feasibility assessments determined that two of the three alternative approaches could technically be used to determine a cost-neutral TFP market basket. However, due to the high barriers for implementation associated with the menu-based approach, the effort and cost involved in scaling up this approach at this time would be considerable. As newer technologies, such as generative AI evolve and mature, it is possible that these barriers will lessen at which point the menu-based approach may prove a more viable alternative in the future. In comparison, the demand system approach is both technically feasible to implement and has low barriers to large-scale implementation. Nonetheless, the demand system proved more complicated to implement than the current optimization-based approach and resulted in a TFP market basket and cost that was not meaningfully different from the current approach. While this finding may suggest that it is not ultimately worth the added complexity to implement a demand system-based approach over the current optimization model, the utility functions that are generated from the demand system could potentially be used in the future to incorporate additional aspects of consumer preferences into the TFP modeling framework not feasible under the current optimization-based approach, offering a potential advantage over the current approach.

Although the expert panelists strongly preferred the purchase-based approach over both the other alternatives and the current optimization-based approach, results from our feasibility assessment coupled with the recent legislative changes to the TFP reevaluation suggest that this approach is no longer a suitable alternative method for reevaluating the TFP. Given the expert panelists' preferences for the current optimization-based approach with certain modifications over the menu-based and econometric-based alternatives, as described in greater detail in the Alternative Approaches report, a natural next step would be to conduct a similar feasibility assessment of those suggested modifications to the current optimization-based approach. Findings from that assessment coupled with those from the current feasibility assessments could jointly be used to support CNPP's goal of determining the strongest option for reevaluating the TFP given currently available data, methods, and technology.

References

Aigner, Dennis, C. A. Knox Lovell, and Peter Schmidt. 1977. "Formulation and Estimation of Stochastic Frontier Production Function Models." *Journal of Econometrics* 6 (1): 21–37. https://doi.org/10.1016/0304-4076(77)90052-5.

Berry, Steven, and Philip Haile. 2021. "Foundations of Demand Estimation." In *Handbook of Industrial Organization*, edited by Kate Ho, Ali Hortaçsu, and Alessandro Lizzeri, 4:1–62. Handbook of Industrial Organization, Volume 4. Elsevier. https://doi.org/10.1016/bs.hesind.2021.11.001.

Berry, Steven, James Levinsohn, and Ariel Pakes. 1995. "Automobile Prices in Market Equilibrium." *Econometrica* 63 (4): 841–90. https://doi.org/10.2307/2171802.

Boyd, Stephen, and Lieven Vandenberghe. 2004. *Convex Optimization*. 1st ed. Cambridge University Press. https://doi.org/10.1017/CBO9780511804441.

Center for Nutrition Policy and Promotion (CNPP). 2021a. "Thrifty Food Plan, 2021." FNS-916. Washington, D.C.: U.S. Department of Agriculture (USDA) Food and Nutrition Service (FNS). https://FNS.usda.gov/TFP.

———. 2021b. "Thrifty Food Plan, 2021: Online Supplement and Optimization Model." Washington, D.C.: U.S. Department of Agriculture (USDA) Food and Nutrition Service (FNS). https://www.fns.usda.gov/cnpp/thrifty-food-plan-2021.

———. 2023. "Healthy Eating Index (HEI) 2020 Update." September 14, 2023. https://www.fns.usda.gov/cnpp/healthy-eating-index-hei.

———. 2025. "USDA Food Plans: Monthly Cost of Food Reports." Washington, D.C.: U.S. Department of Agriculture (USDA) Food and Nutrition Service (FNS). https://www.fns.usda.gov/cnpp/usda-food-plans-cost-food-monthly-reports.

Deaton, Angus, and John Muellbauer. 1980. "An Almost Ideal Demand System." *American Economic Review* 70 (3): 312–26.

Diamond, Steven. 2013. "Disciplined Convex Programming." Stanford University. 2013. https://dcp.stanford.edu.

Diamond, Steven, and Stephen Boyd. 2016. "CVXPY: A Python-Embedded Modeling Language for Convex Optimization." *Journal of Machine Learning Research*, https://www.cvxpy.org, 17 (83): 1–5.

Domahidi, A., E. Chu, and S. Boyd. 2013. "ECOS: An SOCP Solver for Embedded Systems." In *European Control Conference (ECC)*, 3071–76. https://github.com/embotech/ecos.

Ferrier, Peyton M, and Chen Zhen. 2017. "The Role of Income in Explaining the Shift from Preserved to Fresh Vegetable Purchases." *Journal of Agricultural and Resource Economics* 42 (3).

Fu, Anqi, and Balasubramanian Narasimhan. 2015. "ECOSolveR: Embedded Conic Solver in R." R. DOI: 10.32614/CRAN.package.ECOSolveR. CRAN. https://CRAN.R-project.org/package=ECOSolveR.

Fu, Anqi, Balasubramanian Narasimhan, and Stephen Boyd. 2020. "CVXR: An R Package for Disciplined Convex Optimization." *Journal of Statistical Software* 94 (14): 1–34. https://doi.org/10.18637/jss.v094.i14.

Fu, Anqi, Balasubramanian Narasimhan, David W Kang, Steven Diamond, and John Miller. 2017. "CVXR: Disciplined Convex Optimization." R. DOI: 10.32614/CRAN.package.CVXR. CRAN. https://CRAN.R-project.org/package=CVXR.

GAMS Software GmbH. 2024a. "GAMS Info." GAMS Development Corp. December 12, 2024. https://gams.com/products/.

———. 2024b. "Ordering and Pricing Information." GAMS Development Corp. April 1, 2024. https://gams.com/buy_gams/.

Goulart, Paul J., and Yuwen Chen. 2024. "Clarabel: An Interior-Point Solver for Conic Programs with Quadratic Objectives." arXiv. https://doi.org/10.48550/ARXIV.2405.12762.

Government Accountability Office. 2022. "Thrifty Food Plan: Better Planning and Accountability Could Help Ensure Quality of Future Reevaluations | U.S. GAO." GAO-23-105450. Washington, D.C. https://www.gao.gov/products/gao-23-105450.

Greene, William H. 1993. *Econometric Analysis*. Upper Saddle River, N.J: Prentice Hall.

Hu, Mengyao, John A. Kirlin, Brady T. West, Wenyi He, Ai Rene Ong, Shiyu Zhang, and Xingyou Zhang. "Estimation of underreporting in diary surveys: an application using the National Household Food Acquisition and purchase survey." *Journal of Survey Statistics and Methodology* 8, no. 5 (2020): 877-902.

Jones, Christopher, Alice Ann Gola, and Sarah Bardin. 2024. "Alternative Approaches for Reevaluating the Thrifty Food Plan: An Expert Panel's Perspective: Final Report." Report submitted to the Center for Nutrition Policy and Promotion (CNPP) in the USDA's Food and Nutrition Service (FNS). Chicago: Mathematica.

Kranker, Keith. 2024. "Econometric-Based Approaches to Reevaluate the Thrifty Food Plan." Report submitted to the Center for Nutrition Policy and Promotion (CNPP), Food and Nutrition Service (FNS), U.S. Department of Agriculture (USDA). Princeton, N.J.: Mathematica.

Krebs-Smith, Susan M., TusaRebecca E. Pannucci, Amy F. Subar, Sharon I. Kirkpatrick, Jennifer L. Lerman, Janet A. Tooze, Magdalena M. Wilson, and Jill Reedy. 2018. "Update of the Healthy Eating Index: HEI-2015." *Journal of the Academy of Nutrition and Dietetics* 118 (9): 1591–1602. https://doi.org/10.1016/j.jand.2018.05.021.

Kumbhakar, Subal C., Hung-Jen Wang, and Alan Horncastle. 2015. *A Practitioner's Guide to Stochastic Frontier Analysis Using Stata*. 1st ed. New York: Cambridge University Press. https://doi.org/10.1017/CBO9781139342070.

Lewbel, Arthur, and Krishna Pendakur. 2009. "Tricks with Hicks: The EASI Demand System." *American Economic Review* 99 (3): 827–63. https://doi.org/10.1257/aer.99.3.827.

Li, Xun, and Rigoberto A. Lopez. 2016. "Food Environment and Weight Outcomes: A Stochastic Frontier Approach." *Applied Economics* 48 (47): 4526–37. https://doi.org/10.1080/00036846.2016.1161715.

Mancino, Lisa, Jessica E. Todd, and Benjamin Scharadin. 2018. "USDA's National Household Food Acquisition and Purchase Survey: Methodology for Imputing Missing Quantities to Calculate Healthy Eating Index-2010 Scores and Sort Foods into ERS Food Groups." Technical Bulletin TB-1947. Washington D.C.: Economic Research Service. https://www.ers.usda.gov/publications/pub-details?pubid=87012.

Mas-Colell, Andreu, Michael D. Whinston, and Jerry R. Green. 1995. *Microeconomic Theory*. New York, NY: Oxford University Press.

Moreira, Víctor H., and Boris E. Bravo-Ureta. 2010. "Technical Efficiency and Metatechnology Ratios for Dairy Farms in Three Southern Cone Countries: A Stochastic Meta-Frontier Model." *Journal of Productivity Analysis* 33 (1): 33–45. https://doi.org/10.1007/s11123-009-0144-8.

Narasimhan, Balasubramanian, Paul Goulart, and Yuwen Chen. 2023. "Clarabel: Interior Point Conic Optimization Solver." R. DOI: 10.32614/CRAN.package.clarabel. CRAN. https://CRAN.R-project.org/package=clarabel.

National Cancer Institute (NCI). 2025. "Healthy Eating Index (HEI) SAS Code." SAS. Division of Cancer Control and Population Science. https://epi.grants.cancer.gov/hei/sas-code.html.

National Cancer Institute (NCI) and Center for Nutrition Policy and Promotion (CNPP). 2024. "Healthy Eating Index (HEI)." NCI Epidemiology and Genomics Research Program. August 19, 2024. https://epi.grants.cancer.gov/hei/.

National Center for Health Statistics (NCHS). 2020. "National Health and Nutrition Examination Survey (NHANES)." https://www.cdc.gov/nchs/nhanes/.

National Center for Health Statistics (NCHS) and Beltsville Human Nutrition Research Center (BHNRC). 2021. "National Health and Nutrition Examination Survey (NHANES), What We Eat in America (WWEIA)." https://wwwn.cdc.gov/nchs/nhanes/default.aspx.

O'Donoghue, Brendan, Eric Chu, Parikh Neal, and Stephen Boyd. 2016. "Operator Splitting for Conic Optimization via Homogeneous Self-Dual Embedding." *Journal of Optimization Theory and Applications* 169 (3): 1042–68. https://doi.org/10.1007/s10957-016-0892-3.

OpenAI. 2025. ChatGPT (o3). https://chat.openai.com/.

Papastratis I, Konstantinidis D, Daras P, et al. AI nutrition recommendation using a deep generative model and ChatGPT. *Scientific Reports*. 2024;14:14620. doi:10.1038/s41598-024-65438-x.

Public Law 115 - 334. 2018. *2018 Farm Bill*. https://www.govinfo.gov/app/details/PLAW-115publ334/.

Schwendinger, Florian, Brendan O'Donoghue, and Balasubramanian Narasimhan. 2016. "SCS: Splitting Conic Solver." R. DOI: 10.32614/CRAN.package.scs. CRAN. https://CRAN.R-project.org/package=scs.

Shams-White, Marissa M., TusaRebecca E. Pannucci, Jennifer L. Lerman, Kirsten A. Herrick, Meghan Zimmer, Kevin Meyers Mathieu, Eve E. Stoody, and Jill Reedy. 2023. "Healthy Eating Index-2020: Review and Update Process to Reflect the Dietary Guidelines for Americans, 2020-2025." *Journal of the Academy of Nutrition and Dietetics* 123 (9): 1280–88. https://doi.org/10.1016/j.jand.2023.05.015.

StataCorp. 2023a. "Demandsys: Estimation of Flexible Demand Systems." Stata. College Station, Texas: StataCorp. https://www.stata.com/manuals/rdemandsys.pdf.

———. 2023b. "Frontier: Stochastic Frontier Models." Stata. College Station, Texas: StataCorp. https://www.stata.com/manuals/rfrontier.pdf.

Stone, Richard. 1954. "Linear Expenditure Systems and Demand Analysis: An Application to the Pattern of British Demand." *The Economic Journal* 64 (255): 511. https://doi.org/10.2307/2227743.

Theussl, Stefan, and Kurt Hornik. 2013. “Rglpk: R/GNU Linear Programming Kit Interface.” R. DOI: 10.32614/CRAN.package.Rglpk. CRAN. https://CRAN.R-project.org/package=Rglpk.

Udell, Madeleine, Karanveer Mohan, David Zeng, Jenny Hong, Steven Diamond, and Stephen Boyd. 2014. “Convex.Jl: Convex Optimization in Julia.” Julia. SC14 Workshop on High Performance Technical Computing in Dynamic Languages. https://jump.dev/Convex.jl/stable/.

U.S. Department of Agriculture and U.S. Department of Health and Human Services. 2020. “Dietary Guidelines for Americans, 2020-2025.” 9th Edition. https://DietaryGuidelines.gov.

United States. Executive Office of the President. (2025, May 23). Restoring Gold Standard Science (Exec. Order No. 14303). The White House.

Yu, Yang, and Edward C. Jaenicke. 2020. “Estimating Food Waste as Household Production Inefficiency.” *American Journal of Agricultural Economics* 102 (2): 525–47. https://doi.org/10.1002/ajae.12036.

Yan, Ting, and Aaron Maitland. "Review of the FoodAPS 2012 instrument design, response burden, use of incentives, and response rates." *Washington (DC): Economic Research Service, USDA* (2016).

Zhen, Chen, Yu Chen, Biing-Hwan Lin, Shawn Karns, Lisa Mancino, and Michele Ver Ploeg. 2024. “Do Obese and Nonobese Consumers Respond Differently to Price Changes? Implications of Preference Heterogeneity for Obesity-Oriented Food Taxes and Subsidies.” *American Journal of Agricultural Economics* 106 (3): 1058–88. https://doi.org/10.1111/ajae.12418.

Zhen, Chen, Eric A. Finkelstein, James M. Nonnemaker, Shawn A. Karns, and Jessica E. Todd. 2014. “Predicting the Effects of Sugar-Sweetened Beverage Taxes on Food and Beverage Demand in a Large Demand System.” *American Journal of Agricultural Economics* 96 (1): 1–25. https://doi.org/10.1093/ajae/aat049.

Appendices

Appendix A. Guidance to nutritionists for menu-based approach

Please use the following guidance on how to develop menus and the materials to submit.

A.1. Guidance for developing menus

1. Develop 5 weeks of distinct daily menus that include healthy, thrifty meals prepared at home.
   - Week 1: Monday through Sunday (7 daily menus)
   - Week 2: Monday through Sunday (7 daily menus)
   - Week 3: Monday through Sunday (7 daily menus)
   - Week 4: Monday through Sunday (7 daily menus)
   - Week 5: Monday through Sunday (7 daily menus)
2. For each daily menu, include breakfast, lunch, dinner, and one snack. Include foods and beverages.
3. The menus should be planned with the following considerations.
   - Be designed to be lower cost or budget-friendly.
   - Include foods and ingredients that are available to the clientele your program serves.
   - Consider the palatability of meals for adults and elementary school-aged children, and include spices, condiments, and sauces as appropriate.
   - Consider convenience and practicality, such as the form of food to purchase (e.g., refrigerated and ready-to-serve versus shelf stable, dry), preparation time, and kitchen/cooking equipment needed.
   - Incorporate strategies to reduce food waste, such as including frozen and shelf-stable items and using the same foods/ingredients multiple times across the week.
   - Include variation in the types of foods and beverages represented each day. In terms of variation across the week, it is okay to repeat some of the meals (especially at breakfast and lunch) and assume use of leftovers.
   - Be newly developed for this project but can incorporate existing recipes that your program has developed.
4. Design the menus to meet the nutritional needs of a reference family of four, comprising a man and a woman ages 20 to 50 and two children—one between the ages of 6 and 8 and one between the ages of 9 and 11.
5. The menus should be consistent with the Healthy U.S.-Style Dietary Patterns specified in the [2020-2025 Dietary Guidelines for Americans] (Table A3-2). These dietary patterns provide recommendations on daily or weekly amounts of food groups and subgroups (for example, cup equivalents of fruits and ounce equivalents of grains) for an individual to consume based on an appropriate daily calorie level, while limiting amounts of added sugars, refined starches, saturated fat, and sodium.
6. The Dietary Guidelines also specify limits on saturated fat and added sugar—less than 10 percent of calories from saturated fat per day, and less than 10 percent of calories from added sugars per day.
7. USDA has published an appropriate daily calorie level for each reference family member and the associated daily or weekly amounts of food groups and subgroups. Recommend amounts for some food groups are specified at the daily level, while others are specified at the weekly level—specifically vegetable subgroups and protein foods subgroups.

8. The individual amounts have been summed across the four family members to create total daily or weekly recommended amounts of calories, food groups, and subgroups. These amounts, which are shown in **Exhibit A.1**, reflect the combined nutritional needs of the reference family of four.
    - The calorie goal is also listed in **Exhibit A.1** as a range of calories.
    - The amounts of food groups and subgroup listed in **Exhibit A.1** are **minimum amounts**, which can be exceeded on a daily menu or across the week.
9. Your goal is to plan each daily menu (for example, Monday of Week 1, Tuesday of Week 1, etc.) to meet the **<u>combined</u>** nutritional needs of the reference family. In addition, your goal is to plan menus across the week (for example, Monday through Sunday of Week 1) that meet weekly recommended amounts shown in Exhibit A.1.
10. The specified calorie range and the minimum amounts of food groups and subgroups for the reference family (listed in **Exhibit A.1**) should be used as a guide when planning daily and weekly menus; however, they do not need to be met exactly. As recommended in the Dietary Guidelines, try to choose a variety of foods in each group and subgroup over time in recommended amounts, and limit choices that are not in nutrient-dense forms so that the overall calorie limit is not exceeded.
11. As shown in **Exhibit A.1**, the goal is to plan each daily menu to include around 9,200 calories, at least 12.5 cup equivalents of vegetables, at least 8 cup equivalents of fruit, at least 30-ounce equivalents of grains (with at least half being whole grains), at least 11.5 cup equivalents of dairy, 24 ounce equivalents of protein foods, and 126 grams of oils. The daily menus should also be planned to include less than 10 percent of calories from saturated fat and less than 10 percent of calories for added sugars.

    Over the course of a week, the goal is to plan the menus to include minimum amounts of vegetable subgroups and protein food groups to meet the minimum weekly amounts specified in **Exhibit A.1**. For example, week 1 of menus should include at least 8 cup equivalents of dark-green vegetables, at least 25 cup equivalents of red and orange vegetables, etc.

Appendix Exhibit A.1. Nutritional goals for planning menus: Total daily or weekly amounts of calories, food groups, and subgroups for the reference family

Food groups and subgroups	Unit	Daily amounts for the reference family	Weekly amounts for the reference family
Calories	calories	9,200	
	range of calories	9,154 to 9,246	
Saturated fat	% of calories	< 10%	
Added sugars	% of calories	< 10%	
Food groups		**Minimum amounts**	**Minimum amounts**
Vegetables	cup equivalents	12.5	
Dark-green vegetables	cup equivalents		8
Red and orange vegetables	cup equivalents		25
Beans, peas, legumes	cup equivalents		8.5
Starchy vegetables	cup equivalents		25
Other vegetables	cup equivalents		21
Fruits	cup equivalents	8	
Grains	ounce equivalents	30	
Whole grains	ounce equivalents	15	
Refined grains	ounce equivalents	15	
Dairy	cup equivalents	11.5	
Protein foods	ounce equivalents	24	
Meats, poultry, eggs	ounce equivalents		112
Seafood	ounce equivalents		36
Nuts, seeds, soy products	ounce equivalents		20
Oils	grams	126	

A.2. Materials to prepare and submit to Mathematica

1. Enter menus into the Excel template provided. There is one column for each day of the week and a set of rows for each meal (breakfast, lunch, dinner, and snack).
2. Save a copy of the file for each of the 5 weeks of menus. Name each file with your last name and the week number for the menu (for example, Name_Week 1). At the top of each file, enter in the Week number and your name.
3. Ensure the following information is included when entering your menus into the file:
    a. For each item: Food name and details about each food item including the form (such as fresh, canned, frozen, refrigerated, dry, raw, cooked, ready-to-eat/drink, etc.).
    b. For each item: Include the amount for the reference family to prepare (include number of units and unit of measure; for example, 2 cups or 16 oz).
    c. Use red font to identify items prepared from a recipe.

4. Provide recipes for any items prepared by combining two or more ingredients. Ensure recipes include the following information:
   - Name of food item.
   - Recipe yield and size of one serving (e.g., makes 6 servings, 1/2 cup each).
   - Ingredient names and details (including form).
   - Ingredient amounts (include number of units and units of measure).
   - Preparation instructions.
   - Preparation time and cooking time.
   - Nutrition information (per serving), if available.
5. Provide responses to questions in the *Menu Development Questionnaire* and submit copies of resources or materials used when planning the menus. The *Menu Development Questionnaire* asks about the following:
   - Amount of time it took you to develop each of the 5 weekly menus and corresponding recipes.
   - Names of any resources you used to develop the menus or recipes.
     – Please submit copies of resources if feasible.
   - Whether you used any menu or meal planning software, and if so, the name of it.
     – Please submit copies of any reports from the software that you used, if feasible.
   - Questions or considerations you had while developing the menus and recipes.

A.3. Next steps

1. Develop the 5 weekly menus and corresponding recipes using the guidance and template provided.
2. Answer questions in the *Menu Development Questionnaire*.
3. Submit the following to Mathematica by **[insert date]**:
   a. 5 Excel files with your 5 weekly menus
   b. Recipes
   c. Completed *Menu Development Questionnaire*
   d. Copies of resources or materials used when planning the menus
4. Participate in a 30-minute debriefing call with Mathematica to provide feedback on the activity, guidance provided, and considerations for the future. Mathematica will reach out to schedule this call.

Appendix B. Reproducing the TFP, 2021 market baskets

The analyses described in Sections 7.6 and 8.6 and Chapters 7 and 8 (respectively) used disciplined convex programming (DCP) to compute alternative TFP market baskets by way of solving constrained optimization problems. In most cases, these optimization problems were variants of the optimization problems that CNPP had used to compute the TFP, 2021 market baskets (CNPP 2021b) and largely used the same input data. We replicated CNPP's results using DCP using the `cvxr` package for the R programming language (Fu, Narasimhan, and Boyd 2020). This ensured that we had the correct input data and served as a starting point for implementing our analyses.

We successfully reproduced CNPP's published results, both overall (Appendix Exhibit B.1) and for the TFP modeling categories (Appendix Exhibit B.2). In both tables presented below, our results in column 1, substantively match CNPP's published results in column 2. Specifically, we fully reproduced a market basket with the same total TFP market basket cost as CNPP, the same distance from current consumption, and the same Healthy Eating Index (HEI) scores, and confirmed that all constraints were met. We also reproduced the same TFP modeling category quantities and costs at five decimal places' precision for the reference family.[56]

[56] CNPP reported results for the TFP modeling category quantities at 5 decimal places, but our solution from the DCP solver are more precise, with quantities reported to more than 5 decimal places. We used the more detailed quantities for all calculations.

Appendix Exhibit B.1. Using disciplined convex programming to reproduce previous results: Summary statistics

Result	1. TFP, 2021 (reproduce results)	2. Published TFP, 2021 solution
Successfully solved for the reference family's four age-sex groups?	✓	✓
Market basket cost ($ per day)[b]	$27.6000	$27.6000
Distance of combined modeling categories from current consumption (10,000 $gram^2$ units)[b]	5.857	5.857
Distance of combined modeling categories from the published TFP, 2021 solution (10,000 $gram^2$ units)[b]	2.185×10^{-11}	1.419×10^{-21} [a]
Mean squared error distance of TFP modeling categories from the TFP, 2021 solution (100 gram units)[b]	8.050×10^{-12}	2.477×10^{-22} [a]
Energy (kcal)[b]	9,611.7	9,611.7
Calculated HEI-2020 score (0-100)[c]	94.0	94.0[a]
SPF-predicted HEI-2020 score (average inefficiency)[c]	—	—
SPF-predicted HEI-2020 score (no inefficiency)[c]	—	—
Any combined modeling categories with zero quantity?	✓	✓[a]
Number of combined modeling categories with zero quantity?[b]	29	72[a]
Any combined modeling categories with near-zero (< 1e-9) quantity?	✓	✓[a]
Number of combined modeling categories with near-zero (< 1e-9) quantity?[b]	71	72[a, d]
Demand system-predicted utility[b]	0	0[a, d]
Demand system-predicted log(utility)[b]	−Inf	−Inf[a,d]
All TFP, 2021 nutrient constraints met?	✓	✗[a,d]
Number of TFP, 2021 nutrient and food group constraints met[b]	376	373[a, a]
All TFP, 2021 practicality constraints met?	✓	✓[a]
Number of TFP, 2021 practicality constraints met[b]	112	112[a]
Gini impurity of the TFP modeling category expenditure shares (0-1)	0.946	0.946[a]
Gini impurity of the combined modeling category expenditure shares (0-1)	0.929	0.929[a]
Entropy of the TFP modeling category expenditure shares (0-1)	0.230	0.230[a]
Entropy of the combined modeling category expenditure shares (0-1)	0.268	0.268[a]

[a] This result was not published by CNPP (2021b). To obtain it, we used disciplined convex programming to minimize distance between the TFP food modeling categories and the published *TFP, 2021* solution (without any constraints) to many decimal places, then performed the same calculations used elsewhere.

[b] Sum across the reference family's age-sex groups.

[c] Average across the reference family's age-sex groups.

[d] Assessed using quantities rounded to 5 decimal places.

HEI = Healthy Eating Index; TFP = Thrifty Food Plan.

Appendix Exhibit B.2. Using disciplined convex programming to reproduce previous results: 95 TFP modeling categories

TFP modeling category	Quantities (100 gram units)		Costs ($ per day)		Expenditure shares (%)	
	1. TFP, 2021 (reproduce results)	2. Published TFP, 2021 solution	1. TFP, 2021 (reproduce results)	2. Published TFP, 2021 solution	1. TFP, 2021 (reproduce results)	2. Published TFP, 2021 solution
Dairy						
Cheese - higher cost	0.0000000	0.00000	$0.00	$0.00	0.0%	0.0%
Cheese - lower cost	0.3894594	0.38946	$0.32	$0.32	1.2%	1.2%
Milk and yogurt - higher nutrient density	16.4031980	16.40320	$2.14	$2.14	7.7%	7.7%
Milk and yogurt - lower nutrient density	10.1633574	10.16336	$1.52	$1.52	5.5%	5.5%
Meat, poultry, seafood, eggs						
Meat - higher nutrient density - higher cost	0.0000000	0.00000	$0.00	$0.00	0.0%	0.0%
Meat - higher nutrient density - lower cost	0.0000000	0.00000	$0.00	$0.00	0.0%	0.0%
Meat - lower nutrient density - higher cost	0.0000000	0.00000	$0.00	$0.00	0.0%	0.0%
Meat - lower nutrient density - lower cost	1.3223890	1.32239	$1.28	$1.28	4.6%	4.6%
Poultry - higher nutrient density - higher cost	0.0000000	0.00000	$0.00	$0.00	0.0%	0.0%
Poultry - higher nutrient density - lower cost	3.4783040	3.47831	$2.47	$2.47	8.9%	8.9%
Poultry - lower nutrient density - higher cost	0.0000000	0.00000	$0.00	$0.00	0.0%	0.0%
Poultry - lower nutrient density - lower cost	0.0000000	0.00000	$0.00	$0.00	0.0%	0.0%
Seafood - higher cost	0.0000000	0.00000	$0.00	$0.00	0.0%	0.0%
Seafood - lower cost	1.7604254	1.76043	$1.91	$1.91	6.9%	6.9%
Eggs	1.0839009	1.08389	$0.39	$0.39	1.4%	1.4%
Cured meat	0.0000000	0.00000	$0.00	$0.00	0.0%	0.0%
Nuts and seeds, soy products						
Nuts and Seeds - higher nutrient density	0.0000000	0.00000	$0.00	$0.00	0.0%	0.0%
Nuts and Seeds - lower nutrient density	0.0000000	0.00000	$0.00	$0.00	0.0%	0.0%
Nut and seed butters	1.2739941	1.27399	$0.72	$0.72	2.6%	2.6%
Processed soy products	0.0000000	0.00000	$0.00	$0.00	0.0%	0.0%

TFP modeling category	Quantities (100 gram units)		Costs ($ per day)		Expenditure shares (%)	
	1. TFP, 2021 (reproduce results)	2. Published TFP, 2021 solution	1. TFP, 2021 (reproduce results)	2. Published TFP, 2021 solution	1. TFP, 2021 (reproduce results)	2. Published TFP, 2021 solution
Mixed dishes						
Mixed Dishes - Eggs - higher nutrient density	0.2637079	0.26371	$0.10	$0.10	0.4%	0.4%
Mixed Dishes - Eggs - lower nutrient density	0.0000000	0.00000	$0.00	$0.00	0.0%	0.0%
Mixed Dishes - Vegetables - higher nutrient density - higher cost	0.0000000	0.00000	$0.00	$0.00	0.0%	0.0%
Mixed Dishes - Vegetables - higher nutrient density - lower cost	0.2255905	0.22559	$0.07	$0.07	0.3%	0.3%
Mixed Dishes - Vegetables - lower nutrient density - higher cost	0.0000000	0.00000	$0.00	$0.00	0.0%	0.0%
Mixed Dishes - Vegetables - lower nutrient density - lower cost	0.4697962	0.46979	$0.17	$0.17	0.6%	0.6%
Mixed Dishes - Meat-Poultry-Seafood - higher nutrient density - higher cost	0.0000000	0.00000	$0.00	$0.00	0.0%	0.0%
Mixed Dishes - Meat-Poultry-Seafood - higher nutrient density - lower cost	0.0000000	0.00000	$0.00	$0.00	0.0%	0.0%
Mixed Dishes - Meat-Poultry-Seafood - lower nutrient density - higher cost	0.0000000	0.00000	$0.00	$0.00	0.0%	0.0%
Mixed Dishes - Meat-Poultry-Seafood - lower nutrient density - lower cost	0.0000000	0.00000	$0.00	$0.00	0.0%	0.0%
Mixed Dishes - Grain based - higher nutrient density - higher cost	0.0000000	0.00000	$0.00	$0.00	0.0%	0.0%
Mixed Dishes - Grain based - higher nutrient density - lower cost	2.6668538	2.66685	$0.59	$0.59	2.1%	2.1%
Mixed Dishes - Grain based - lower nutrient density - higher cost	0.0000000	0.00000	$0.00	$0.00	0.0%	0.0%
Mixed Dishes - Grain based - lower nutrient density - lower cost	0.0000000	0.00000	$0.00	$0.00	0.0%	0.0%
Mixed Dishes - Pizza - higher nutrient density - higher cost	0.0000000	0.00000	$0.00	$0.00	0.0%	0.0%
Mixed Dishes - Pizza - higher nutrient density - lower cost	0.0000000	0.00000	$0.00	$0.00	0.0%	0.0%
Mixed Dishes - Pizza - lower nutrient density - higher cost	0.0000000	0.00000	$0.00	$0.00	0.0%	0.0%

TFP modeling category	Quantities (100 gram units)		Costs ($ per day)		Expenditure shares (%)	
	1. TFP, 2021 (reproduce results)	2. Published TFP, 2021 solution	1. TFP, 2021 (reproduce results)	2. Published TFP, 2021 solution	1. TFP, 2021 (reproduce results)	2. Published TFP, 2021 solution
Mixed Dishes - Pizza - lower nutrient density - lower cost	0.2995585	0.29956	$0.20	$0.20	0.7%	0.7%
Mixed Dishes - Sandwiches - higher nutrient density - higher cost	0.0000000	0.00000	$0.00	$0.00	0.0%	0.0%
Mixed Dishes - Sandwiches - higher nutrient density - lower cost	0.0000000	0.00000	$0.00	$0.00	0.0%	0.0%
Mixed Dishes - Sandwiches - lower nutrient density - higher cost	0.0000000	0.00000	$0.00	$0.00	0.0%	0.0%
Mixed Dishes - Sandwiches - lower nutrient density - lower cost	0.5223435	0.52235	$0.30	$0.30	1.1%	1.1%
Mixed Dishes - Soups - higher nutrient density - higher cost	0.0000000	0.00000	$0.00	$0.00	0.0%	0.0%
Mixed Dishes - Soups - higher nutrient density - lower cost	0.9250749	0.92507	$0.11	$0.11	0.4%	0.4%
Mixed Dishes - Soups - lower nutrient density - higher cost	0.0000000	0.00000	$0.00	$0.00	0.0%	0.0%
Mixed Dishes - Soups - lower nutrient density - lower cost	0.0000000	0.00000	$0.00	$0.00	0.0%	0.0%
Mixed Dishes - Beans-peas-lentils - higher nutrient density - higher cost	0.0839929	0.08399	$0.03	$0.03	0.1%	0.1%
Mixed Dishes - Beans-peas-lentils - higher nutrient density - lower cost	0.0000000	0.00000	$0.00	$0.00	0.0%	0.0%
Mixed Dishes - Beans-peas-lentils - lower nutrient density - higher cost	0.0000000	0.00000	$0.00	$0.00	0.0%	0.0%
Mixed Dishes - Beans-peas-lentils - lower nutrient density - lower cost	0.0000000	0.00000	$0.00	$0.00	0.0%	0.0%
Grains and cereals						
Grains - higher nutrient density - higher cost	0.0000000	0.00000	$0.00	$0.00	0.0%	0.0%
Grains - higher nutrient density - lower cost	5.2186333	5.21863	$2.19	$2.19	7.9%	7.9%
Grains - lower nutrient density - higher cost	0.0000000	0.00000	$0.00	$0.00	0.0%	0.0%
Grains - lower nutrient density - lower cost	4.3617531	4.36175	$1.10	$1.10	4.0%	4.0%
Biscuits-muffins-quick breads	0.0000000	0.00000	$0.00	$0.00	0.0%	0.0%

TFP modeling category	Quantities (100 gram units)		Costs ($ per day)		Expenditure shares (%)	
	1. TFP, 2021 (reproduce results)	2. Published TFP, 2021 solution	1. TFP, 2021 (reproduce results)	2. Published TFP, 2021 solution	1. TFP, 2021 (reproduce results)	2. Published TFP, 2021 solution
Breakfast cereals - higher nutrient density	1.8789387	1.87894	$0.45	$0.45	1.6%	1.6%
Breakfast cereals - lower nutrient density	0.3538827	0.35388	$0.20	$0.20	0.7%	0.7%
Snack foods and sweets						
Tortilla-corn-other chips	0.0878615	0.08786	$0.09	$0.09	0.3%	0.3%
Popcorn - higher nutrient density	0.0000000	0.00000	$0.00	$0.00	0.0%	0.0%
Popcorn - lower nutrient density	0.1359440	0.13595	$0.10	$0.10	0.4%	0.4%
Pretzels-snack mix	0.0000000	0.00000	$0.00	$0.00	0.0%	0.0%
Crackers - higher nutrient density	0.0000000	0.00000	$0.00	$0.00	0.0%	0.0%
Crackers - lower nutrient density	0.0000000	0.00000	$0.00	$0.00	0.0%	0.0%
Snack-Meal Bars	0.0518297	0.05183	$0.08	$0.08	0.3%	0.3%
Sweet bakery products	0.0000000	0.00000	$0.00	$0.00	0.0%	0.0%
Candy	0.0000000	0.00000	$0.00	$0.00	0.0%	0.0%
Other Desserts	0.2500374	0.25004	$0.11	$0.11	0.4%	0.4%
Sugars	0.1955561	0.19556	$0.08	$0.08	0.3%	0.3%
Fruits and fruit juice						
Fruit - higher nutrient density - higher cost	0.0000000	0.00000	$0.00	$0.00	0.0%	0.0%
Fruit - higher nutrient density - lower cost	8.2424317	8.24244	$2.76	$2.76	10.0%	10.0%
Fruit - lower nutrient density - higher cost	0.0000000	0.00000	$0.00	$0.00	0.0%	0.0%
Fruit - lower nutrient density - lower cost	0.0000000	0.00000	$0.00	$0.00	0.0%	0.0%
100 percent fruit juice - higher cost	0.5184871	0.51849	$0.11	$0.11	0.4%	0.4%
100 percent fruit juice - lower cost	5.6832962	5.68329	$0.98	$0.98	3.5%	3.5%
Vegetables						
Red orange vegetables - higher cost	0.8410241	0.84102	$0.47	$0.47	1.7%	1.7%
Red orange vegetables - lower cost	3.7586726	3.75866	$1.30	$1.30	4.7%	4.7%
Dark green vegetables - higher cost	0.0000000	0.00000	$0.00	$0.00	0.0%	0.0%
Dark green vegetables - lower cost	1.6863755	1.68638	$0.83	$0.83	3.0%	3.0%
Other vegetables and vegetable combinations - higher cost	0.0000000	0.00000	$0.00	$0.00	0.0%	0.0%

TFP modeling category	Quantities (100 gram units)		Costs ($ per day)		Expenditure shares (%)	
	1. TFP, 2021 (reproduce results)	2. Published TFP, 2021 solution	1. TFP, 2021 (reproduce results)	2. Published TFP, 2021 solution	1. TFP, 2021 (reproduce results)	2. Published TFP, 2021 solution
Other vegetables and vegetable combinations - lower cost	3.9669892	3.96700	$1.33	$1.33	4.8%	4.8%
Starchy vegetables - higher cost	0.0000000	0.00000	$0.00	$0.00	0.0%	0.0%
Starchy vegetables - lower cost	3.1309533	3.13095	$0.91	$0.91	3.3%	3.3%
Beans - peas - lentils	2.4740492	2.47405	$0.76	$0.76	2.7%	2.7%
Other fried potato products	0.9424718	0.94247	$0.78	$0.78	2.8%	2.8%
Beverages						
Fruit drinks - higher nutrient density	0.0000000	0.00000	$0.00	$0.00	0.0%	0.0%
Fruit drinks - lower nutrient density	0.0000000	0.00000	$0.00	$0.00	0.0%	0.0%
Soft drinks	0.0000000	0.00000	$0.00	$0.00	0.0%	0.0%
Diet beverages	0.0000000	0.00000	$0.00	$0.00	0.0%	0.0%
Coffee and Tea - higher nutrient density	3.8592966	3.85930	$0.20	$0.20	0.7%	0.7%
Coffee and Tea - lower nutrient density	0.9407034	0.94070	$0.12	$0.12	0.4%	0.4%
Other beverages - smoothies grain-based milk substitutes nutritional beverages	0.0000000	0.00000	$0.00	$0.00	0.0%	0.0%
Fats, oils and condiments						
Butter and animal fats	0.0610000	0.06100	$0.06	$0.06	0.2%	0.2%
Margarine and oils	0.5897925	0.58980	$0.30	$0.30	1.1%	1.1%
Condiments and Sauces - higher cost	0.0000000	0.00000	$0.00	$0.00	0.0%	0.0%
Condiments and Sauces - lower cost	0.0000000	0.00000	$0.00	$0.00	0.0%	0.0%

Note: Quantities may be reported as zero due to rounding.
TFP = Thrifty Food Plan.

Appendix C. The demand system- and SPF-based market baskets: Detailed results

This appendix provides detailed tables with additional information about the demand system-based alternative Thrifty Food Plan (TFP) market basket from Chapter 7 and the stochastic production frontier (SPF)-based TFP market basket from Chapter 8.

C.1. Demand system approach

The following two tables present the quantities, costs, and expenditure shares for the 45 combined modeling categories and the 95 TFP food modeling categories from the demand system-based alternative TFP market basket from Chapter 7. At this level of granularity there are some differences between the two market baskets, although differences tend to be relatively minor.

Appendix Exhibit C.1. The demand system-based TFP market basket: 45 combined modeling categories

	Quantities (100 gram units)		Costs ($ per day)		Expenditure shares (%)	
Combined modeling category	TFP, 2021 (reproduce results)	Demand system approach	TFP, 2021 (reproduce results)	Demand system approach	TFP, 2021 (reproduce results)	Demand system approach
Dairy						
Cheese	0.38946	0.12506	$0.32	$0.10	1.2%	0.4%
Milk and yogurt	26.56656	27.59496	$3.66	$3.79	13.2%	13.7%
Meat, poultry, seafood, eggs						
Meat	1.32239	1.23562	$1.28	$1.20	4.6%	4.3%
Poultry	3.47830	3.43671	$2.47	$2.44	8.9%	8.8%
Seafood	1.76043	1.76043	$1.91	$1.91	6.9%	6.9%
Eggs	1.08390	1.02507	$0.39	$0.37	1.4%	1.3%
Cured meat	0.00000	0.03458	$0.00	$0.05	0.0%	0.2%
Nuts and seeds, soy products						
Nuts and Seeds	0.00000	0.00317	$0.00	$0.00	0.0%	0.0%
Nut and seed butters	1.27399	1.25371	$0.72	$0.71	2.6%	2.6%
Processed soy products	0.00000	0.00000	$0.00	$0.00	0.0%	0.0%
Mixed dishes						
Mixed Dishes - Eggs	0.26371	0.20683	$0.10	$0.08	0.4%	0.3%
Mixed Dishes - Vegetables	0.69539	0.69539	$0.24	$0.23	0.9%	0.8%
Mixed Dishes - Meat-Poultry-Seafood	0.00000	0.38476	$0.00	$0.17	0.0%	0.6%
Mixed Dishes - Grain based	2.66685	2.66685	$0.59	$0.59	2.1%	2.1%
Mixed Dishes - Pizza	0.29956	0.30680	$0.20	$0.21	0.7%	0.8%
Mixed Dishes - Sandwiches	0.52234	0.65093	$0.30	$0.37	1.1%	1.3%
Mixed Dishes - Soups	0.92507	0.85975	$0.11	$0.10	0.4%	0.4%
Mixed Dishes - Beans-peas-lentils	0.08399	0.09793	$0.03	$0.03	0.1%	0.1%

Combined modeling category	Quantities (100 gram units)		Costs ($ per day)		Expenditure shares (%)	
	TFP, 2021 (reproduce results)	Demand system approach	TFP, 2021 (reproduce results)	Demand system approach	TFP, 2021 (reproduce results)	Demand system approach
Grains and cereals						
Grains - rice pasta cooked grains breads	9.58039	9.36338	$3.29	$3.24	11.9%	11.7%
Biscuits-muffins-quick breads	0.00000	0.01748	$0.00	$0.01	0.0%	0.0%
Breakfast cereals	2.23282	2.14504	$0.64	$0.62	2.3%	2.2%
Snack foods and sweets						
Tortilla-corn-other chips	0.08786	0.12541	$0.09	$0.13	0.3%	0.5%
Popcorn	0.13594	0.13594	$0.10	$0.10	0.4%	0.4%
Pretzels-snack mix	0.00000	0.00100	$0.00	$0.00	0.0%	0.0%
Crackers	0.00000	0.06103	$0.00	$0.05	0.0%	0.2%
Snack-Meal Bars	0.05183	0.06118	$0.08	$0.09	0.3%	0.3%
Sweet bakery products	0.00000	0.00000	$0.00	$0.00	0.0%	0.0%
Candy	0.00000	0.01172	$0.00	$0.01	0.0%	0.0%
Other Desserts	0.25004	0.25684	$0.11	$0.11	0.4%	0.4%
Sugars	0.19556	0.23477	$0.08	$0.10	0.3%	0.4%
Fruits and fruit juice						
Fruit	8.24243	8.26233	$2.76	$2.77	10.0%	10.0%
100 percent fruit juice	6.20178	6.12595	$1.08	$1.07	3.9%	3.9%
Vegetables						
Red orange vegetables	4.59970	4.58660	$1.77	$1.77	6.4%	6.4%
Dark green vegetables	1.68638	1.68020	$0.83	$0.83	3.0%	3.0%
Other vegetables and vegetable combinations	3.96699	3.94494	$1.33	$1.32	4.8%	4.8%
Starchy vegetables	3.13095	3.08726	$0.91	$0.90	3.3%	3.2%
Potatoes	0.94247	0.94247	$0.78	$0.78	2.8%	2.8%
Beans - peas - lentils	2.47405	2.46293	$0.76	$0.75	2.7%	2.7%
Beverages						
Fruit drinks	0.00000	0.06035	$0.00	$0.01	0.0%	0.0%
Other beverages	0.00000	0.00668	$0.00	$0.00	0.0%	0.0%
Soft drinks	0.00000	0.14935	$0.00	$0.02	0.0%	0.1%
Coffee and Tea	4.80000	4.80000	$0.32	$0.29	1.2%	1.1%
Fats, oils and condiments						
Butter and animal fats	0.06100	0.06100	$0.06	$0.06	0.2%	0.2%
Margarine and oils	0.58979	0.53311	$0.30	$0.27	1.1%	1.0%
Condiments and Sauces	0.00000	0.02730	$0.00	$0.01	0.0%	0.0%

Note: Quantities and costs may be reported as zero due to rounding. After computing the alternative TFP market basket quantities for all 95 food modeling categories, we calculated total quantities (in 100-gram units), costs ($ per day), and expenditure shares (a percentage) for the 45 combined modeling categories.

TFP = Thrifty Food Plan.

Appendix Exhibit C.2. The demand system-based TFP market basket: 95 TFP modeling categories

TFP modeling category	Quantities (100 gram units)		Costs ($ per day)		Expenditure shares (%)	
	TFP, 2021 (reproduce results)	Demand system approach	TFP, 2021 (reproduce results)	Demand system approach	TFP, 2021 (reproduce results)	Demand system approach
Dairy						
Cheese - higher cost	0.00000	0.00000	$0.00	$0.00	0.0%	0.0%
Cheese - lower cost	0.38946	0.12506	$0.32	$0.10	1.2%	0.4%
Milk and yogurt - higher nutrient density	16.40320	17.27884	$2.14	$2.25	7.7%	8.1%
Milk and yogurt - lower nutrient density	10.16336	10.31612	$1.52	$1.54	5.5%	5.6%
Meat, poultry, seafood, eggs						
Meat - higher nutrient density - higher cost	0.00000	0.00000	$0.00	$0.00	0.0%	0.0%
Meat - higher nutrient density - lower cost	0.00000	0.00000	$0.00	$0.00	0.0%	0.0%
Meat - lower nutrient density - higher cost	0.00000	0.00000	$0.00	$0.00	0.0%	0.0%
Meat - lower nutrient density - lower cost	1.32239	1.23562	$1.28	$1.20	4.6%	4.3%
Poultry - higher nutrient density - higher cost	0.00000	0.00000	$0.00	$0.00	0.0%	0.0%
Poultry - higher nutrient density - lower cost	3.47830	3.43671	$2.47	$2.44	8.9%	8.8%
Poultry - lower nutrient density - higher cost	0.00000	0.00000	$0.00	$0.00	0.0%	0.0%
Poultry - lower nutrient density - lower cost	0.00000	0.00000	$0.00	$0.00	0.0%	0.0%
Seafood - higher cost	0.00000	0.00000	$0.00	$0.00	0.0%	0.0%
Seafood - lower cost	1.76043	1.76043	$1.91	$1.91	6.9%	6.9%
Eggs	1.08390	1.02507	$0.39	$0.37	1.4%	1.3%
Cured meat	0.00000	0.03458	$0.00	$0.05	0.0%	0.2%
Nuts and seeds, soy products						
Nuts and Seeds - higher nutrient density	0.00000	0.00000	$0.00	$0.00	0.0%	0.0%
Nuts and Seeds - lower nutrient density	0.00000	0.00317	$0.00	$0.00	0.0%	0.0%
Nut and seed butters	1.27399	1.25371	$0.72	$0.71	2.6%	2.6%
Processed soy products	0.00000	0.00000	$0.00	$0.00	0.0%	0.0%
Mixed dishes						
Mixed Dishes - Eggs - higher nutrient density	0.26371	0.20683	$0.10	$0.08	0.4%	0.3%
Mixed Dishes - Eggs - lower nutrient density	0.00000	0.00000	$0.00	$0.00	0.0%	0.0%
Mixed Dishes - Vegetables - higher nutrient density - higher cost	0.00000	0.00000	$0.00	$0.00	0.0%	0.0%
Mixed Dishes - Vegetables - higher nutrient density - lower cost	0.22559	0.37348	$0.07	$0.11	0.3%	0.4%
Mixed Dishes - Vegetables - lower nutrient density - higher cost	0.00000	0.00000	$0.00	$0.00	0.0%	0.0%
Mixed Dishes - Vegetables - lower nutrient density - lower cost	0.46980	0.32191	$0.17	$0.12	0.6%	0.4%

TFP modeling category	Quantities (100 gram units)		Costs ($ per day)		Expenditure shares (%)	
	TFP, 2021 (reproduce results)	Demand system approach	TFP, 2021 (reproduce results)	Demand system approach	TFP, 2021 (reproduce results)	Demand system approach
Mixed Dishes - Meat-Poultry-Seafood - higher nutrient density - higher cost	0.00000	0.00000	$0.00	$0.00	0.0%	0.0%
Mixed Dishes - Meat-Poultry-Seafood - higher nutrient density - lower cost	0.00000	0.38476	$0.00	$0.17	0.0%	0.6%
Mixed Dishes - Meat-Poultry-Seafood - lower nutrient density - higher cost	0.00000	0.00000	$0.00	$0.00	0.0%	0.0%
Mixed Dishes - Meat-Poultry-Seafood - lower nutrient density - lower cost	0.00000	0.00000	$0.00	$0.00	0.0%	0.0%
Mixed Dishes - Grain based - higher nutrient density - higher cost	0.00000	0.00000	$0.00	$0.00	0.0%	0.0%
Mixed Dishes - Grain based - higher nutrient density - lower cost	2.66685	2.66685	$0.59	$0.59	2.1%	2.1%
Mixed Dishes - Grain based - lower nutrient density - higher cost	0.00000	0.00000	$0.00	$0.00	0.0%	0.0%
Mixed Dishes - Grain based - lower nutrient density - lower cost	0.00000	0.00000	$0.00	$0.00	0.0%	0.0%
Mixed Dishes - Pizza - higher nutrient density - higher cost	0.00000	0.00000	$0.00	$0.00	0.0%	0.0%
Mixed Dishes - Pizza - higher nutrient density - lower cost	0.00000	0.00000	$0.00	$0.00	0.0%	0.0%
Mixed Dishes - Pizza - lower nutrient density - higher cost	0.00000	0.00000	$0.00	$0.00	0.0%	0.0%
Mixed Dishes - Pizza - lower nutrient density - lower cost	0.29956	0.30680	$0.20	$0.21	0.7%	0.8%
Mixed Dishes - Sandwiches - higher nutrient density - higher cost	0.00000	0.00000	$0.00	$0.00	0.0%	0.0%
Mixed Dishes - Sandwiches - higher nutrient density - lower cost	0.00000	0.08504	$0.00	$0.04	0.0%	0.2%
Mixed Dishes - Sandwiches - lower nutrient density - higher cost	0.00000	0.00000	$0.00	$0.00	0.0%	0.0%
Mixed Dishes - Sandwiches - lower nutrient density - lower cost	0.52234	0.56589	$0.30	$0.33	1.1%	1.2%
Mixed Dishes - Soups - higher nutrient density - higher cost	0.00000	0.00000	$0.00	$0.00	0.0%	0.0%
Mixed Dishes - Soups - higher nutrient density - lower cost	0.92507	0.85975	$0.11	$0.10	0.4%	0.4%
Mixed Dishes - Soups - lower nutrient density - higher cost	0.00000	0.00000	$0.00	$0.00	0.0%	0.0%
Mixed Dishes - Soups - lower nutrient density - lower cost	0.00000	0.00000	$0.00	$0.00	0.0%	0.0%
Mixed Dishes - Beans-peas-lentils - higher nutrient density - higher cost	0.08399	0.09052	$0.03	$0.03	0.1%	0.1%
Mixed Dishes - Beans-peas-lentils - higher nutrient density - lower cost	0.00000	0.00000	$0.00	$0.00	0.0%	0.0%

TFP modeling category	Quantities (100 gram units)		Costs ($ per day)		Expenditure shares (%)	
	TFP, 2021 (reproduce results)	Demand system approach	TFP, 2021 (reproduce results)	Demand system approach	TFP, 2021 (reproduce results)	Demand system approach
Mixed Dishes - Beans-peas-lentils - lower nutrient density - higher cost	0.00000	0.00000	$0.00	$0.00	0.0%	0.0%
Mixed Dishes - Beans-peas-lentils - lower nutrient density - lower cost	0.00000	0.00741	$0.00	$0.00	0.0%	0.0%
Grains and cereals						
Grains - higher nutrient density - higher cost	0.00000	0.00000	$0.00	$0.00	0.0%	0.0%
Grains - higher nutrient density - lower cost	5.21863	5.22328	$2.19	$2.19	7.9%	7.9%
Grains - lower nutrient density - higher cost	0.00000	0.00000	$0.00	$0.00	0.0%	0.0%
Grains - lower nutrient density - lower cost	4.36175	4.14010	$1.10	$1.04	4.0%	3.8%
Biscuits-muffins-quick breads	0.00000	0.01748	$0.00	$0.01	0.0%	0.0%
Breakfast cereals - higher nutrient density	1.87894	1.79074	$0.45	$0.43	1.6%	1.5%
Breakfast cereals - lower nutrient density	0.35388	0.35430	$0.20	$0.20	0.7%	0.7%
Snack foods and sweets						
Tortilla-corn-other chips	0.08786	0.12541	$0.09	$0.13	0.3%	0.5%
Popcorn - higher nutrient density	0.00000	0.00000	$0.00	$0.00	0.0%	0.0%
Popcorn - lower nutrient density	0.13594	0.13594	$0.10	$0.10	0.4%	0.4%
Pretzels-snack mix	0.00000	0.00100	$0.00	$0.00	0.0%	0.0%
Crackers - higher nutrient density	0.00000	0.00829	$0.00	$0.01	0.0%	0.0%
Crackers - lower nutrient density	0.00000	0.05273	$0.00	$0.04	0.0%	0.2%
Snack-Meal Bars	0.05183	0.06118	$0.08	$0.09	0.3%	0.3%
Sweet bakery products	0.00000	0.00000	$0.00	$0.00	0.0%	0.0%
Candy	0.00000	0.01172	$0.00	$0.01	0.0%	0.0%
Other Desserts	0.25004	0.25684	$0.11	$0.11	0.4%	0.4%
Sugars	0.19556	0.23477	$0.08	$0.10	0.3%	0.4%
Fruits and fruit juice						
Fruit - higher nutrient density - higher cost	0.00000	0.00000	$0.00	$0.00	0.0%	0.0%
Fruit - higher nutrient density - lower cost	8.24243	8.26233	$2.76	$2.77	10.0%	10.0%
Fruit - lower nutrient density - higher cost	0.00000	0.00000	$0.00	$0.00	0.0%	0.0%
Fruit - lower nutrient density - lower cost	0.00000	0.00000	$0.00	$0.00	0.0%	0.0%
100 percent fruit juice - higher cost	0.51849	0.39807	$0.11	$0.08	0.4%	0.3%
100 percent fruit juice - lower cost	5.68330	5.72787	$0.98	$0.99	3.5%	3.6%
Vegetables						
Red orange vegetables - higher cost	0.84102	0.85947	$0.47	$0.48	1.7%	1.7%
Red orange vegetables - lower cost	3.75867	3.72714	$1.30	$1.29	4.7%	4.6%
Dark green vegetables - higher cost	0.00000	0.00000	$0.00	$0.00	0.0%	0.0%
Dark green vegetables - lower cost	1.68638	1.68020	$0.83	$0.83	3.0%	3.0%

TFP modeling category	Quantities (100 gram units)		Costs ($ per day)		Expenditure shares (%)	
	TFP, 2021 (reproduce results)	Demand system approach	TFP, 2021 (reproduce results)	Demand system approach	TFP, 2021 (reproduce results)	Demand system approach
Other vegetables and vegetable combinations - higher cost	0.00000	0.00000	$0.00	$0.00	0.0%	0.0%
Other vegetables and vegetable combinations - lower cost	3.96699	3.94494	$1.33	$1.32	4.8%	4.8%
Starchy vegetables - higher cost	0.00000	0.00000	$0.00	$0.00	0.0%	0.0%
Starchy vegetables - lower cost	3.13095	3.08726	$0.91	$0.90	3.3%	3.2%
Beans - peas - lentils	2.47405	2.46293	$0.76	$0.75	2.7%	2.7%
Other fried potato products	0.94247	0.94247	$0.78	$0.78	2.8%	2.8%
Beverages						
Fruit drinks - higher nutrient density	0.00000	0.00000	$0.00	$0.00	0.0%	0.0%
Fruit drinks - lower nutrient density	0.00000	0.06035	$0.00	$0.01	0.0%	0.0%
Soft drinks	0.00000	0.14935	$0.00	$0.02	0.0%	0.1%
Diet beverages	0.00000	0.00000	$0.00	$0.00	0.0%	0.0%
Coffee and Tea - higher nutrient density	3.85930	4.18278	$0.20	$0.22	0.7%	0.8%
Coffee and Tea - lower nutrient density	0.94070	0.61722	$0.12	$0.08	0.4%	0.3%
Other beverages - smoothies grain-based milk substitutes nutritional beverages	0.00000	0.00668	$0.00	$0.00	0.0%	0.0%
Fats, oils and condiments						
Butter and animal fats	0.06100	0.06100	$0.06	$0.06	0.2%	0.2%
Margarine and oils	0.58979	0.53311	$0.30	$0.27	1.1%	1.0%
Condiments and Sauces - higher cost	0.00000	0.00000	$0.00	$0.00	0.0%	0.0%
Condiments and Sauces - lower cost	0.00000	0.02730	$0.00	$0.01	0.0%	0.0%

TFP = Thrifty Food Plan.

C.2. Stochastic production frontier approach

The following three tables present the nutritional and food group content and the quantities, costs, and expenditure shares for the 45 combined modeling categories and the 95 TFP food modeling categories from the SPF-based TFP market basket from Chapter 8. At this level of rounding, most quantities are reported as zero. The major exception is the expenditure shares for the modeling categories, which must add up to 100 percent, by definition, despite being calculated with trivially small quantities.

Appendix Exhibit C.3. The SPF-based TFP market basket: Nutrient and food group content

Nutrient	TFP, 2021 (reproduce results)	SPF approach (average inefficiency)	SPF approach (no inefficiency)
Food energy			
Energy (kcal)	9,611.7	0.0	0.0
Macro-nutrients			
Carbohydrates (g)	1,237.5	0.0	0.0
Protein (g)	455.8	0.0	0.0
18:02 (linoleic acid) (g)	77.9	0.0	0.0
18:03 (linolenic acid) (g)	6.8	0.0	0.0
Fatty acids total monounsaturated (g)	122.5	0.0	0.0
Fatty acids total polyunsaturated (g)	86.8	0.0	0.0
Saturated fat (g)	97.8	0.0	0.0
Total Fat (g)	336.9	0.0	0.0
Fiber total dietary (g)	135.2	0.0	0.0
Micro-nutrient			
Calcium (mg)	6,296.7	0.0	0.0
Cholesterol (mg)	1,249.2	0.0	0.0
Choline total (mg)	1,843.6	0.0	0.0
Copper (mg)	6.4	0.0	0.0
Iron (mg)	73.3	0.0	0.0
Folic acid (µg)	716.0	0.0	0.0
Folate (µg DFE)	2,876.2	0.0	0.0
Potassium (mg)	17,782.2	0.0	0.0
Magnesium (mg)	1,950.0	0.0	0.0
Sodium (mg)	11,149.2	0.0	0.0
Niacin (mg)	132.0	0.0	0.0
Phosphorus (mg)	8,215.6	0.0	0.0
Riboflavin (mg)	11.6	0.0	0.0
Selenium (µg)	632.9	0.0	0.0
Thiamin (mg)	9.0	0.0	0.0
Vitamin E (alpha-tocopherol) (mg)	49.8	0.0	0.0
Vitamin A RAE	6,293.4	0.0	0.0

Nutrient	TFP, 2021 (reproduce results)	SPF approach (average inefficiency)	SPF approach (no inefficiency)
Vitamin B-12 (µg)	24.5	0.0	0.0
Vitamin B-6 (mg)	11.9	0.0	0.0
Vitamin C (mg)	497.2	0.0	0.0
Vitamin D (D2 + D3) (µg)	44.4	0.0	0.0
Vitamin K (phylloquinone) (µg)	668.0	0.0	0.0
Zinc (mg)	55.0	0.0	0.0
Calories from macro-nutrients			
Kcal from protein	1,823.3	0.0	0.0
Kcal from carbohydrates	4,950.1	0.0	0.0
Kcal from fat	3,031.9	0.0	0.0
Kcal from saturated fat	879.9	0.0	0.0
FPED food groups			
Fruit juices - citrus and non citrus (cup eq.)	2.4	0.0	0.0
Total intact or cut fruits and fruit juices (cup eq.)	8.4	0.0	0.0
Dark green vegetables (cup eq.)	1.2	0.0	0.0
Total red and orange vegetables (tomatoes + other red and orange) (cup eq.)	3.8	0.0	0.0
Total starchy vegetables (white potatoes + other starchy) (cup eq.)	3.9	0.0	0.0
Other vegetables not in the vegetable components listed above (cup eq.)	3.1	0.0	0.0
Legumes computed as vegetables (cup eq.)	1.5	0.0	0.0
Total dark green red and orange starchy and other vegetables; excludes legumes (cup eq.)	13.5	0.0	0.0
Whole grains (oz. eq.)	17.9	0.0	0.0
Refined or non-whole grains (oz. eq.)	17.9	0.0	0.0
Total whole and refined grains (oz. eq.)	35.8	0.0	0.0
Beef veal pork lamb game meat; excludes organ meats and cured meat (oz. eq.)	3.9	0.0	0.0
Chicken turkey Cornish hens and game birds; excludes organ meats and cured meat (oz. eq.)	9.7	0.0	0.0
Eggs (chicken duck goose quail) and egg substitutes (oz. eq.)	2.7	0.0	0.0
Soy products excluding calcium fortified soy milk and immature soybeans (oz. eq.)	0.1	0.0	0.0
Peanuts tree nuts and seeds excludes coconut (oz. eq.)	8.0	0.0	0.0
Total meat poultry seafood organ meats cured meat eggs soy and nuts and seeds; excludes legumes (oz. eq.)	30.4	0.0	0.0
Total milk yogurt cheese and whey (cup eq.)	12.1	0.0	0.0
Oils (g)	141.0	0.0	0.0
Meat poultry egg aggregate (oz. eq.)	16.9	0.0	0.0
Seafood aggregate (oz. eq.)	5.4	0.0	0.0
Nut seed soy aggregate (oz. eq.)	8.1	0.0	0.0
Kcal from added sugars	384.8	0.0	0.0

Nutrient	TFP, 2021 (reproduce results)	SPF approach (average inefficiency)	SPF approach (no inefficiency)
Calories by eating occasion			
Kcal from breakfast	2,210.7	0.0	0.0
Kcal from lunch	2,690.6	0.0	0.0
Kcal from dinner	3,283.8	0.0	0.0
Kcal from snacks	1,241.6	0.0	0.0
Kcal from drinks	109.9	0.0	0.0
Kcal from extended consumption	75.1	0.0	0.0

Note: Quantities may be reported as zero due to rounding.

TFP = Thrifty Food Plan; SPF = Stochastic production frontier; DFE = dietary folate equivalent; eq. = equivalent; g = gram; kcal = kilocalorie; oz = ounce; mg = milligram; µg = microgram; RAE = retinol activity equivalent.

Appendix Exhibit C.4. The SPF-based TFP market baskets: 45 combined modeling categories

Combined modeling category	Quantities (100 gram units)			Costs ($ per day)			Expenditure shares (%)		
	TFP, 2021 (reproduce results)	SPF approach (average ineff.)	SPF approach (no ineff.)	TFP, 2021 (reproduce results)	SPF approach (average ineff.)	SPF approach (no ineff.)	TFP, 2021 (reproduce results)	SPF approach (average ineff.)	SPF approach (no ineff.)
Dairy									
Cheese	0.38946	0.00000	0.00000	$0.32	$0.00	$0.00	1.2%	0.0%	0.0%
Milk and yogurt	26.56656	0.00000	0.00000	$3.66	$0.00	$0.00	13.2%	1.0%	1.0%
Meat, poultry, seafood, eggs									
Meat	1.32239	0.00000	0.00000	$1.28	$0.00	$0.00	4.6%	0.2%	0.2%
Poultry	3.47830	0.00000	0.00000	$2.47	$0.00	$0.00	8.9%	0.4%	0.4%
Seafood	1.76043	0.00000	0.00000	$1.91	$0.00	$0.00	6.9%	1.3%	2.5%
Eggs	1.08390	0.00000	0.00000	$0.39	$0.00	$0.00	1.4%	0.0%	0.0%
Cured meat	0.00000	0.00000	0.00000	$0.00	$0.00	$0.00	0.0%	0.0%	0.0%
Nuts and seeds, soy products									
Nuts and Seeds	0.00000	0.00000	0.00000	$0.00	$0.00	$0.00	0.0%	8.8%	9.8%
Nut and seed butters	1.27399	0.00000	0.00000	$0.72	$0.00	$0.00	2.6%	2.3%	1.9%
Processed soy products	0.00000	0.00000	0.00000	$0.00	$0.00	$0.00	0.0%	0.5%	0.3%
Mixed dishes									
Mixed Dishes - Eggs	0.26371	0.00000	0.00000	$0.10	$0.00	$0.00	0.4%	0.2%	0.2%
Mixed Dishes - Vegetables	0.69539	0.00000	0.00000	$0.24	$0.00	$0.00	0.9%	0.4%	0.4%
Mixed Dishes - Meat-Poultry-Seafood	0.00000	0.00000	0.00000	$0.00	$0.00	$0.00	0.0%	1.8%	1.5%
Mixed Dishes - Grain based	2.66685	0.00000	0.00000	$0.59	$0.00	$0.00	2.1%	0.2%	0.2%
Mixed Dishes - Pizza	0.29956	0.00000	0.00000	$0.20	$0.00	$0.00	0.7%	0.0%	0.0%
Mixed Dishes - Sandwiches	0.52234	0.00000	0.00000	$0.30	$0.00	$0.00	1.1%	0.4%	0.4%
Mixed Dishes - Soups	0.92507	0.00000	0.00000	$0.11	$0.00	$0.00	0.4%	0.2%	0.2%
Mixed Dishes - Beans-peas-lentils	0.08399	0.00000	0.00000	$0.03	$0.00	$0.00	0.1%	31.8%	32.5%
Grains and cereals									
Grains - rice pasta cooked grains breads	9.58039	0.00000	0.00000	$3.29	$0.00	$0.00	11.9%	8.1%	7.6%
Biscuits-muffins-quick breads	0.00000	0.00000	0.00000	$0.00	$0.00	$0.00	0.0%	0.0%	0.0%
Breakfast cereals	2.23282	0.00000	0.00000	$0.64	$0.00	$0.00	2.3%	3.9%	3.9%
Snack foods and sweets									
Tortilla-corn-other chips	0.08786	0.00000	0.00000	$0.09	$0.00	$0.00	0.3%	0.3%	0.2%
Popcorn	0.13594	0.00000	0.00000	$0.10	$0.00	$0.00	0.4%	1.8%	1.5%
Pretzels-snack mix	0.00000	0.00000	0.00000	$0.00	$0.00	$0.00	0.0%	0.0%	0.0%
Crackers	0.00000	0.00000	0.00000	$0.00	$0.00	$0.00	0.0%	2.6%	2.4%
Snack-Meal Bars	0.05183	0.00000	0.00000	$0.08	$0.00	$0.00	0.3%	0.6%	0.6%
Sweet bakery products	0.00000	0.00000	0.00000	$0.00	$0.00	$0.00	0.0%	0.0%	0.0%

Combined modeling category	Quantities (100 gram units) TFP, 2021 (reproduce results)	SPF approach (average ineff.)	SPF approach (no ineff.)	Costs ($ per day) TFP, 2021 (reproduce results)	SPF approach (average ineff.)	SPF approach (no ineff.)	Expenditure shares (%) TFP, 2021 (reproduce results)	SPF approach (average ineff.)	SPF approach (no ineff.)
Candy	0.00000	0.00000	0.00000	$0.00	$0.00	$0.00	0.0%	0.0%	0.0%
Other Desserts	0.25004	0.00000	0.00000	$0.11	$0.00	$0.00	0.4%	0.0%	0.0%
Sugars	0.19556	0.00000	0.00000	$0.08	$0.00	$0.00	0.3%	0.0%	0.0%
Fruits and fruit juice									
Fruit	8.24243	0.00000	0.00000	$2.76	$0.00	$0.00	10.0%	10.4%	10.1%
100 percent fruit juice	6.20178	0.00000	0.00000	$1.08	$0.00	$0.00	3.9%	1.4%	1.4%
Vegetables									
Red orange vegetables	4.59970	0.00000	0.00000	$1.77	$0.00	$0.00	6.4%	0.3%	0.3%
Dark green vegetables	1.68638	0.00000	0.00000	$0.83	$0.00	$0.00	3.0%	2.1%	1.7%
Other vegetables and vegetable combinations	3.96699	0.00000	0.00000	$1.33	$0.00	$0.00	4.8%	0.4%	0.4%
Starchy vegetables	3.13095	0.00000	0.00000	$0.91	$0.00	$0.00	3.3%	0.2%	0.2%
Potatoes	0.94247	0.00000	0.00000	$0.78	$0.00	$0.00	2.8%	1.3%	1.0%
Beans - peas - lentils	2.47405	0.00000	0.00000	$0.76	$0.00	$0.00	2.7%	14.5%	14.8%
Beverages									
Fruit drinks	0.00000	0.00000	0.00000	$0.00	$0.00	$0.00	0.0%	0.1%	0.2%
Other beverages	0.00000	0.00000	0.00000	$0.00	$0.00	$0.00	0.0%	2.5%	2.2%
Soft drinks	0.00000	0.00000	0.00000	$0.00	$0.00	$0.00	0.0%	0.0%	0.1%
Coffee and Tea	4.80000	0.00000	0.00000	$0.32	$0.00	$0.00	1.2%	0.0%	0.1%
Fats, oils and condiments									
Butter and animal fats	0.06100	0.00000	0.00000	$0.06	$0.00	$0.00	0.2%	0.0%	0.0%
Margarine and oils	0.58979	0.00000	0.00000	$0.30	$0.00	$0.00	1.1%	0.0%	0.0%
Condiments and Sauces	0.00000	0.00000	0.00000	$0.00	$0.00	$0.00	0.0%	0.0%	0.0%

Note: Quantities and costs may be reported as zero due to rounding. After computing the alternative TFP market basket quantities for all 95 food modeling categories, we calculated total quantities (in 100-gram units), costs ($ per day), and expenditure shares (a percentage) for the 45 combined modeling categories shown in this table.

ineff = inefficiency; TFP = Thrifty Food Plan; SPF = Stochastic production frontier.

Appendix Exhibit C.5. The SPF-based TFP market baskets: 95 TFP modeling categories

TFP modeling category	Quantities (100 gram units)			Costs ($ per day)			Expenditure shares (%)		
	TFP, 2021 (reproduce results)	SPF approach (average ineff.)	SPF approach (no ineff.)	TFP, 2021 (reproduce results)	SPF approach (average ineff.)	SPF approach (no ineff.)	TFP, 2021 (reproduce results)	SPF approach (average ineff.)	SPF approach (no ineff.)
Dairy									
Cheese - higher cost	0.00000	0.00000	0.00000	$0.00	$0.00	$0.00	0.0%	0.0%	0.0%
Cheese - lower cost	0.38946	0.00000	0.00000	$0.32	$0.00	$0.00	1.2%	0.0%	0.0%
Milk and yogurt - higher nutrient density	16.40320	0.00000	0.00000	$2.14	$0.00	$0.00	7.7%	0.6%	0.5%
Milk and yogurt - lower nutrient density	10.16336	0.00000	0.00000	$1.52	$0.00	$0.00	5.5%	0.5%	0.5%
Meat, poultry, seafood, eggs									
Meat - higher nutrient density - higher cost	0.00000	0.00000	0.00000	$0.00	$0.00	$0.00	0.0%	0.0%	0.0%
Meat - higher nutrient density - lower cost	0.00000	0.00000	0.00000	$0.00	$0.00	$0.00	0.0%	0.1%	0.1%
Meat - lower nutrient density - higher cost	0.00000	0.00000	0.00000	$0.00	$0.00	$0.00	0.0%	0.0%	0.0%
Meat - lower nutrient density - lower cost	1.32239	0.00000	0.00000	$1.28	$0.00	$0.00	4.6%	0.1%	0.1%
Poultry - higher nutrient density - higher cost	0.00000	0.00000	0.00000	$0.00	$0.00	$0.00	0.0%	0.2%	0.2%
Poultry - higher nutrient density - lower cost	3.47830	0.00000	0.00000	$2.47	$0.00	$0.00	8.9%	0.1%	0.1%
Poultry - lower nutrient density - higher cost	0.00000	0.00000	0.00000	$0.00	$0.00	$0.00	0.0%	0.0%	0.0%
Poultry - lower nutrient density - lower cost	0.00000	0.00000	0.00000	$0.00	$0.00	$0.00	0.0%	0.0%	0.0%
Seafood - higher cost	0.00000	0.00000	0.00000	$0.00	$0.00	$0.00	0.0%	1.0%	2.3%
Seafood - lower cost	1.76043	0.00000	0.00000	$1.91	$0.00	$0.00	6.9%	0.3%	0.2%
Eggs	1.08390	0.00000	0.00000	$0.39	$0.00	$0.00	1.4%	0.0%	0.0%
Cured meat	0.00000	0.00000	0.00000	$0.00	$0.00	$0.00	0.0%	0.0%	0.0%
Nuts and seeds, soy products									
Nuts and Seeds - higher nutrient density	0.00000	0.00000	0.00000	$0.00	$0.00	$0.00	0.0%	5.2%	6.2%
Nuts and Seeds - lower nutrient density	0.00000	0.00000	0.00000	$0.00	$0.00	$0.00	0.0%	3.6%	3.6%
Nut and seed butters	1.27399	0.00000	0.00000	$0.72	$0.00	$0.00	2.6%	2.3%	1.9%
Processed soy products	0.00000	0.00000	0.00000	$0.00	$0.00	$0.00	0.0%	0.5%	0.3%
Mixed dishes									
Mixed Dishes - Eggs - higher nutrient density	0.26371	0.00000	0.00000	$0.10	$0.00	$0.00	0.4%	0.2%	0.2%
Mixed Dishes - Eggs - lower nutrient density	0.00000	0.00000	0.00000	$0.00	$0.00	$0.00	0.0%	0.0%	0.1%

TFP modeling category	Quantities (100 gram units)			Costs ($ per day)			Expenditure shares (%)		
	TFP, 2021 (reproduce results)	SPF approach (average ineff.)	SPF approach (no ineff.)	TFP, 2021 (reproduce results)	SPF approach (average ineff.)	SPF approach (no ineff.)	TFP, 2021 (reproduce results)	SPF approach (average ineff.)	SPF approach (no ineff.)
Mixed Dishes - Vegetables - higher nutrient density - higher cost	0.00000	0.00000	0.00000	$0.00	$0.00	$0.00	0.0%	0.1%	0.1%
Mixed Dishes - Vegetables - higher nutrient density - lower cost	0.22559	0.00000	0.00000	$0.07	$0.00	$0.00	0.3%	0.0%	0.0%
Mixed Dishes - Vegetables - lower nutrient density - higher cost	0.00000	0.00000	0.00000	$0.00	$0.00	$0.00	0.0%	0.1%	0.1%
Mixed Dishes - Vegetables - lower nutrient density - lower cost	0.46980	0.00000	0.00000	$0.17	$0.00	$0.00	0.6%	0.1%	0.1%
Mixed Dishes - Meat-Poultry-Seafood - higher nutrient density - higher cost	0.00000	0.00000	0.00000	$0.00	$0.00	$0.00	0.0%	1.0%	0.7%
Mixed Dishes - Meat-Poultry-Seafood - higher nutrient density - lower cost	0.00000	0.00000	0.00000	$0.00	$0.00	$0.00	0.0%	0.3%	0.3%
Mixed Dishes - Meat-Poultry-Seafood - lower nutrient density - higher cost	0.00000	0.00000	0.00000	$0.00	$0.00	$0.00	0.0%	0.2%	0.2%
Mixed Dishes - Meat-Poultry-Seafood - lower nutrient density - lower cost	0.00000	0.00000	0.00000	$0.00	$0.00	$0.00	0.0%	0.3%	0.3%
Mixed Dishes - Grain based - higher nutrient density - higher cost	0.00000	0.00000	0.00000	$0.00	$0.00	$0.00	0.0%	0.1%	0.1%
Mixed Dishes - Grain based - higher nutrient density - lower cost	2.66685	0.00000	0.00000	$0.59	$0.00	$0.00	2.1%	0.1%	0.1%
Mixed Dishes - Grain based - lower nutrient density - higher cost	0.00000	0.00000	0.00000	$0.00	$0.00	$0.00	0.0%	0.0%	0.0%
Mixed Dishes - Grain based - lower nutrient density - lower cost	0.00000	0.00000	0.00000	$0.00	$0.00	$0.00	0.0%	0.0%	0.0%

TFP modeling category	Quantities (100 gram units)			Costs ($ per day)			Expenditure shares (%)		
	TFP, 2021 (reproduce results)	SPF approach (average ineff.)	SPF approach (no ineff.)	TFP, 2021 (reproduce results)	SPF approach (average ineff.)	SPF approach (no ineff.)	TFP, 2021 (reproduce results)	SPF approach (average ineff.)	SPF approach (no ineff.)
Mixed Dishes - Pizza - higher nutrient density - higher cost	0.00000	0.00000	0.00000	$0.00	$0.00	$0.00	0.0%	0.0%	0.0%
Mixed Dishes - Pizza - higher nutrient density - lower cost	0.00000	0.00000	0.00000	$0.00	$0.00	$0.00	0.0%	0.0%	0.0%
Mixed Dishes - Pizza - lower nutrient density - higher cost	0.00000	0.00000	0.00000	$0.00	$0.00	$0.00	0.0%	0.0%	0.0%
Mixed Dishes - Pizza - lower nutrient density - lower cost	0.29956	0.00000	0.00000	$0.20	$0.00	$0.00	0.7%	0.0%	0.0%
Mixed Dishes - Sandwiches - higher nutrient density - higher cost	0.00000	0.00000	0.00000	$0.00	$0.00	$0.00	0.0%	0.0%	0.0%
Mixed Dishes - Sandwiches - higher nutrient density - lower cost	0.00000	0.00000	0.00000	$0.00	$0.00	$0.00	0.0%	0.4%	0.4%
Mixed Dishes - Sandwiches - lower nutrient density - higher cost	0.00000	0.00000	0.00000	$0.00	$0.00	$0.00	0.0%	0.0%	0.0%
Mixed Dishes - Sandwiches - lower nutrient density - lower cost	0.52234	0.00000	0.00000	$0.30	$0.00	$0.00	1.1%	0.0%	0.0%
Mixed Dishes - Soups - higher nutrient density - higher cost	0.00000	0.00000	0.00000	$0.00	$0.00	$0.00	0.0%	0.2%	0.2%
Mixed Dishes - Soups - higher nutrient density - lower cost	0.92507	0.00000	0.00000	$0.11	$0.00	$0.00	0.4%	0.0%	0.0%
Mixed Dishes - Soups - lower nutrient density - higher cost	0.00000	0.00000	0.00000	$0.00	$0.00	$0.00	0.0%	0.0%	0.1%
Mixed Dishes - Soups - lower nutrient density - lower cost	0.00000	0.00000	0.00000	$0.00	$0.00	$0.00	0.0%	0.0%	0.0%
Mixed Dishes - Beans-peas-lentils - higher nutrient density - higher cost	0.08399	0.00000	0.00000	$0.03	$0.00	$0.00	0.1%	14.4%	14.7%

TFP modeling category	Quantities (100 gram units)			Costs ($ per day)			Expenditure shares (%)		
	TFP, 2021 (reproduce results)	SPF approach (average ineff.)	SPF approach (no ineff.)	TFP, 2021 (reproduce results)	SPF approach (average ineff.)	SPF approach (no ineff.)	TFP, 2021 (reproduce results)	SPF approach (average ineff.)	SPF approach (no ineff.)
Mixed Dishes - Beans-peas-lentils - higher nutrient density - lower cost	0.00000	0.00000	0.00000	$0.00	$0.00	$0.00	0.0%	3.2%	3.1%
Mixed Dishes - Beans-peas-lentils - lower nutrient density - higher cost	0.00000	0.00000	0.00000	$0.00	$0.00	$0.00	0.0%	12.0%	12.7%
Mixed Dishes - Beans-peas-lentils - lower nutrient density - lower cost	0.00000	0.00000	0.00000	$0.00	$0.00	$0.00	0.0%	2.1%	2.0%
Grains and cereals									
Grains - higher nutrient density - higher cost	0.00000	0.00000	0.00000	$0.00	$0.00	$0.00	0.0%	2.5%	2.1%
Grains - higher nutrient density - lower cost	5.21863	0.00000	0.00000	$2.19	$0.00	$0.00	7.9%	5.6%	5.5%
Grains - lower nutrient density - higher cost	0.00000	0.00000	0.00000	$0.00	$0.00	$0.00	0.0%	0.0%	0.0%
Grains - lower nutrient density - lower cost	4.36175	0.00000	0.00000	$1.10	$0.00	$0.00	4.0%	0.0%	0.0%
Biscuits-muffins-quick breads	0.00000	0.00000	0.00000	$0.00	$0.00	$0.00	0.0%	0.0%	0.0%
Breakfast cereals - higher nutrient density	1.87894	0.00000	0.00000	$0.45	$0.00	$0.00	1.6%	3.7%	3.7%
Breakfast cereals - lower nutrient density	0.35388	0.00000	0.00000	$0.20	$0.00	$0.00	0.7%	0.2%	0.2%
Snack foods and sweets									
Tortilla-corn-other chips	0.08786	0.00000	0.00000	$0.09	$0.00	$0.00	0.3%	0.3%	0.2%
Popcorn - higher nutrient density	0.00000	0.00000	0.00000	$0.00	$0.00	$0.00	0.0%	1.7%	1.4%
Popcorn - lower nutrient density	0.13594	0.00000	0.00000	$0.10	$0.00	$0.00	0.4%	0.1%	0.1%
Pretzels-snack mix	0.00000	0.00000	0.00000	$0.00	$0.00	$0.00	0.0%	0.0%	0.0%
Crackers - higher nutrient density	0.00000	0.00000	0.00000	$0.00	$0.00	$0.00	0.0%	2.6%	2.4%
Crackers - lower nutrient density	0.00000	0.00000	0.00000	$0.00	$0.00	$0.00	0.0%	0.0%	0.0%
Snack-Meal Bars	0.05183	0.00000	0.00000	$0.08	$0.00	$0.00	0.3%	0.6%	0.6%
Sweet bakery products	0.00000	0.00000	0.00000	$0.00	$0.00	$0.00	0.0%	0.0%	0.0%
Candy	0.00000	0.00000	0.00000	$0.00	$0.00	$0.00	0.0%	0.0%	0.0%
Other Desserts	0.25004	0.00000	0.00000	$0.11	$0.00	$0.00	0.4%	0.0%	0.0%
Sugars	0.19556	0.00000	0.00000	$0.08	$0.00	$0.00	0.3%	0.0%	0.0%

TFP modeling category	Quantities (100 gram units)			Costs ($ per day)			Expenditure shares (%)		
	TFP, 2021 (reproduce results)	SPF approach (average ineff.)	SPF approach (no ineff.)	TFP, 2021 (reproduce results)	SPF approach (average ineff.)	SPF approach (no ineff.)	TFP, 2021 (reproduce results)	SPF approach (average ineff.)	SPF approach (no ineff.)
Fruits and fruit juice									
Fruit - higher nutrient density - higher cost	0.00000	0.00000	0.00000	$0.00	$0.00	$0.00	0.0%	1.6%	1.3%
Fruit - higher nutrient density - lower cost	8.24243	0.00000	0.00000	$2.76	$0.00	$0.00	10.0%	6.5%	6.9%
Fruit - lower nutrient density - higher cost	0.00000	0.00000	0.00000	$0.00	$0.00	$0.00	0.0%	0.4%	0.3%
Fruit - lower nutrient density - lower cost	0.00000	0.00000	0.00000	$0.00	$0.00	$0.00	0.0%	1.8%	1.6%
100 percent fruit juice - higher cost	0.51849	0.00000	0.00000	$0.11	$0.00	$0.00	0.4%	0.3%	0.3%
100 percent fruit juice - lower cost	5.68330	0.00000	0.00000	$0.98	$0.00	$0.00	3.5%	1.1%	1.0%
Vegetables									
Red orange vegetables - higher cost	0.84102	0.00000	0.00000	$0.47	$0.00	$0.00	1.7%	0.3%	0.3%
Red orange vegetables - lower cost	3.75867	0.00000	0.00000	$1.30	$0.00	$0.00	4.7%	0.0%	0.0%
Dark green vegetables - higher cost	0.00000	0.00000	0.00000	$0.00	$0.00	$0.00	0.0%	1.0%	0.7%
Dark green vegetables - lower cost	1.68638	0.00000	0.00000	$0.83	$0.00	$0.00	3.0%	1.1%	1.0%
Other vegetables and vegetable combinations - higher cost	0.00000	0.00000	0.00000	$0.00	$0.00	$0.00	0.0%	0.1%	0.1%
Other vegetables and vegetable combinations - lower cost	3.96699	0.00000	0.00000	$1.33	$0.00	$0.00	4.8%	0.2%	0.3%
Starchy vegetables - higher cost	0.00000	0.00000	0.00000	$0.00	$0.00	$0.00	0.0%	0.1%	0.1%
Starchy vegetables - lower cost	3.13095	0.00000	0.00000	$0.91	$0.00	$0.00	3.3%	0.1%	0.1%
Beans - peas - lentils	2.47405	0.00000	0.00000	$0.76	$0.00	$0.00	2.7%	14.5%	14.8%
Other fried potato products	0.94247	0.00000	0.00000	$0.78	$0.00	$0.00	2.8%	1.3%	1.0%
Beverages									
Fruit drinks - higher nutrient density	0.00000	0.00000	0.00000	$0.00	$0.00	$0.00	0.0%	0.1%	0.1%
Fruit drinks - lower nutrient density	0.00000	0.00000	0.00000	$0.00	$0.00	$0.00	0.0%	0.0%	0.0%
Soft drinks	0.00000	0.00000	0.00000	$0.00	$0.00	$0.00	0.0%	0.0%	0.0%
Diet beverages	0.00000	0.00000	0.00000	$0.00	$0.00	$0.00	0.0%	0.0%	0.1%

TFP modeling category	Quantities (100 gram units)			Costs ($ per day)			Expenditure shares (%)		
	TFP, 2021 (reproduce results)	SPF approach (average ineff.)	SPF approach (no ineff.)	TFP, 2021 (reproduce results)	SPF approach (average ineff.)	SPF approach (no ineff.)	TFP, 2021 (reproduce results)	SPF approach (average ineff.)	SPF approach (no ineff.)
Coffee and Tea - higher nutrient density	3.85930	0.00000	0.00000	$0.20	$0.00	$0.00	0.7%	0.0%	0.0%
Coffee and Tea - lower nutrient density	0.94070	0.00000	0.00000	$0.12	$0.00	$0.00	0.4%	0.0%	0.0%
Other beverages - smoothies grain-based milk substitutes nutritional beverages	0.00000	0.00000	0.00000	$0.00	$0.00	$0.00	0.0%	2.5%	2.2%
Fats, oils and condiments									
Butter and animal fats	0.06100	0.00000	0.00000	$0.06	$0.00	$0.00	0.2%	0.0%	0.0%
Margarine and oils	0.58979	0.00000	0.00000	$0.30	$0.00	$0.00	1.1%	0.0%	0.0%
Condiments and Sauces - higher cost	0.00000	0.00000	0.00000	$0.00	$0.00	$0.00	0.0%	0.0%	0.0%
Condiments and Sauces - lower cost	0.00000	0.00000	0.00000	$0.00	$0.00	$0.00	0.0%	0.0%	0.0%

Note: Quantities and costs may be reported as zero due to rounding.

ineff = inefficiency; TFP = Thrifty Food Plan; SPF = Stochastic production frontier.

Appendix D. Solving for TFP market baskets in a single step

In this appendix, we explore alternative approaches for solving for the lowest-cost feasible market basket in Equations 4 and 5 from Chapter 7, Section 7.6. Specifically, we show how it is possible to directly obtain the market basket without repeatedly increasing the cost constraint (y_i^*) in one-cent increments and trying to solve the optimization problem until a feasible solution is found (CNPP 2021b). There are a few ways to obtain these results, and we find there are only a few minor differences in the results depending on which method is used.

D.1. Methods

This appendix explores the results from alternative methods that are computationally simpler than the original iterative approach used in TFP, 2021. The first uses the same optimization framework but reduces it to a single equation, with or without requiring the total market basket costs for the age-sex group to be reported as a whole integer (in cents). The second method further simplifies the optimization framework by allowing non-integer solutions. We modify both the distance-based and demand system-based objective functions in this way.

Given the process described above essentially solves for the lowest *feasible* value of y, we can combine the "inner" and "outer" optimization problems from the 2021 TFP revaluation (Equation 5 and constraint C.5.1) into a single objective function to compute the quantities, $\boldsymbol{q}$, that minimize:

$$\min_{\boldsymbol{q}_i} \sum_{j=1}^{J} p_j\, q_j + c \sum_{j=1}^{J} \frac{p_j\, \bar{q}_j}{\sum_k p_k \bar{q}_k} \left(q_j - \bar{q}_j\right)^2 \qquad 10$$

subject to constraints C.3.2 through C.3.5

$$\text{and} \qquad 100 \sum_{j=1}^{J} p_j\, q_j \in \mathbb{Z} \qquad \text{C.10.1}$$

where the terms are defined the same as in Chapter 7 (Section 7.6) and we set c to be a small, constant scaler. We can similarly re-write the optimization problem for the demand system-based approach (Equation 4 and constraint C.4.1) as:

$$\min_{\boldsymbol{q}_i} \sum_{j=1}^{J} p_j\, q_j + c \sum_{j=1}^{J} \hat{\beta}_j \left(q_{ij} - \left(\hat{\mu}_j + \hat{\boldsymbol{v}}_j\, \boldsymbol{z}_i\right)\right) \qquad 11$$

subject to constraints C.3.2 through C.3.5

$$\text{and} \qquad 100 \sum_{j=1}^{J} p_j\, q_j \in \mathbb{Z} \qquad \text{C.11.1}$$

Here, the constant (c) must be set small enough for the term on the right (after the plus) to remain less than 0.01 (for example, c = 0.00001); otherwise, the model would not necessarily minimize the total cost of the market basket. However, c must remain large enough that the term on the right does not become zero; otherwise, the solver could not converge on a solution to the problem (depending on the solver's numerical precision and convergence criteria). The term on the right allocates a small amount of expenditures (less than $0.01 for a single age-sex group) in settings where total expenditures (in cents) is required to be an integer. Equations 10 and 11 can be solved in a single step with mixed integer programming (MIP) methods, which reduces computational burden compared to the iterative process (programming loop) that was previously used to solve Equation 5. Two open-source solvers with MIP capabilities for the R programming language were compatible with DCP methods implemented by the `cvxr` package and could solve these problems.[57]

If CNPP were not concerned about the market basket costs falling on an increment of exactly one cent, then there would be no concern about how the part-cent is allocated across goods. In this case, we can decrease the constant c to zero, and simply compute the quantities, $\boldsymbol{q}$, that minimize the cost of the TFP market basket subject to the nutrient, food group, and practicality constraints:

$$\min_{\boldsymbol{q}_i} \sum_{j=1}^{J} p_j \, q_j \qquad 12$$

subject to constraints C.3.2 through C.3.5

We attempted to solve various versions of Equations 10, 11, and 12 to produce the results in this appendix.

D.2. Results

In short, the market baskets obtained with these methods are remarkably similar to the TFP, 2021 market basket in terms of costs, the composition of the market baskets, and the nutrient content while, as expected, being computationally easier to obtain. The computational benefits from running a single optimization model (rather than optimizing the model multiple times in an iterative loop) were noticed in the model run times. On our computer, it cumulatively took 48 minutes to solve the iterative TFP, 2021 optimization model (Equation 5) for the four age-sex groups that comprise the reference family (starting the iterations at $0.01, as one needs to do the first time the model is solved). In comparison, we could solve each of Equations 10, 11, and 12 in less than a minute in total for the same age-sex groups.[58]

The distance-based methods that only require a single optimization step—Equation 10 without MIP (column 2), Equation 10 with MIP (column 3), and Equation 12 (column 4)—produced market baskets with similar quantities, costs, and budget shares for aggregate food and beverage categories to the TFP, 2021 market basket, although they were comprised of slightly more dairy and fruits and slightly less vegetables (Appendix Exhibit D.1) and had a slightly higher average HEI-2020 score (Appendix Exhibit D.2). The market basket from Equation 10 had daily total expenditures $0.03 higher than the TFP, 2021 market basket cost (Appendix Exhibit D.2), but we suspect that we could obtain the TFP, 2021 market basket by continuing to further "tune" the magnitude of the constant (c), changing the parameters that govern the behavior of the MIP solver, or using a different solver. Removing the requirement that total expenditures (in cents) be an integer (that is, solving Equation 12) obtains the corner solution where costs are minimized for the four age-sex groups at $27.5761, about $0.0239 less than the TFP, 2021 market basket cost.[59] (We can obtain virtually identical solutions by solving Equation 10 without MIP or by solving Equation 12, but Equation 12 is computationally faster to solve and requires less data.) All these market baskets were required to meet the nutrient, food group, and practicality constraints from TFP, 2021 and, for this reason, the nutrient and food group content of

[57] We used the `ecos_bb` and `glpk_mi` solvers for MIP problems. These solvers are from the `ECOSolveR` and `Rglpk` packages for the R programming language, respectively (Domahidi, Chu, and Boyd 2013; Theussl and Hornik 2013; Fu and Narasimhan 2015).

[58] It cumulatively took 18 seconds to solve Equation 10 as a continuous problem for the four age sex groups (30 seconds with MIP), 26 seconds to solve Equation 11 (19 seconds with MIP), and 32 seconds to solve Equation 12 (35 seconds with the additional subsistence constraint).

[59] The market basket cost for the reference family is the sum of the daily total expenditures across the four age-sex groups that comprise the reference family. Therefore, costs for the reference family could decrease no more than $0.04 (four times a maximum of $0.01 for each age sex group).

these alternative market baskets were generally in line with the nutrient and food group content of the TFP, 2021 market basket (Appendix Exhibit D.3).

The demand-system-based methods that only require a single optimization step—Equation 11 without MIP (column 2) and Equation 11 with MIP (column 3)—produced market baskets similar to the main demand system-based approach and, by extension, generally similar to the TFP, 2021 market basket (Appendix Exhibit D.4). The demand system-based methods produce slightly more expensive market baskets than the TFP, 2021 market basket cost since the demand system-based approach requires at least $0.0609 higher spending to ensure that the subsistence quantities are met (Appendix Exhibit D.5). Requiring total expenditures (in cents) to be an integer (rounding up to the nearest cent) further increases the cost of the market basket a few additional cents. The MIP solver encountered some numerical issues with one age-sex group (children ages 6 to 8) but nonetheless produced a market basket for the reference family that was similar to the other approaches.[60] Again, there was only modest variation in the nutrient content of these alternative market baskets (Appendix Exhibit D.6).

[60] The market basket cost for children aged 6 to 8 year was $5.87 in the MIP solution, compared to $5.689 when we allowed continuous market basket costs. Again, we suspect that we could work around this issue by further "tuning" the magnitude of the constant (*c*), adjusting other parameters that govern the behavior of the MIP solver, or using a different MIP solver.

Appendix Exhibit D.1. Comparing distance-based methods to minimize costs: 10 aggregate food and beverage categories

Category	Quantities (100 gram units)				Costs ($ per day)				Expenditure shares (%)			
	1. TFP, 2021 (reproduce results)	2. Combine costs (continuous) and distance	3. Combine costs (integer cents) and distance	4. Minimize costs (continuous)	1. TFP, 2021 (reproduce results)	2. Combine costs (continuous) and distance	3. Combine costs (integer cents) and distance	4. Minimize costs (continuous)	1. TFP, 2021 (reproduce results)	2. Combine costs (continuous) and distance	3. Combine costs (integer cents) and distance	4. Minimize costs (continuous)
Dairy	26.95601	28.14631	27.48394	28.14631	$3.98	$3.87	$3.93	$3.87	14.4%	14.0%	14.2%	14.0%
Meat, poultry, seafood, eggs	7.64502	7.67359	7.59916	7.67359	$6.05	$6.08	$6.03	$6.08	21.9%	22.1%	21.9%	22.1%
Nuts and seeds, soy products	1.27399	1.27185	1.27186	1.27185	$0.72	$0.72	$0.72	$0.72	2.6%	2.6%	2.6%	2.6%
Mixed dishes	5.45692	5.25886	5.61218	5.25886	$1.57	$1.49	$1.65	$1.49	5.7%	5.4%	6.0%	5.4%
Grains and cereals	11.81321	11.80562	11.62351	11.80562	$3.93	$3.94	$3.88	$3.94	14.2%	14.3%	14.1%	14.3%
Snack foods and sweets	0.72123	0.81570	0.77634	0.81570	$0.46	$0.53	$0.51	$0.53	1.7%	1.9%	1.8%	1.9%
Fruits and fruit juice	14.44422	14.57199	14.35572	14.57199	$3.85	$3.91	$3.87	$3.91	13.9%	14.2%	14.0%	14.2%
Vegetables	16.80054	16.71568	16.69925	16.71568	$6.37	$6.34	$6.34	$6.34	23.1%	23.0%	23.0%	23.0%
Beverages	4.80000	4.80000	4.80000	4.80000	$0.32	$0.34	$0.32	$0.34	1.2%	1.2%	1.2%	1.2%
Fats, oils and condiments	0.65079	0.65070	0.63148	0.65070	$0.36	$0.36	$0.35	$0.36	1.3%	1.3%	1.3%	1.3%

Note: All these analyses used nutrient and food group constraints and practicality constraints from the TFP, 2021 approach. Quantities and costs may be reported as zero due to rounding. After computing the alternative TFP market basket quantities for all 95 food modeling categories, we calculated total quantities (in 100-gram units), costs ($ per day), and expenditure shares (a percentage) for the 10 categories shown in this table.

Appendix Exhibit D.2. Comparing distance-based methods to minimize costs: Summary statistics

Result	1. TFP, 2021 (reproduce results)	2. Combine costs (continuous) and distance	3. Combine costs (integer cents) and distance	4. Minimize costs (continuous)
Successfully solved for the reference family's four age-sex groups?	✓	✓	✓	✓
Market basket cost ($ per day)[a]	$27.6000	$27.5761	$27.6000	$27.5761
Distance of combined modeling categories from current consumption (10,000 $gram^2$ units)[a]	5.857	6.378	6.063	6.378
Distance of combined modeling categories from the published TFP, 2021 solution (10,000 $gram^2$ units)[a]	2.185 × 10−11	0.036	0.013	0.036
Mean squared error distance of TFP modeling categories from the TFP, 2021 solution (100 gram units)[a]	8.050 × 10−12	0.035	0.03	0.035
Energy (kcal)[a]	9,611.7	9,611.7	9,611.7	9,611.7
Calculated HEI-2020 score (0-100)[b]	94.0	95.0	94.1	95.0
SPF-predicted HEI-2020 score (average inefficiency)[b]	—	—	10.3	—
SPF-predicted HEI-2020 score (no inefficiency)[b]	—	—	11.7	—
Any combined modeling categories with zero quantity?	✓	✓	✗	✗
Number of combined modeling categories with zero quantity?[a]	29	7	0	0
Any combined modeling categories with near-zero (< 1e-9) quantity?	✓	✓	✓	✓
Number of combined modeling categories with near-zero (< 1e-9) quantity?[a]	71	71	8	50
Demand system-predicted utility[a]	0	0	—	—
Demand system-predicted log(utility)[a]	−Inf	−Inf	—	—
All TFP, 2021 nutrient constraints met?	✓	✓	✓	✓
Number of TFP, 2021 nutrient and food group constraints met[a]	376	376	376	376
All TFP, 2021 practicality constraints met?	✓	✓	✓	✓
Number of TFP, 2021 practicality constraints met[a]	112	112	112	112
Gini impurity of the TFP modeling category expenditure shares (0-1)	0.946	0.945	0.946	0.945
Gini impurity of the combined modeling category expenditure shares (0-1)	0.929	0.926	0.928	0.926
Entropy of the TFP modeling category expenditure shares (0-1)	0.230	0.232	0.233	0.232
Entropy of the combined modeling category expenditure shares (0-1)	0.268	0.275	0.272	0.275

Note: All these analyses used nutrient and food group constraints and practicality constraints from the TFP, 2021 approach.

[a] Sum across the reference family's age-sex groups.

[b] Average across the reference family's age-sex groups.

HEI = Healthy Eating Index; TFP = Thrifty Food Plan.

Appendix Exhibit D.3. Comparing distance-based methods to minimize costs: Nutrient and food group content

Nutrient	1. TFP, 2021 (reproduce results)	2. Combine costs (continuous) and distance	3. Combine costs (integer cents) and distance	4. Minimize costs (continuous)
Food energy				
Energy (kcal)	9,611.7	9,611.7	9,611.7	9,611.7
Macro-nutrients				
Carbohydrates (g)	1,237.5	1,250.6	1,239.9	1,250.6
Protein (g)	455.8	455.7	455.0	455.7
18:02 (linoleic acid) (g)	77.9	77.9	77.8	77.9
18:03 (linolenic acid) (g)	6.8	6.8	6.8	6.8
Fatty acids total monounsaturated (g)	122.5	120.9	122.5	120.9
Fatty acids total polyunsaturated (g)	86.8	86.9	86.7	86.9
Saturated fat (g)	97.8	94.5	97.6	94.5
Total Fat (g)	336.9	331.1	336.4	331.1
Fiber total dietary (g)	135.2	135.2	135.2	135.2
Micro-nutrient				
Calcium (mg)	6,296.7	6,148.7	6,190.6	6,148.7
Cholesterol (mg)	1,249.2	1,209.3	1,224.7	1,209.3
Choline total (mg)	1,843.6	1,844.8	1,832.4	1,844.8
Copper (mg)	6.4	6.4	6.4	6.4
Iron (mg)	73.3	72.6	73.3	72.6
Folic acid (µg)	716.0	703.3	722.9	703.3
Folate (µg DFE)	2,876.2	2,854.3	2,879.9	2,854.3
Potassium (mg)	17,782.2	17,897.8	17,804.9	17,897.8
Magnesium (mg)	1,950.0	1,961.3	1,949.6	1,961.3
Sodium (mg)	11,149.2	10,894.3	11,062.4	10,894.3
Niacin (mg)	132.0	132.3	132.3	132.3
Phosphorus (mg)	8,215.6	8,158.8	8,165.7	8,158.8
Riboflavin (mg)	11.6	11.7	11.7	11.7
Selenium (µg)	632.9	631.6	629.1	631.6
Thiamin (mg)	9.0	9.1	9.1	9.1
Vitamin E (alpha-tocopherol) (mg)	49.8	49.7	49.8	49.7
Vitamin A RAE	6,293.4	6,210.4	6,252.6	6,210.4
Vitamin B-12 (µg)	24.5	24.7	24.7	24.7
Vitamin B-6 (mg)	11.9	11.9	12.0	11.9
Vitamin C (mg)	497.2	505.5	495.1	505.5
Vitamin D (D2 + D3) (µg)	44.4	44.5	44.4	44.5
Vitamin K (phylloquinone) (µg)	668.0	669.1	668.0	669.1
Zinc (mg)	55.0	54.7	55.1	54.7

Nutrient	1. TFP, 2021 (reproduce results)	2. Combine costs (continuous) and distance	3. Combine costs (integer cents) and distance	4. Minimize costs (continuous)
Calories from macro-nutrients				
Kcal from protein	1,823.3	1,822.6	1,820.0	1,822.6
Kcal from carbohydrates	4,950.1	5,002.6	4,959.4	5,002.6
Kcal from fat	3,031.9	2,980.3	3,027.6	2,980.3
Kcal from saturated fat	879.9	850.1	878.6	850.1
FPED food groups				
Fruit juices - citrus and non citrus (cup eq.)	2.4	2.4	2.3	2.4
Total intact or cut fruits and fruit juices (cup eq.)	8.4	8.4	8.4	8.4
Dark green vegetables (cup eq.)	1.2	1.2	1.2	1.2
Total red and orange vegetables (tomatoes + other red and orange) (cup eq.)	3.8	3.8	3.8	3.8
Total starchy vegetables (white potatoes + other starchy) (cup eq.)	3.9	3.9	3.9	3.9
Other vegetables not in the vegetable components listed above (cup eq.)	3.1	3.1	3.1	3.1
Legumes computed as vegetables (cup eq.)	1.5	1.5	1.5	1.5
Total dark green red and orange starchy and other vegetables; excludes legumes (cup eq.)	13.5	13.5	13.5	13.5
Whole grains (oz. eq.)	17.9	18.0	17.8	18.0
Refined or non-whole grains (oz. eq.)	17.9	18.0	17.8	18.0
Total whole and refined grains (oz. eq.)	35.8	36.1	35.6	36.1
Beef veal pork lamb game meat; excludes organ meats and cured meat (oz. eq.)	3.9	3.9	3.9	3.9
Chicken turkey Cornish hens and game birds; excludes organ meats and cured meat (oz. eq.)	9.7	9.8	9.8	9.8
Eggs (chicken duck goose quail) and egg substitutes (oz. eq.)	2.7	2.5	2.5	2.5
Soy products excluding calcium fortified soy milk and immature soybeans (oz. eq.)	0.1	0.1	0.1	0.1
Peanuts tree nuts and seeds excludes coconut (oz. eq.)	8.0	8.0	8.0	8.0
Total meat poultry seafood organ meats cured meat eggs soy and nuts and seeds; excludes legumes (oz. eq.)	30.4	30.3	30.4	30.3
Total milk yogurt cheese and whey (cup eq.)	12.1	12.1	12.1	12.1
Oils (g)	141.0	141.7	141.2	141.7
Meat poultry egg aggregate (oz. eq.)	16.9	16.9	16.9	16.9
Seafood aggregate (oz. eq.)	5.4	5.4	5.4	5.4
Nut seed soy aggregate (oz. eq.)	8.1	8.1	8.1	8.1
Kcal from added sugars	384.8	406.1	394.4	406.1

Nutrient	1. TFP, 2021 (reproduce results)	2. Combine costs (continuous) and distance	3. Combine costs (integer cents) and distance	4. Minimize costs (continuous)
Calories by eating occasion				
Kcal from breakfast	2,210.7	2,210.7	2,210.7	2,210.7
Kcal from lunch	2,690.6	2,682.7	2,673.5	2,682.7
Kcal from dinner	3,283.8	3,270.4	3,276.0	3,270.4
Kcal from snacks	1,241.6	1,254.9	1,261.8	1,254.9
Kcal from drinks	109.9	116.6	113.1	116.6
Kcal from extended consumption	75.1	76.4	76.6	76.4

Note: All these analyses used nutrient and food group constraints and practicality constraints from the TFP, 2021 approach.

TFP = Thrifty Food Plan; DFE = dietary folate equivalent; eq. = equivalent; g = gram; kcal = kilocalorie; oz = ounce; mg = milligram; µg = microgram; RAE = retinol activity equivalent.

Appendix Exhibit D.4. Comparing demand system-based methods to minimize costs: 10 aggregate food and beverage categories

Category	Quantities (100 gram units)				Costs ($ per day)				Expenditure shares (%)			
	1. Demand system approach (utility)	2. Combine costs (continuous) and utility	3. Combine costs (integer cents) and utility	4. Minimize costs (continuous) and meet demand subsistence	1. Demand system approach (utility)	2. Combine costs (continuous) and utility	3. Combine costs (integer cents) and utility	4. Minimize costs (continuous) and meet demand subsistence	1. Demand system approach (utility)	2. Combine costs (continuous) and utility	3. Combine costs (integer cents) and utility	4. Minimize costs (continuous) and meet demand subsistence
Dairy	27.72002	28.02521	27.55795	28.02523	$3.90	$3.86	$3.91	$3.86	14.1%	14.0%	13.9%	14.0%
Meat, poultry, seafood, eggs	7.49240	7.64626	7.56786	7.64626	$5.96	$6.07	$6.06	$6.07	21.5%	22.0%	21.6%	22.0%
Nuts and seeds, soy products	1.25688	1.26718	1.25908	1.26718	$0.71	$0.72	$0.74	$0.72	2.6%	2.6%	2.6%	2.6%
Mixed dishes	5.86925	5.27818	5.57692	5.27818	$1.78	$1.54	$1.75	$1.54	6.4%	5.6%	6.2%	5.6%
Grains and cereals	11.52590	11.67522	11.39890	11.67523	$3.87	$3.91	$3.85	$3.91	14.0%	14.1%	13.7%	14.1%
Snack foods and sweets	0.88788	0.88753	1.02024	0.88753	$0.60	$0.61	$0.77	$0.61	2.2%	2.2%	2.7%	2.2%
Fruits and fruit juice	14.38828	14.58832	14.49593	14.58833	$3.84	$3.90	$3.87	$3.90	13.9%	14.1%	13.8%	14.1%
Vegetables	16.70441	16.71172	16.79817	16.71171	$6.34	$6.34	$6.38	$6.34	22.9%	22.9%	22.7%	22.9%
Beverages	5.01638	4.93800	5.42425	4.93800	$0.32	$0.33	$0.37	$0.33	1.2%	1.2%	1.3%	1.2%
Fats, oils and condiments	0.62141	0.62419	0.68222	0.62419	$0.34	$0.34	$0.37	$0.34	1.2%	1.2%	1.3%	1.2%

Note: All these analyses used nutrient and food group constraints and practicality constraints from the TFP, 2021 approach. Quantities and costs may be reported as zero due to rounding. After computing the alternative TFP market basket quantities for all 95 food modeling categories, we calculated total quantities (in 100-gram units), costs ($ per day), and expenditure shares (a percentage) for the 10 categories shown in this table.

Appendix Exhibit D.5. Comparing demand system-based methods to minimize costs: Summary statistics

Result	1. Demand system approach (utility)	2. Combine costs (continuous) and utility	3. Combine costs (integer cents) and utility	4. Minimize costs (continuous) and meet demand subsistence
Successfully solved for the reference family's four age-sex groups?	✓	✓	✓	✓
Market basket cost ($ per day)[a]	$27.6600	$27.6370	$28.0800	$27.6370
Distance of combined modeling categories from current consumption (10,000 gram^2 units)[a]	6.141	6.276	6.004	6.276
Distance of combined modeling categories from the published TFP, 2021 solution (10,000 gram^2 units)[a]	0.022	0.032	0.019	0.032
Mean squared error distance of TFP modeling categories from the TFP, 2021 solution (100 gram units)[a]	0.011	0.029	0.016	0.029
Energy (kcal)[a]	9,611.7	9,611.7	9,614.8	9,611.7
Calculated HEI-2020 score (0-100)[b]	94.7	94.9	94.7	94.9
SPF-predicted HEI-2020 score (average inefficiency)[b]	1.8	7.3	156.5	—
SPF-predicted HEI-2020 score (no inefficiency)[b]	2.1	8.2	178.1	—
Any combined modeling categories with zero quantity?	✗	✗	✗	✗
Number of combined modeling categories with zero quantity?[a]	0	0	0	0
Any combined modeling categories with near-zero (< 1e-9) quantity?	✓	✓	✗	✓
Number of combined modeling categories with near-zero (< 1e-9) quantity?[a]	26	2	0	22
Demand system-predicted utility[a]	—	—	—	—
Demand system-predicted log(utility)[a]	—	—	—	—
All TFP, 2021 nutrient constraints met?	✓	✓	✓	✓
Number of TFP, 2021 nutrient and food group constraints met[a]	376	376	376	376
All TFP, 2021 practicality constraints met?	✓	✓	✓	✓
Number of TFP, 2021 practicality constraints met[a]	112	112	112	112
Gini impurity of the TFP modeling category expenditure shares (0-1)	0.947	0.946	0.949	0.946
Gini impurity of the combined modeling category expenditure shares (0-1)	0.929	0.928	0.932	0.928
Entropy of the TFP modeling category expenditure shares (0-1)	0.230	0.231	0.227	0.231
Entropy of the combined modeling category expenditure shares (0-1)	0.272	0.274	0.269	0.274

Note: All these analyses used nutrient and food group constraints and practicality constraints from the TFP, 2021 approach.

[a] Sum across the reference family's age-sex groups.

[b] Average across the reference family's age-sex groups.

HEI = Healthy Eating Index; TFP = Thrifty Food Plan.

Appendix Exhibit D.6. Comparing demand system-based methods to minimize costs: Nutrient and food group content

Nutrient	1. Demand system approach (utility)	2. Combine costs (continuous) and utility	3. Combine costs (integer cents) and utility	4. Minimize costs (continuous) and meet demand subsistence
Food energy				
Energy (kcal)	9,611.7	9,611.7	9,614.8	9,611.7
Macro-nutrients				
Carbohydrates (g)	1,245.2	1,249.9	1,244.6	1,249.9
Protein (g)	454.6	455.1	455.5	455.1
18:02 (linoleic acid) (g)	78.0	77.9	78.4	77.9
18:03 (linolenic acid) (g)	6.8	6.8	6.8	6.8
Fatty acids total monounsaturated (g)	122.0	121.2	121.9	121.2
Fatty acids total polyunsaturated (g)	86.9	86.8	87.4	86.8
Saturated fat (g)	96.0	94.8	95.9	94.8
Total Fat (g)	334.2	331.8	334.6	331.8
Fiber total dietary (g)	135.2	135.2	135.5	135.2
Micro-nutrient				
Calcium (mg)	6,219.7	6,163.8	6,228.2	6,163.8
Cholesterol (mg)	1,209.6	1,206.3	1,211.1	1,206.3
Choline total (mg)	1,836.4	1,841.3	1,840.3	1,841.3
Copper (mg)	6.4	6.4	6.5	6.4
Iron (mg)	72.8	72.8	73.5	72.8
Folic acid (µg)	709.1	706.6	719.9	706.6
Folate (µg DFE)	2,861.7	2,858.1	2,874.5	2,858.1
Potassium (mg)	17,877.6	17,897.7	17,902.0	17,897.7
Magnesium (mg)	1,954.5	1,960.8	1,958.2	1,960.8
Sodium (mg)	11,106.5	10,959.9	11,190.3	10,959.9
Niacin (mg)	132.0	132.3	132.5	132.3
Phosphorus (mg)	8,172.9	8,165.6	8,201.6	8,165.6
Riboflavin (mg)	11.7	11.8	11.8	11.8
Selenium (µg)	628.3	629.9	628.0	629.9
Thiamin (mg)	9.0	9.1	9.1	9.1
Vitamin E (alpha-tocopherol) (mg)	49.9	49.9	50.1	49.9
Vitamin A RAE	6,269.6	6,217.3	6,273.4	6,217.3
Vitamin B-12 (µg)	24.7	24.8	25.0	24.8
Vitamin B-6 (mg)	11.9	11.9	12.0	11.9
Vitamin C (mg)	496.5	507.4	507.1	507.4
Vitamin D (D2 + D3) (µg)	44.5	44.5	44.5	44.5
Vitamin K (phylloquinone) (µg)	667.8	667.1	671.9	667.1
Zinc (mg)	54.9	54.9	55.4	54.9

Nutrient	1. Demand system approach (utility)	2. Combine costs (continuous) and utility	3. Combine costs (integer cents) and utility	4. Minimize costs (continuous) and meet demand subsistence
Calories from macro-nutrients				
Kcal from protein	1,818.4	1,820.4	1,822.0	1,820.4
Kcal from carbohydrates	4,980.8	4,999.8	4,978.3	4,999.8
Kcal from fat	3,007.4	2,985.9	3,011.0	2,985.9
Kcal from saturated fat	863.8	852.8	863.4	852.8
FPED food groups				
Fruit juices - citrus and non citrus (cup eq.)	2.4	2.4	2.5	2.4
Total intact or cut fruits and fruit juices (cup eq.)	8.4	8.4	8.4	8.4
Dark green vegetables (cup eq.)	1.2	1.2	1.2	1.2
Total red and orange vegetables (tomatoes + other red and orange) (cup eq.)	3.8	3.8	3.8	3.8
Total starchy vegetables (white potatoes + other starchy) (cup eq.)	3.9	3.9	4.0	3.9
Other vegetables not in the vegetable components listed above (cup eq.)	3.1	3.1	3.2	3.1
Legumes computed as vegetables (cup eq.)	1.5	1.5	1.5	1.5
Total dark green red and orange starchy and other vegetables; excludes legumes (cup eq.)	13.5	13.5	13.6	13.5
Whole grains (oz. eq.)	17.9	18.0	17.9	18.0
Refined or non-whole grains (oz. eq.)	17.9	18.0	17.8	18.0
Total whole and refined grains (oz. eq.)	35.8	36.0	35.7	36.0
Beef veal pork lamb game meat; excludes organ meats and cured meat (oz. eq.)	3.8	3.8	4.0	3.8
Chicken turkey Cornish hens and game birds; excludes organ meats and cured meat (oz. eq.)	9.7	9.7	9.7	9.7
Eggs (chicken duck goose quail) and egg substitutes (oz. eq.)	2.5	2.5	2.5	2.5
Soy products excluding calcium fortified soy milk and immature soybeans (oz. eq.)	0.1	0.1	0.1	0.1
Peanuts tree nuts and seeds excludes coconut (oz. eq.)	8.0	8.0	8.0	8.0
Total meat poultry seafood organ meats cured meat eggs soy and nuts and seeds; excludes legumes (oz. eq.)	30.3	30.3	30.4	30.3
Total milk yogurt cheese and whey (cup eq.)	12.1	12.1	12.1	12.1
Oils (g)	142.1	141.7	142.3	141.7
Meat poultry egg aggregate (oz. eq.)	16.9	16.9	16.9	16.9
Seafood aggregate (oz. eq.)	5.4	5.4	5.4	5.4
Nut seed soy aggregate (oz. eq.)	8.1	8.1	8.1	8.1
Kcal from added sugars	399.6	405.2	397.7	405.2

Nutrient	1. Demand system approach (utility)	2. Combine costs (continuous) and utility	3. Combine costs (integer cents) and utility	4. Minimize costs (continuous) and meet demand subsistence
Calories by eating occasion				
Kcal from breakfast	2,210.7	2,210.7	2,200.8	2,210.7
Kcal from lunch	2,690.5	2,678.9	2,673.7	2,678.9
Kcal from dinner	3,254.0	3,260.1	3,247.3	3,260.1
Kcal from snacks	1,270.0	1,271.2	1,307.8	1,271.2
Kcal from drinks	111.3	115.3	111.1	115.3
Kcal from extended consumption	75.2	75.6	74.1	75.6

Note: All these analyses used nutrient and food group constraints and practicality constraints from the TFP, 2021 approach.

DFE = dietary folate equivalent; eq. = equivalent; g = gram; kcal = kilocalorie; oz = ounce; mg = milligram; µg = microgram; RAE = retinol activity equivalent.

D.3. Implications

The equations above and the results from solving them have practical implications on CNPP's methodology for evaluating TFP market baskets. In particular, these results shed light on the practical effect of requiring the total expenditures (the market basket cost) be an integer for each age-sex group. This requirement increases the cost of the market basket for the reference family by a little more than two cents. With this integer requirement comes a need for increasing the model's complexity, so the model can determine how the two cents are spent. In this setting, the inner objective function (minimizing distance, maximizing utility, or something else) can have a small role in determining the composition and cost of the TFP market basket. This small role of the integer requirement is magnified somewhat because CNPP solves the optimization problem separately for each age-sex group, then aggregates the four market baskets together to create the TFP market basket for the reference family. Because of this approach, the integer requirement can increase the cost of the market basket anywhere from $0 to $0.04.

These results also demonstrate that CNPP could obtain similar market baskets by solving a single optimization problem for each age-sex group. If CNPP allowed the total cost of the market basket to be a continuous number, rather than an integer, then it could simply minimize the cost of the market basket. The resulting market basket would be similar, but CNPP would no longer need to compile data on current consumption and the optimization step would become less complex. There would no longer be any need to choose between minimizing distance to current consumption or maximizing utility. If CNPP maintained the same approach (requiring the market basket cost, in cents, to be an integer for each age-sex group), it could use Equation 10 and a MIP solver to do so, reducing the computational burden of iteratively solving hundreds of optimization problems to discover the lowest-cost feasible solution for each group. Likewise, Equation 11 and an MIP solver could obtain a demand-based solution in a single step.

These results further help us assess the role of the demand systems' subsistence quantities in the demand system-based approach. Comparing the last columns of Appendix Exhibit D.2 and Appendix Exhibit D.5, the subsistence quantities in the demand system are responsible for increasing the cost of the market basket by about $0.0609. Because the total cost of the market basket is higher with the demand system approach than the optimization approach, it would not be feasible to use a demand system approach to estimate an alternative TFP market basket that meets all nutrient, food group, and practicality constraints and that also has the same total cost as the TFP, 2021 solution.

Appendix E. Using published formula for the HEI-2020 scores

In this appendix, we explore the limit of what CNPP could expect to achieve from improving the SPF models (or other econometric models) to the point where they *perfectly* predict HEI-2020 scores. Specifically, we used the *actual* formula for computing HEI-2020 scores in place of SPF model's formula for predicting HEI-2020 scores. Then, we used DCP methods to compute the lowest-cost TFP market baskets that had an HEI-2020 score of 100 (the highest possible score) and have sufficient energy content at the age-sex group's Recommended Energy Intake (REI). By removing *all* error that resulted from using econometric modeling to "rediscover" the HEI score formulas (see Chapter 8), this approach helps clarify the potential for more informative results to be obtained by improving the stochastic production frontier (SPF)-based approach, for example, by fitting the SPF models with alternative regression specifications or different data sources.

E.1. Methods

In this appendix we begin by computing the quantities, $\boldsymbol{q}$, that minimize:

$$\min_{\boldsymbol{q}} \sum_{j=1}^{J} p_j \, q_j \qquad 13$$

subject to

$$100 = \text{hei}(\boldsymbol{q}\,; \boldsymbol{d}, \boldsymbol{f}) \qquad \text{C.13.1}$$

$$0 \le q_g \quad \forall \, g \qquad \text{C.13.2}$$

$$D_{kcal}^{LB} \le \sum_{j=1}^{J} q_j d_{j,kcal} \le D_{kcal}^{UB} \qquad \text{C.13.3}$$

$$Q_g^{LB} \le q_g \le Q_g^{UB} \quad \forall \, g \qquad \text{C.13.4}$$

where the terms are defined the same as in Chapters 7 and 8 (Sections 7.6 and 8.6, respectively) and $\text{hei}(\boldsymbol{q})$ is the actual (computed) HEI-2020 score for a market basket based on the quantities of each modeling category ($\boldsymbol{q}$), conditional on each modeling categories' per-unit nutrient content ($\boldsymbol{d}$) and contribution to FPED food groups ($\boldsymbol{f}$). We obtained the published definition of the HEI-2020 score (Shams-White et al. 2023, 1285; CNPP 2023; NCI and CNPP 2024) and implemented $\text{hei}(\boldsymbol{q})$ using disciplined convex programming (DCP)-compatible programming code. The first constraint (C.13.1) requires the market basket to achieve an HEI-2020 score of 100, which is the highest possible score.[61] The third constraint (C.13.3) requires the energy content (kcal) of the market basket to meet the REI for the respective age-sex group.[62] This approach does not impose the other nutrient or food group constraints, but additional constraints could be added in future work. The other two constraints (C.13.2 and C.13.4) are the usual non-negativity and practicality constraints. We also tested the sensitivity of results to (1) removing one or both of these latter two constraints (C.13.2 and C.13.4) from Equation 13 or (2) computing the lowest feasible cost that minimized distance to current consumption (the objective in Equation 5 in chapter 7) subject to constraints C.13.1 through C.13.4 (with and without setting the cost of the market basket cost equal to the TFP, 2021 market basket cost).

[61] We considered testing the sensitivity of the results to allowing lower HEI-2020 scores than 100, but $\text{hei}(\boldsymbol{q})$ is not, in general, a DCP-compliant function. It was only feasible to solve Equation 13 using DCP methods when we constrained HEI scores to be 100.

[62] HEI-2020 scores can equal 100 with near-zero modeling category quantities because the HEI-2020 score is independent of the size of the market basket (or diet). We require the market basket to meet the REI for the respective age-sex group to avoid market baskets with zero (or near-zero) quantities and costs.

E.2. Results

Solving Equation 13 produced a more reasonable TFP market basket than the SPF-based approach (presented in Chater 8) in the sense that the market basket quantities and costs were no longer zero. Nonetheless, the nutritional content of the market basket remains a concern. Compared with the TFP, 2021 market basket the approach produced a market basket with larger quantities of dairy, nuts and seeds and soy, but completely eliminated any consumption of meat, poultry, seafood, and eggs and fats, oils and condiments (column 1 in Appendix Exhibit E.1). The market basket cost was $19.29, which is $8.29 (30 percent), less than the cost of the TFP, 2021 market basket (Appendix Exhibit E.2). Various summary measures show an increased distance between this market basket and current consumption and the quantities are more concentrated in fewer modeling categories. That is, the market basket resulting from Equation 13 is less varied than the TFP, 2021 market basket.

By construction, this basket achieved an HEI-2020 score of 100 and includes sufficient energy (kcal) to meet the REI for all four age-sex groups that comprise the reference family. The nutrient content of the market basket from this approach had higher amounts of dietary fiber, calcium, iron, folate, and carbohydrates than the TFP, 2021 basket, but lower amounts of Vitamin D, potassium, sodium, saturated fats, total fat added sugars, and protein (Appendix Exhibit E.3). In total, we found the market basket would not have met 85 out of 376 nutrient and food group constraints (23 percent) from the TFP, 2021 optimization approach, meaning that in a variety of the ways this market basket does not meet current dietary guidance. This occurs because requiring a high HEI-2020 score for a market basket did not functionally *guarantee* that the market basket would comply with current dietary guidance. (We separately required the market basket to have sufficient energy [kcal] to meet the REI for each age-sex group, but that was all.) However, the HEI was designed to assess alignment with the Dietary Guidelines for Americans (DGA) (USDA and HHS 2020), and the quantities of foods and beverages in the FPED groups indicate the HEI score constraint approximately achieved this goal for major categories such as dairy, fruits, vegetables, and grains.

In sensitivity analyses, we found that:

1. The cost of the reference family's market basket would decrease further (from $19.29 to $17.56) if we did not include the practicality constraints (C.13.4) in the optimization model (column 2). The decrease in cost was driven by a particularly large decrease of vegetable consumption (and dairy and beverages, to a lesser extent), offset by an increase in costs for nuts and seeds, soy products and mixed dishes. Fewer nutrient and food group constraints from the TFP, 2021 optimization approach were met in this approach (288 in column 2 versus 291 in column 1).
2. Removing the constraint on the basket's energy content (C.13.2) results in market basket with near-zero quantities for all food groups and market basket cost of $0.00000000018 (column 3). This is not surprising because the HEI score is a summary "measure of overall diet quality, *independent of quantity*, that can be used to assess alignment with the DGA." (Shams-White et al. 2023, 1280 [*emphasis added*]).
3. The lowest feasible market basket cost for the reference family that satisfies the constraints based on current dietary guidance from TFP, 2021 would be $19.31 (column 4). This total cost is about $0.02 cents higher than the main result (column 1) because we require the market costs, in cents, to be an integer. Otherwise, the two market baskets are similar.
4. Finally, we assessed a model that would allow the consumer to minimize distance to current consumption, allocating the full $27.60 (the cost of the TFP, 2021 market basket) in any way that achieved a HEI score of 100, the REI, and the practicality constraints. Compared to this appendix's main results (column 1), this "cost neutral" TFP market basket was considerably more similar to current consumption (column 5). This is seen at the TFP modeling category level, where we see shifts in

consumption across food modeling categories (for example, from the lower to the higher nutrient density milk and yogurt categories). Along with these changes in the market basket composition came some shifts in the nutrient and food group content of the market basket, such as decreased protein and increased calcium levels. The FPED food group content of the two market baskets (in columns 1 and 5) were similar, however, since many of these levels are determined by focusing the market basket to have a HEI-2020 score of 100. In all, the cost-neutral diet met 308 of the 376 nutrient and food group constraints from TFP, 2021.

Appendix Exhibit E.1. Comparing HEI-based methods that minimize costs: 10 aggregate food and beverage categories

Category	Quantities (100 gram units)					Costs ($ per day)					Expenditure shares (%)				
	1. Min. cost with HEI = 100, REI, and practicality[a]	2. Min. cost with HEI = 100 and REI (only)[a]	3. Min. cost with HEI = 100 (only)[a]	4. Min. distance and cost with HEI = 100, REI, and practicality[b,c]	5. Min. distance and cost neutral (=) with HEI = 100, REI, and practicality[b]	1. Min. cost with HEI = 100, REI, and practicality	2. Min. cost with HEI = 100 and REI (only)	3. Min. cost with HEI = 100 (only)	4. Min. distance and cost with HEI = 100, REI, and practicality	5. Min. distance and cost neutral (=) with HEI = 100, REI, and practicality	1. Min. cost with HEI = 100, REI, and practicality	2. Min. cost with HEI = 100 and REI (only)	3. Min. cost with HEI = 100 (only)	4. Min. distance and cost with HEI = 100, REI, and practicality	5. Min. distance and cost neutral (=) with HEI = 100, REI, and practicality
Dairy	30.70411	30.54616	0.00000	29.58753	16.71144	$4.35	$3.98	$0.00	$4.42	$4.86	22.6%	22.6%	6.9%	22.9%	17.6%
Meat, poultry, seafood, eggs	0.00000	0.00000	0.00000	0.00000	0.65486	$0.00	$0.00	$0.00	$0.00	$1.06	0.0%	0.0%	0.5%	0.0%	3.8%
Nuts and seeds, soy products	3.40834	5.53672	0.00000	3.32046	2.39059	$2.17	$3.13	$0.00	$2.00	$3.53	11.3%	17.8%	4.3%	10.3%	12.8%
Mixed dishes	2.66685	6.90497	0.00000	2.66685	2.80263	$0.59	$1.86	$0.00	$0.59	$0.96	3.1%	10.6%	11.8%	3.1%	3.5%
Grains and cereals	10.82153	11.73017	0.00000	10.82933	11.56639	$3.51	$3.77	$0.00	$3.52	$3.17	18.2%	21.5%	7.5%	18.2%	11.5%
Snack foods and sweets	0.13594	1.27662	0.00000	0.13594	1.22437	$0.10	$0.54	$0.00	$0.10	$1.30	0.5%	3.1%	0.6%	0.5%	4.7%
Fruits and fruit juice	14.78148	14.92593	0.00000	14.84939	12.81490	$3.39	$3.44	$0.00	$3.41	$3.67	17.6%	19.6%	38.0%	17.7%	13.3%
Vegetables	16.11467	2.72175	0.00000	16.47759	19.28954	$4.92	$0.83	$0.00	$5.03	$6.85	25.5%	4.7%	23.5%	26.1%	24.8%
Beverages	4.80000	0.00000	0.00000	4.80000	12.76754	$0.25	$0.00	$0.00	$0.25	$2.20	1.3%	0.0%	5.1%	1.3%	8.0%
Fats, oils and condiments	0.00000	0.00000	0.00000	0.00000	0.00000	$0.00	$0.00	$0.00	$0.00	$0.00	0.0%	0.0%	1.8%	0.0%	0.0%

Note: Quantities and costs may be reported as zero due to rounding. After computing the alternative TFP market basket quantities for all 95 food modeling categories, we calculated total quantities (in 100-gram units), costs ($ per day), and expenditure shares (a percentage) for the 10 categories shown in this table.

[a] The objective function minimized costs using the approach from Appendix B.

[b] The objective function minimized distance to current consumption using the approach from TFP, 2021.

[c] An incremental approach was used to identify the lowest feasible cost, similar to TFP, 2021.

HEI = Healthy Eating Index; REI = Recommended Energy Intake; TFP = Thrifty Food Plan.

Appendix Exhibit E.2. Comparing HEI-based methods that minimize costs: Summary statistics

Result	1. Min. cost with HEI = 100, REI, and practicality[a]	2. Min. cost with HEI = 100 and REI (only)[a]	3. Min. cost with HEI = 100 (only)[a]	4. Min. distance and cost with HEI = 100, REI, and practicality[b,c]	5. Min. distance and cost neutral (=) with HEI = 100, REI, and practicality[b]
Successfully solved for the reference family's four age-sex groups?	✓	✓	✓	✓	✓
Market basket cost ($ per day)[d]	$19.29	$17.56	$0.00000000018	$19.31	$27.60
Distance of combined modeling categories from current consumption (10,000 gram^2 units)[d]	7.332	7.234	0.902	6.784	1.523
Distance of combined modeling categories from the published TFP, 2021 solution (10,000 gram^2 units)[d]	1.349	1.445	8.91	1.318	3.059
Mean squared error distance of TFP modeling categories from the TFP, 2021 solution (100 gram units)[d]	1.249	1.644	1.932	1.123	1.367
Energy (kcal)[d]	9,611.7	9,611.7	0.0	9,611.7	9,611.7
Calculated HEI-2020 score (0-100)[e]	100.0	100.0	93.4	100.0	100.0
SPF-predicted HEI-2020 score (average inefficiency)[e]	0.6	0.9	—	—	26.2
SPF-predicted HEI-2020 score (no inefficiency)[e]	0.6	1.1	—	—	29.5
Any combined modeling categories with zero quantity?	✗	✗	✓	✓	✗
Number of combined modeling categories with zero quantity?[d]	0	0	100	52	0
Any combined modeling categories with near-zero (< 1e-9) quantity?	✓	✓	✓	✓	✓
Number of combined modeling categories with near-zero (< 1e-9) quantity?[d]	122	144	180	138	50
Demand system-predicted utility[d]	—	—	0	0	—
Demand system-predicted log(utility)[d]	—	—	−Inf	−Inf	—
All TFP, 2021 nutrient constraints met?	✗	✗	✗	✗	✗
Number of TFP, 2021 nutrient and food group constraints met[d]	291	288	200	292	308
All TFP, 2021 practicality constraints met?	✓	✗	✗	✓	✓
Number of TFP, 2021 practicality constraints met[d]	112	98	110	112	112

Result	1. Min. cost with HEI = 100, REI, and practicality[a]	2. Min. cost with HEI = 100 and REI (only)[a]	3. Min. cost with HEI = 100 (only)[a]	4. Min. distance and cost with HEI = 100, REI, and practicality[b,c]	5. Min. distance and cost neutral (=) with HEI = 100, REI, and practicality[b]
Gini impurity of the TFP modeling category expenditure shares (0-1)	0.866	0.860	0.853	0.867	0.932
Gini impurity of the combined modeling category expenditure shares (0-1)	0.826	0.837	0.846	0.828	0.925
Entropy of the TFP modeling category expenditure shares (0-1)	0.349	0.336	0.345	0.350	0.267
Entropy of the combined modeling category expenditure shares (0-1)	0.349	0.336	0.345	0.350	0.267

[a] The objective function minimized costs using the approach from Appendix B.

[b] The objective function minimized distance to current consumption using the approach from TFP, 2021.

[c] An incremental approach was used to identify the lowest feasible cost, similar to TFP, 2021.

[d] Sum across the reference family's age-sex groups.

[e] Average across the reference family's age-sex groups Insert table e04 appendix d-2 here.

HEI = Healthy Eating Index; REI = Recommended Energy Intake; TFP = Thrifty Food Plan.

Appendix Exhibit E.3. Comparing HEI-based methods that minimize costs: Nutrient and food group content

Nutrient	1. Min. cost with HEI = 100, REI, and practicality[a]	2. Min. cost with HEI = 100 and REI (only)[a]	3. Min. cost with HEI = 100 (only)[b,c]	4. Min. distance and cost with HEI = 100, REI, and practicality[b]	5. Min. distance and cost neutral (=) with HEI = 100, REI, and practicality
Food energy					
Energy (kcal)	9,611.7	9,611.7	0.0	9,611.7	9,611.7
Macro-nutrients					
Carbohydrates (g)	1,316.4	1,214.1	0.0	1,312.6	1,345.4
Protein (g)	421.7	390.7	0.0	425.1	388.1
18:02 (linoleic acid) (g)	75.8	98.9	0.0	75.7	79.3
18:03 (linolenic acid) (g)	6.5	5.1	0.0	6.5	9.0
Fatty acids total monounsaturated (g)	130.3	175.7	0.0	130.4	124.2
Fatty acids total polyunsaturated (g)	83.3	105.8	0.0	83.3	89.4
Saturated fat (g)	85.4	85.4	0.0	85.4	85.4
Total Fat (g)	323.1	391.0	0.0	323.2	331.5
Fiber total dietary (g)	208.5	143.5	0.0	210.8	203.6
Micro-nutrient					
Calcium (mg)	6,306.5	6,194.8	0.0	6,443.4	7,524.1
Cholesterol (mg)	228.3	116.3	0.0	229.8	365.9
Choline total (mg)	1,526.2	1,384.6	0.0	1,525.5	1,336.7
Copper (mg)	8.4	7.2	0.0	8.4	9.4
Iron (mg)	74.9	57.8	0.0	75.8	107.7
Folic acid (µg)	416.9	372.8	0.0	416.3	1,044.2
Folate (µg DFE)	4,011.1	2,641.8	0.0	4,055.6	4,507.4
Potassium (mg)	17,661.7	15,515.7	0.0	17,655.9	17,440.3
Magnesium (mg)	2,459.8	2,360.3	0.0	2,466.5	2,349.2
Sodium (mg)	8,415.8	9,384.2	0.0	8,692.1	10,572.9
Niacin (mg)	96.5	119.3	0.0	96.7	92.7
Phosphorus (mg)	8,350.1	7,857.2	0.0	8,420.1	8,992.0
Riboflavin (mg)	9.9	9.7	0.0	9.8	9.8
Selenium (µg)	420.1	381.7	0.0	417.2	436.0
Thiamin (mg)	8.9	7.1	0.0	8.9	8.8
Vitamin E (alpha-tocopherol) (mg)	57.6	68.5	0.0	58.0	61.4
Vitamin A RAE	1,774.1	1,809.5	0.0	1,779.7	3,513.0
Vitamin B-12 (µg)	15.7	15.9	0.0	15.4	21.0
Vitamin B-6 (mg)	8.4	7.9	0.0	8.4	11.3
Vitamin C (mg)	354.7	362.9	0.0	355.0	486.4
Vitamin D (D2 + D3) (µg)	38.4	37.0	0.0	37.7	36.8

Nutrient	1. Min. cost with HEI = 100, REI, and practicality[a]	2. Min. cost with HEI = 100 and REI (only)[a]	3. Min. cost with HEI = 100 (only)[b,c]	4. Min. distance and cost with HEI = 100, REI, and practicality[b]	5. Min. distance and cost neutral (=) with HEI = 100, REI, and practicality
Vitamin K (phylloquinone) (µg)	180.4	128.2	0.0	182.5	422.7
Zinc (mg)	53.4	47.8	0.0	53.5	64.5
Calories from macro-nutrients					
Kcal from protein	1,687.0	1,562.8	0.0	1,700.6	1,552.5
Kcal from carbohydrates	5,265.4	4,856.3	0.0	5,250.4	5,381.6
Kcal from fat	2,908.0	3,519.0	0.0	2,909.2	2,983.3
Kcal from saturated fat	768.9	768.9	0.0	768.9	768.9
FPED food groups					
Fruit juices - citrus and non citrus (cup eq.)	3.8	3.8	0.0	3.8	3.1
Total intact or cut fruits and fruit juices (cup eq.)	7.7	7.7	0.0	7.7	7.7
Dark green vegetables (cup eq.)	0.0	0.0	0.0	0.0	0.7
Total red and orange vegetables (tomatoes + other red and orange) (cup eq.)	0.3	0.0	0.0	0.3	1.0
Total starchy vegetables (white potatoes + other starchy) (cup eq.)	0.0	0.0	0.0	0.0	3.9
Other vegetables not in the vegetable components listed above (cup eq.)	0.1	0.3	0.0	0.1	0.8
Legumes computed as vegetables (cup eq.)	9.2	5.1	0.0	9.4	6.9
Total dark green red and orange starchy and other vegetables; excludes legumes (cup eq.)	9.6	5.4	0.0	9.8	13.3
Whole grains (oz. eq.)	14.4	14.4	0.0	14.4	14.4
Refined or non-whole grains (oz. eq.)	17.3	17.3	0.0	17.3	11.3
Total whole and refined grains (oz. eq.)	31.7	31.7	0.0	31.7	25.7
Beef veal pork lamb game meat; excludes organ meats and cured meat (oz. eq.)	0.3	0.0	0.0	0.3	0.3
Chicken turkey Cornish hens and game birds; excludes organ meats and cured meat (oz. eq.)	0.0	0.0	0.0	0.0	0.1
Eggs (chicken duck goose quail) and egg substitutes (oz. eq.)	0.0	0.0	0.0	0.0	0.0
Soy products excluding calcium fortified soy milk and immature soybeans (oz. eq.)	0.0	0.0	0.0	0.0	0.3
Peanuts tree nuts and seeds excludes coconut (oz. eq.)	20.7	34.6	0.0	20.4	16.1

Nutrient	1. Min. cost with HEI = 100, REI, and practicality[a]	2. Min. cost with HEI = 100 and REI (only)[a]	3. Min. cost with HEI = 100 (only)[b,c]	4. Min. distance and cost with HEI = 100, REI, and practicality[b]	5. Min. distance and cost neutral (=) with HEI = 100, REI, and practicality
Total meat poultry seafood organ meats cured meat eggs soy and nuts and seeds; excludes legumes (oz. eq.)	21.1	34.6	0.0	20.8	18.9
Total milk yogurt cheese and whey (cup eq.)	12.5	12.5	0.0	12.5	12.5
Oils (g)	174.7	248.3	0.0	175.4	160.3
Meat poultry egg aggregate (oz. eq.)	0.4	0.0	0.0	0.4	0.5
Seafood aggregate (oz. eq.)	0.0	0.0	0.0	0.0	2.0
Nut seed soy aggregate (oz. eq.)	20.7	34.6	0.0	20.5	16.4
Kcal from added sugars	282.1	624.8	0.0	261.9	556.8
Calories by eating occasion					
Kcal from breakfast	2,210.7	3,152.8	0.0	2,210.7	2,099.1
Kcal from lunch	2,635.9	2,386.9	0.0	2,664.6	2,320.5
Kcal from dinner	3,058.8	2,128.6	0.0	3,108.6	3,110.9
Kcal from snacks	1,518.4	1,780.6	0.0	1,457.1	1,829.1
Kcal from drinks	122.7	115.8	0.0	115.0	122.0
Kcal from extended consumption	65.2	47.0	0.0	55.7	130.0

Note: Quantities may be reported as zero due to rounding.

[a] The objective function minimized costs using the approach from Appendix B.

[b] The objective function minimized distance to current consumption using the approach from TFP, 2021.

[c] An incremental approach was used to identify the lowest feasible cost, similar to TFP, 2021.

HEI = Healthy Eating Index; REI = Recommended Energy Intake; TFP = Thrifty Food Plan; DFE = dietary folate equivalent; eq. = equivalent; g = gram; kcal = kilocalorie; oz = ounce; mg = milligram; µg = microgram; RAE = retinol activity equivalent.

Appendix Exhibit E.4. Comparing HEI-based methods that minimize costs: 95 TFP modeling categories

	Quantities (100 gram units)					Costs ($ per day)					Expenditure shares (%)				
TFP modeling category	1. Min. cost with HEI = 100, REI, and practicality[a]	2. Min. cost with HEI = 100 and REI (only)[a]	3. Min. cost with HEI = 100 (only)[b,c]	4. Min. distance and cost with HEI = 100, REI, and practicality[b]	5. Min. distance and cost neutral (=) with HEI = 100, REI, and practicality	1. Min. cost with HEI = 100, REI, and practicality	2. Min. cost with HEI = 100 and REI (only)	3. Min. cost with HEI = 100 (only)	4. Min. distance and cost with HEI = 100, REI, and practicality	5. Min. distance and cost neutral (=) with HEI = 100, REI, and practicality	1. Min. cost with HEI = 100, REI, and practicality	2. Min. cost with HEI = 100 and REI (only)	3. Min. cost with HEI = 100 (only)	4. Min. distance and cost with HEI = 100, REI, and practicality	5. Min. distance and cost neutral (=) with HEI = 100, REI, and practicality
Dairy															
Cheese - higher cost	0.00000	0.00000	0.00000	0.00000	0.00000	$0.00	$0.00	$0.00	$0.00	$0.00	0.0%	0.0%	0.0%	0.0%	0.0%
Cheese - lower cost	0.00000	0.00000	0.00000	0.38268	3.87507	$0.00	$0.00	$0.00	$0.31	$3.19	0.0%	0.0%	0.6%	1.6%	11.5%
Milk and yogurt - higher nutrient density	12.38454	30.54616	0.00000	13.76626	12.83637	$1.61	$3.98	$0.00	$1.79	$1.67	8.4%	22.6%	4.9%	9.3%	6.1%
Milk and yogurt - lower nutrient density	18.31957	0.00000	0.00000	15.43860	0.00000	$2.74	$0.00	$0.00	$2.31	$0.00	14.2%	0.0%	1.5%	12.0%	0.0%
Meat, poultry, seafood, eggs															
Meat - higher nutrient density - higher cost	0.00000	0.00000	0.00000	0.00000	0.00000	$0.00	$0.00	$0.00	$0.00	$0.00	0.0%	0.0%	0.0%	0.0%	0.0%
Meat - higher nutrient density - lower cost	0.00000	0.00000	0.00000	0.00000	0.00000	$0.00	$0.00	$0.00	$0.00	$0.00	0.0%	0.0%	0.0%	0.0%	0.0%
Meat - lower nutrient density - higher cost	0.00000	0.00000	0.00000	0.00000	0.00000	$0.00	$0.00	$0.00	$0.00	$0.00	0.0%	0.0%	0.0%	0.0%	0.0%
Meat - lower nutrient density - lower cost	0.00000	0.00000	0.00000	0.00000	0.00000	$0.00	$0.00	$0.00	$0.00	$0.00	0.0%	0.0%	0.0%	0.0%	0.0%
Poultry - higher nutrient density - higher cost	0.00000	0.00000	0.00000	0.00000	0.02045	$0.00	$0.00	$0.00	$0.00	$0.02	0.0%	0.0%	0.0%	0.0%	0.1%
Poultry - higher nutrient density - lower cost	0.00000	0.00000	0.00000	0.00000	0.00000	$0.00	$0.00	$0.00	$0.00	$0.00	0.0%	0.0%	0.0%	0.0%	0.0%
Poultry - lower nutrient density - higher cost	0.00000	0.00000	0.00000	0.00000	0.00000	$0.00	$0.00	$0.00	$0.00	$0.00	0.0%	0.0%	0.0%	0.0%	0.0%
Poultry - lower nutrient density - lower cost	0.00000	0.00000	0.00000	0.00000	0.00000	$0.00	$0.00	$0.00	$0.00	$0.00	0.0%	0.0%	0.0%	0.0%	0.0%
Seafood - higher cost	0.00000	0.00000	0.00000	0.00000	0.39172	$0.00	$0.00	$0.00	$0.00	$0.78	0.0%	0.0%	0.0%	0.0%	2.8%
Seafood - lower cost	0.00000	0.00000	0.00000	0.00000	0.24269	$0.00	$0.00	$0.00	$0.00	$0.26	0.0%	0.0%	0.0%	0.0%	1.0%
Eggs	0.00000	0.00000	0.00000	0.00000	0.00000	$0.00	$0.00	$0.00	$0.00	$0.00	0.0%	0.0%	0.0%	0.0%	0.0%
Cured meat	0.00000	0.00000	0.00000	0.00000	0.00000	$0.00	$0.00	$0.00	$0.00	$0.00	0.0%	0.0%	0.5%	0.0%	0.0%

TFP modeling category	Quantities (100 gram units)					Costs ($ per day)					Expenditure shares (%)				
	1. Min. cost with HEI = 100, REI, and practicality[a]	2. Min. cost with HEI = 100 and REI (only)[a]	3. Min. cost with HEI = 100 (only)[b,c]	4. Min. distance and cost with HEI = 100, REI, and practicality[b]	5. Min. distance and cost neutral (=) with HEI = 100, REI, and practicality	1. Min. cost with HEI = 100, REI, and practicality	2. Min. cost with HEI = 100 and REI (only)	3. Min. cost with HEI = 100 (only)	4. Min. distance and cost with HEI = 100, REI, and practicality	5. Min. distance and cost neutral (=) with HEI = 100, REI, and practicality	1. Min. cost with HEI = 100, REI, and practicality	2. Min. cost with HEI = 100 and REI (only)	3. Min. cost with HEI = 100 (only)	4. Min. distance and cost with HEI = 100, REI, and practicality	5. Min. distance and cost neutral (=) with HEI = 100, REI, and practicality
Nuts and seeds, soy products															
Nuts and Seeds - higher nutrient density	0.00000	0.00000	0.00000	0.00000	2.39059	$0.00	$0.00	$0.00	$0.00	$3.53	0.0%	0.0%	0.0%	0.0%	12.8%
Nuts and Seeds - lower nutrient density	0.44103	0.00000	0.00000	0.21284	0.00000	$0.49	$0.00	$0.00	$0.24	$0.00	2.5%	0.0%	0.0%	1.2%	0.0%
Nut and seed butters	2.96732	5.53672	0.00000	3.10762	0.00000	$1.68	$3.13	$0.00	$1.76	$0.00	8.7%	17.8%	4.3%	9.1%	0.0%
Processed soy products	0.00000	0.00000	0.00000	0.00000	0.00000	$0.00	$0.00	$0.00	$0.00	$0.00	0.0%	0.0%	0.0%	0.0%	0.0%
Mixed dishes															
Mixed Dishes - Eggs - higher nutrient density	0.00000	0.00000	0.00000	0.00000	0.00000	$0.00	$0.00	$0.00	$0.00	$0.00	0.0%	0.0%	0.0%	0.0%	0.0%
Mixed Dishes - Eggs - lower nutrient density	0.00000	0.00000	0.00000	0.00000	0.00000	$0.00	$0.00	$0.00	$0.00	$0.00	0.0%	0.0%	0.3%	0.0%	0.0%
Mixed Dishes - Vegetables - higher nutrient density - higher cost	0.00000	0.00000	0.00000	0.00000	0.00000	$0.00	$0.00	$0.00	$0.00	$0.00	0.0%	0.0%	0.0%	0.0%	0.0%
Mixed Dishes - Vegetables - higher nutrient density - lower cost	0.00000	0.00000	0.00000	0.00000	0.00000	$0.00	$0.00	$0.00	$0.00	$0.00	0.0%	0.0%	0.0%	0.0%	0.0%
Mixed Dishes - Vegetables - lower nutrient density - higher cost	0.00000	0.00000	0.00000	0.00000	0.00000	$0.00	$0.00	$0.00	$0.00	$0.00	0.0%	0.0%	0.0%	0.0%	0.0%
Mixed Dishes - Vegetables - lower nutrient density - lower cost	0.00000	0.00000	0.00000	0.00000	0.00000	$0.00	$0.00	$0.00	$0.00	$0.00	0.0%	0.0%	0.1%	0.0%	0.0%
Mixed Dishes - Meat-Poultry-Seafood - higher nutrient density - higher cost	0.00000	0.00000	0.00000	0.00000	0.00000	$0.00	$0.00	$0.00	$0.00	$0.00	0.0%	0.0%	0.0%	0.0%	0.0%
Mixed Dishes - Meat-Poultry-Seafood - higher nutrient density - lower cost	0.00000	0.00000	0.00000	0.00000	0.13642	$0.00	$0.00	$0.00	$0.00	$0.06	0.0%	0.0%	0.0%	0.0%	0.2%

TFP modeling category	Quantities (100 gram units)					Costs ($ per day)					Expenditure shares (%)				
	1. Min. cost with HEI = 100, REI, and practicality[a]	2. Min. cost with HEI = 100 and REI (only)[a]	3. Min. cost with HEI = 100 (only)[b,c]	4. Min. distance and cost with HEI = 100, REI, and practicality[b]	5. Min. distance and cost neutral (=) with HEI = 100, REI, and practicality	1. Min. cost with HEI = 100, REI, and practicality	2. Min. cost with HEI = 100 and REI (only)	3. Min. cost with HEI = 100 (only)	4. Min. distance and cost with HEI = 100, REI, and practicality	5. Min. distance and cost neutral (=) with HEI = 100, REI, and practicality	1. Min. cost with HEI = 100, REI, and practicality	2. Min. cost with HEI = 100 and REI (only)	3. Min. cost with HEI = 100 (only)	4. Min. distance and cost with HEI = 100, REI, and practicality	5. Min. distance and cost neutral (=) with HEI = 100, REI, and practicality
Mixed Dishes - Meat-Poultry-Seafood - lower nutrient density - higher cost	0.00000	0.00000	0.00000	0.00000	0.00000	$0.00	$0.00	$0.00	$0.00	$0.00	0.0%	0.0%	0.0%	0.0%	0.0%
Mixed Dishes - Meat-Poultry-Seafood - lower nutrient density - lower cost	0.00000	0.00000	0.00000	0.00000	0.00000	$0.00	$0.00	$0.00	$0.00	$0.00	0.0%	0.0%	0.0%	0.0%	0.0%
Mixed Dishes - Grain based - higher nutrient density - higher cost	0.00000	0.00000	0.00000	0.00000	0.00000	$0.00	$0.00	$0.00	$0.00	$0.00	0.0%	0.0%	0.0%	0.0%	0.0%
Mixed Dishes - Grain based - higher nutrient density - lower cost	2.66685	0.00000	0.00000	2.66685	1.98431	$0.59	$0.00	$0.00	$0.59	$0.44	3.1%	0.0%	0.0%	3.1%	1.6%
Mixed Dishes - Grain based - lower nutrient density - higher cost	0.00000	0.00000	0.00000	0.00000	0.00000	$0.00	$0.00	$0.00	$0.00	$0.00	0.0%	0.0%	0.0%	0.0%	0.0%
Mixed Dishes - Grain based - lower nutrient density - lower cost	0.00000	0.00000	0.00000	0.00000	0.00000	$0.00	$0.00	$0.00	$0.00	$0.00	0.0%	0.0%	0.3%	0.0%	0.0%
Mixed Dishes - Pizza - higher nutrient density - higher cost	0.00000	0.00000	0.00000	0.00000	0.00000	$0.00	$0.00	$0.00	$0.00	$0.00	0.0%	0.0%	0.0%	0.0%	0.0%
Mixed Dishes - Pizza - higher nutrient density - lower cost	0.00000	0.00000	0.00000	0.00000	0.00000	$0.00	$0.00	$0.00	$0.00	$0.00	0.0%	0.0%	0.0%	0.0%	0.0%
Mixed Dishes - Pizza - lower nutrient density - higher cost	0.00000	0.00000	0.00000	0.00000	0.45997	$0.00	$0.00	$0.00	$0.00	$0.39	0.0%	0.0%	0.0%	0.0%	1.4%
Mixed Dishes - Pizza - lower nutrient density - lower cost	0.00000	0.00000	0.00000	0.00000	0.00000	$0.00	$0.00	$0.00	$0.00	$0.00	0.0%	0.0%	0.0%	0.0%	0.0%
Mixed Dishes - Sandwiches - higher nutrient density - higher cost	0.00000	0.00000	0.00000	0.00000	0.00000	$0.00	$0.00	$0.00	$0.00	$0.00	0.0%	0.0%	0.0%	0.0%	0.0%
Mixed Dishes - Sandwiches - higher nutrient density - lower cost	0.00000	0.00000	0.00000	0.00000	0.00000	$0.00	$0.00	$0.00	$0.00	$0.00	0.0%	0.0%	0.0%	0.0%	0.0%

TFP modeling category	Quantities (100 gram units)					Costs ($ per day)					Expenditure shares (%)				
	1. Min. cost with HEI = 100, REI, and practicality[a]	2. Min. cost with HEI = 100 and REI (only)[a]	3. Min. cost with HEI = 100 (only)[b,c]	4. Min. distance and cost with HEI = 100, REI, and practicality[b]	5. Min. distance and cost neutral (=) with HEI = 100, REI, and practicality	1. Min. cost with HEI = 100, REI, and practicality	2. Min. cost with HEI = 100 and REI (only)	3. Min. cost with HEI = 100 (only)	4. Min. distance and cost with HEI = 100, REI, and practicality	5. Min. distance and cost neutral (=) with HEI = 100, REI, and practicality	1. Min. cost with HEI = 100, REI, and practicality	2. Min. cost with HEI = 100 and REI (only)	3. Min. cost with HEI = 100 (only)	4. Min. distance and cost with HEI = 100, REI, and practicality	5. Min. distance and cost neutral (=) with HEI = 100, REI, and practicality
Mixed Dishes - Sandwiches - lower nutrient density - higher cost	0.00000	0.00000	0.00000	0.00000	0.00000	$0.00	$0.00	$0.00	$0.00	$0.00	0.0%	0.0%	0.0%	0.0%	0.0%
Mixed Dishes - Sandwiches - lower nutrient density - lower cost	0.00000	0.00000	0.00000	0.00000	0.00000	$0.00	$0.00	$0.00	$0.00	$0.00	0.0%	0.0%	0.2%	0.0%	0.0%
Mixed Dishes - Soups - higher nutrient density - higher cost	0.00000	0.00000	0.00000	0.00000	0.00000	$0.00	$0.00	$0.00	$0.00	$0.00	0.0%	0.0%	0.4%	0.0%	0.0%
Mixed Dishes - Soups - higher nutrient density - lower cost	0.00000	0.00000	0.00000	0.00000	0.00000	$0.00	$0.00	$0.00	$0.00	$0.00	0.0%	0.0%	0.8%	0.0%	0.0%
Mixed Dishes - Soups - lower nutrient density - higher cost	0.00000	0.00000	0.00000	0.00000	0.00000	$0.00	$0.00	$0.00	$0.00	$0.00	0.0%	0.0%	0.6%	0.0%	0.0%
Mixed Dishes - Soups - lower nutrient density - lower cost	0.00000	0.00000	0.00000	0.00000	0.00000	$0.00	$0.00	$0.00	$0.00	$0.00	0.0%	0.0%	1.0%	0.0%	0.0%
Mixed Dishes - Beans-peas-lentils - higher nutrient density - higher cost	0.00000	0.00000	0.00000	0.00000	0.22193	$0.00	$0.00	$0.00	$0.00	$0.07	0.0%	0.0%	1.6%	0.0%	0.3%
Mixed Dishes - Beans-peas-lentils - higher nutrient density - lower cost	0.00000	6.90497	0.00000	0.00000	0.00000	$0.00	$1.86	$0.00	$0.00	$0.00	0.0%	10.6%	3.7%	0.0%	0.0%
Mixed Dishes - Beans-peas-lentils - lower nutrient density - higher cost	0.00000	0.00000	0.00000	0.00000	0.00000	$0.00	$0.00	$0.00	$0.00	$0.00	0.0%	0.0%	1.7%	0.0%	0.0%
Mixed Dishes - Beans-peas-lentils - lower nutrient density - lower cost	0.00000	0.00000	0.00000	0.00000	0.00000	$0.00	$0.00	$0.00	$0.00	$0.00	0.0%	0.0%	1.3%	0.0%	0.0%

TFP modeling category	Quantities (100 gram units)					Costs ($ per day)					Expenditure shares (%)				
	1. Min. cost with HEI = 100, REI, and practicality[a]	2. Min. cost with HEI = 100 and REI (only)[a]	3. Min. cost with HEI = 100 (only)[b,c]	4. Min. distance and cost with HEI = 100, REI, and practicality[b]	5. Min. distance and cost neutral (=) with HEI = 100, REI, and practicality	1. Min. cost with HEI = 100, REI, and practicality	2. Min. cost with HEI = 100 and REI (only)	3. Min. cost with HEI = 100 (only)	4. Min. distance and cost with HEI = 100, REI, and practicality	5. Min. distance and cost neutral (=) with HEI = 100, REI, and practicality	1. Min. cost with HEI = 100, REI, and practicality	2. Min. cost with HEI = 100 and REI (only)	3. Min. cost with HEI = 100 (only)	4. Min. distance and cost with HEI = 100, REI, and practicality	5. Min. distance and cost neutral (=) with HEI = 100, REI, and practicality
Grains and cereals															
Grains - higher nutrient density - higher cost	0.00000	0.00000	0.00000	0.00000	0.00000	$0.00	$0.00	$0.00	$0.00	$0.00	0.0%	0.0%	0.0%	0.0%	0.0%
Grains - higher nutrient density - lower cost	4.70281	4.87714	0.00000	4.70244	1.96370	$1.98	$2.05	$0.00	$1.98	$0.82	10.2%	11.7%	7.5%	10.2%	3.0%
Grains - lower nutrient density - higher cost	0.00000	0.00000	0.00000	0.00000	0.00000	$0.00	$0.00	$0.00	$0.00	$0.00	0.0%	0.0%	0.0%	0.0%	0.0%
Grains - lower nutrient density - lower cost	6.11872	6.85303	0.00000	6.12689	2.35575	$1.54	$1.72	$0.00	$1.54	$0.59	8.0%	9.8%	0.0%	8.0%	2.1%
Biscuits-muffins-quick breads	0.00000	0.00000	0.00000	0.00000	0.00000	$0.00	$0.00	$0.00	$0.00	$0.00	0.0%	0.0%	0.0%	0.0%	0.0%
Breakfast cereals - higher nutrient density	0.00000	0.00000	0.00000	0.00000	7.13563	$0.00	$0.00	$0.00	$0.00	$1.69	0.0%	0.0%	0.0%	0.0%	6.1%
Breakfast cereals - lower nutrient density	0.00000	0.00000	0.00000	0.00000	0.11131	$0.00	$0.00	$0.00	$0.00	$0.06	0.0%	0.0%	0.0%	0.0%	0.2%
Snack foods and sweets															
Tortilla-corn-other chips	0.00000	0.00000	0.00000	0.00000	0.41634	$0.00	$0.00	$0.00	$0.00	$0.45	0.0%	0.0%	0.0%	0.0%	1.6%
Popcorn - higher nutrient density	0.00000	0.00000	0.00000	0.00000	0.13594	$0.00	$0.00	$0.00	$0.00	$0.14	0.0%	0.0%	0.0%	0.0%	0.5%
Popcorn - lower nutrient density	0.13594	0.00000	0.00000	0.13594	0.00000	$0.10	$0.00	$0.00	$0.10	$0.00	0.5%	0.0%	0.0%	0.5%	0.0%
Pretzels-snack mix	0.00000	0.00000	0.00000	0.00000	0.07385	$0.00	$0.00	$0.00	$0.00	$0.06	0.0%	0.0%	0.2%	0.0%	0.2%
Crackers - higher nutrient density	0.00000	0.00000	0.00000	0.00000	0.17633	$0.00	$0.00	$0.00	$0.00	$0.19	0.0%	0.0%	0.0%	0.0%	0.7%
Crackers - lower nutrient density	0.00000	0.00000	0.00000	0.00000	0.00000	$0.00	$0.00	$0.00	$0.00	$0.00	0.0%	0.0%	0.0%	0.0%	0.0%
Snack-Meal Bars	0.00000	0.00000	0.00000	0.00000	0.27330	$0.00	$0.00	$0.00	$0.00	$0.40	0.0%	0.0%	0.0%	0.0%	1.4%
Sweet bakery products	0.00000	0.00000	0.00000	0.00000	0.00000	$0.00	$0.00	$0.00	$0.00	$0.00	0.0%	0.0%	0.0%	0.0%	0.0%
Candy	0.00000	0.00000	0.00000	0.00000	0.00000	$0.00	$0.00	$0.00	$0.00	$0.00	0.0%	0.0%	0.0%	0.0%	0.0%
Other Desserts	0.00000	0.00000	0.00000	0.00000	0.00000	$0.00	$0.00	$0.00	$0.00	$0.00	0.0%	0.0%	0.0%	0.0%	0.0%
Sugars	0.00000	1.27662	0.00000	0.00000	0.14861	$0.00	$0.54	$0.00	$0.00	$0.06	0.0%	3.1%	0.3%	0.0%	0.2%

TFP modeling category	Quantities (100 gram units)					Costs ($ per day)					Expenditure shares (%)				
	1. Min. cost with HEI = 100, REI, and practicality[a]	2. Min. cost with HEI = 100 and REI (only)[a]	3. Min. cost with HEI = 100 (only)[b,c]	4. Min. distance and cost with HEI = 100, REI, and practicality[b]	5. Min. distance and cost neutral (=) with HEI = 100, REI, and practicality	1. Min. cost with HEI = 100, REI, and practicality	2. Min. cost with HEI = 100 and REI (only)	3. Min. cost with HEI = 100 (only)	4. Min. distance and cost with HEI = 100, REI, and practicality	5. Min. distance and cost neutral (=) with HEI = 100, REI, and practicality	1. Min. cost with HEI = 100, REI, and practicality	2. Min. cost with HEI = 100 and REI (only)	3. Min. cost with HEI = 100 (only)	4. Min. distance and cost with HEI = 100, REI, and practicality	5. Min. distance and cost neutral (=) with HEI = 100, REI, and practicality
Fruits and fruit juice															
Fruit - higher nutrient density - higher cost	0.00000	0.00000	0.00000	0.00000	1.20162	$0.00	$0.00	$0.00	$0.00	$0.93	0.0%	0.0%	0.0%	0.0%	3.4%
Fruit - higher nutrient density - lower cost	5.18054	5.34616	0.00000	5.24856	4.57122	$1.74	$1.79	$0.00	$1.76	$1.53	9.0%	10.2%	24.5%	9.1%	5.5%
Fruit - lower nutrient density - higher cost	0.00000	0.00000	0.00000	0.00000	0.00000	$0.00	$0.00	$0.00	$0.00	$0.00	0.0%	0.0%	0.0%	0.0%	0.0%
Fruit - lower nutrient density - lower cost	0.00000	0.00000	0.00000	0.00000	0.00000	$0.00	$0.00	$0.00	$0.00	$0.00	0.0%	0.0%	0.0%	0.0%	0.0%
100 percent fruit juice - higher cost	0.00000	0.00000	0.00000	0.00000	0.00000	$0.00	$0.00	$0.00	$0.00	$0.00	0.0%	0.0%	0.0%	0.0%	0.0%
100 percent fruit juice - lower cost	9.60094	9.57977	0.00000	9.60084	7.04206	$1.65	$1.65	$0.00	$1.65	$1.21	8.6%	9.4%	13.5%	8.6%	4.4%
Vegetables															
Red orange vegetables - higher cost	0.00000	0.00000	0.00000	0.00000	0.64059	$0.00	$0.00	$0.00	$0.00	$0.36	0.0%	0.0%	0.0%	0.0%	1.3%
Red orange vegetables - lower cost	0.00000	0.00000	0.00000	0.00000	0.48053	$0.00	$0.00	$0.00	$0.00	$0.17	0.0%	0.0%	0.0%	0.0%	0.6%
Dark green vegetables - higher cost	0.00000	0.00000	0.00000	0.00000	0.60086	$0.00	$0.00	$0.00	$0.00	$0.52	0.0%	0.0%	0.0%	0.0%	1.9%
Dark green vegetables - lower cost	0.00000	0.00000	0.00000	0.00000	0.08896	$0.00	$0.00	$0.00	$0.00	$0.04	0.0%	0.0%	0.0%	0.0%	0.2%
Other vegetables and vegetable combinations - higher cost	0.00000	0.00000	0.00000	0.00000	0.00000	$0.00	$0.00	$0.00	$0.00	$0.00	0.0%	0.0%	0.0%	0.0%	0.0%
Other vegetables and vegetable combinations - lower cost	0.00000	0.00000	0.00000	0.00000	1.03189	$0.00	$0.00	$0.00	$0.00	$0.34	0.0%	0.0%	0.0%	0.0%	1.2%
Starchy vegetables - higher cost	0.00000	0.00000	0.00000	0.00000	0.00000	$0.00	$0.00	$0.00	$0.00	$0.00	0.0%	0.0%	0.0%	0.0%	0.0%
Starchy vegetables - lower cost	0.00000	0.00000	0.00000	0.00000	3.69641	$0.00	$0.00	$0.00	$0.00	$1.08	0.0%	0.0%	0.0%	0.0%	3.9%

TFP modeling category	Quantities (100 gram units)					Costs ($ per day)					Expenditure shares (%)				
	1. Min. cost with HEI = 100, REI, and practicality[a]	2. Min. cost with HEI = 100 and REI (only)[a]	3. Min. cost with HEI = 100 (only)[b,c]	4. Min. distance and cost with HEI = 100, REI, and practicality[b]	5. Min. distance and cost neutral (=) with HEI = 100, REI, and practicality	1. Min. cost with HEI = 100, REI, and practicality	2. Min. cost with HEI = 100 and REI (only)	3. Min. cost with HEI = 100 (only)	4. Min. distance and cost with HEI = 100, REI, and practicality	5. Min. distance and cost neutral (=) with HEI = 100, REI, and practicality	1. Min. cost with HEI = 100, REI, and practicality	2. Min. cost with HEI = 100 and REI (only)	3. Min. cost with HEI = 100 (only)	4. Min. distance and cost with HEI = 100, REI, and practicality	5. Min. distance and cost neutral (=) with HEI = 100, REI, and practicality
Beans - peas - lentils	16.11467	2.72175	0.00000	16.47759	11.90433	$4.92	$0.83	$0.00	$5.03	$3.63	25.5%	4.7%	23.5%	26.1%	13.2%
Other fried potato products	0.00000	0.00000	0.00000	0.00000	0.84596	$0.00	$0.00	$0.00	$0.00	$0.70	0.0%	0.0%	0.0%	0.0%	2.6%
Beverages															
Fruit drinks - higher nutrient density	0.00000	0.00000	0.00000	0.00000	1.51240	$0.00	$0.00	$0.00	$0.00	$0.32	0.0%	0.0%	0.0%	0.0%	1.1%
Fruit drinks - lower nutrient density	0.00000	0.00000	0.00000	0.00000	0.00000	$0.00	$0.00	$0.00	$0.00	$0.00	0.0%	0.0%	0.5%	0.0%	0.0%
Soft drinks	0.00000	0.00000	0.00000	0.00000	3.76178	$0.00	$0.00	$0.00	$0.00	$0.50	0.0%	0.0%	0.3%	0.0%	1.8%
Diet beverages	0.00000	0.00000	0.00000	0.00000	0.65184	$0.00	$0.00	$0.00	$0.00	$0.06	0.0%	0.0%	1.5%	0.0%	0.2%
Coffee and Tea - higher nutrient density	4.80000	0.00000	0.00000	4.80000	0.00000	$0.25	$0.00	$0.00	$0.25	$0.00	1.3%	0.0%	2.4%	1.3%	0.0%
Coffee and Tea - lower nutrient density	0.00000	0.00000	0.00000	0.00000	4.80000	$0.00	$0.00	$0.00	$0.00	$0.60	0.0%	0.0%	0.4%	0.0%	2.2%
Other beverages - smoothies grain-based milk substitutes nutritional beverages	0.00000	0.00000	0.00000	0.00000	2.04152	$0.00	$0.00	$0.00	$0.00	$0.72	0.0%	0.0%	0.0%	0.0%	2.6%
Fats, oils and condiments															
Butter and animal fats	0.00000	0.00000	0.00000	0.00000	0.00000	$0.00	$0.00	$0.00	$0.00	$0.00	0.0%	0.0%	0.0%	0.0%	0.0%
Margarine and oils	0.00000	0.00000	0.00000	0.00000	0.00000	$0.00	$0.00	$0.00	$0.00	$0.00	0.0%	0.0%	0.0%	0.0%	0.0%
Condiments and Sauces - higher cost	0.00000	0.00000	0.00000	0.00000	0.00000	$0.00	$0.00	$0.00	$0.00	$0.00	0.0%	0.0%	0.9%	0.0%	0.0%
Condiments and Sauces - lower cost	0.00000	0.00000	0.00000	0.00000	0.00000	$0.00	$0.00	$0.00	$0.00	$0.00	0.0%	0.0%	0.9%	0.0%	0.0%

Note: Quantities and costs may be reported as zero due to rounding.

[a] The objective function minimized costs using the approach from Appendix B.

[b] The objective function minimized distance to current consumption using the approach from TFP, 2021.

[c] An incremental approach was used to identify the lowest feasible cost, similar to TFP, 2021.

HEI = Healthy Eating Index; REI = Recommended Energy Intake; TFP = Thrifty Food Plan.

E.3. Implications

Altogether, these analyses suggest the SPF-based approach would have produced a TFP market basket—that is, a basket with positive qualities of foods and beverages—if the SPF model had better predicted HEI-2020 scores. However, the nutrient and food group content of the SPF-based market basket would have been a significant departure from current requirements, since obtaining an HEI-2020 score of 100 does not ensure the market baskets comply with current dietary guidance regarding recommended levels of food groups, nutrients, and caloric intakes. The SPF-based approach would likely need to have been further enhanced to obtain a market basket better aligned with dietary guidelines (for example, imposing more nutrition and food group constraints). These types of enhancements would make alternative TFP market baskets more similar to current consumption and increase the cost of the market basket closer to the levels seen in TFP, 2021.

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