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The U.S. Grain Consumption Landscape

Who Eats Grain, in What Form, Where, and How Much?

Biing-Hwan Lin and Steven T. Yen

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Who Eats Grain, in What Form, Where, and How Much?

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Abstract

The U.S. Government is promoting whole-grain foods, responding to mounting evidence of their association with maintaining a healthy weight and reducing the risk of heart problems and other diseases. This study compared Americans' consumption of grains with the recommendations in the Government's *2005 Dietary Guidelines*, using data from USDA's *Continuing Survey of Food Intakes by Individuals*, 1994-96 and 1998. The analysis confirmed a national preference for refined grains—only 7 percent of survey respondents met the 2005 whole-grain recommendation. The authors compared grain consumption by economic and demographic characteristics of consumers, and also examined the effects of consumers' social, economic, and demographic characteristics and dietary perceptions and practices. The results suggest that consumers who perceive grain consumption as important and read food labels during shopping tend to eat more whole grains than other people. When data from more recent surveys are analyzed, results of the present study can serve as a baseline from which to gauge changes in the American diet and the consumption of whole grains.

Keywords: Whole grain consumption, grain consumption, dietary guidelines, food consumption survey data.

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Contents

Summary

The *2005 Dietary Guidelines*, issued by the U.S. Department of Health and Human Services and the U.S. Department of Agriculture, are intended to help consumers choose diets that meet their nutritional needs and improve their health. As part of a healthy diet, the *Guidelines* emphasize the value of whole grains. There is growing evidence that those who consume enough whole grains may reduce their risk of heart disease as well as their likelihood of becoming overweight.

What Is the Issue?

Are Americans actually following the grain consumption recommendations in the *2005 Dietary Guidelines?* More specifically, how much grain do Americans eat? At which meals? What characteristics are associated with low or high consumption of refined and whole grains? Which subpopulations are particularly deficient in meeting the whole-grain recommendations? Answers to these questions can serve as guidelines for developing intervention strategies.

What Did the Study Find?

The analysis showed a strong preference in the American diet for refined grains over whole grains. Ninety-three percent of Americans failed to meet the recommendation to consume 3 ounces per day of whole grains for a 2,000-calorie diet. Specific findings include:

- Americans eat too much refined grain and not enough whole grain. During 1994-96 and 1998, Americans consumed 6.7 ounces of total grains per day, or 106 percent of the recommendation. However, they overconsumed refined grains, averaging 77 percent more than the recommended daily amount, while eating 34 percent of the amount of whole grains recommended in the *2005 Dietary Guidelines.* Children, even more than adults, favored refined over whole grains, and the presence of children in the home had a negative effect on adults' whole-grain consumption.
- Breakfast foods are good sources of whole grains. Americans ate 40 percent of their whole grains at breakfast, 23 percent at lunch, and 17 percent at dinner, with the rest provided by snack foods.
- Restaurant foods are not a good source of whole grain. A third of Americans' calories came from meals prepared away from home, yet 1,000 calories of a restaurant meal averages less than one-third ounce of whole grains. Thus, it takes over 10,000 calories of restaurant food to obtain the amount of whole grains needed to meet the Government guidelines.
- Grain consumption varies by race and ethnicity. The study found that Asians averaged 22 percent of the recommended amount of whole grains, compared with 25 percent for Blacks, 35 percent for Whites, and 41 percent for Hispanics.

- Food-label use matters, as do personal perceptions about grains in the diet. Both food-label use (or non-use) and an individual's perception of whether grains affect health influenced the person's total grain intake, with perception having the greater impact. Those who considered it important to eat enough grains were 36 percent more likely to consume whole grains than those who did not.
- Some demographic characteristics are associated with grain consumption. Individuals most likely to read food labels and to value grains in the diet included those with higher educational attainment, meal planners, and people who exercise vigorously. Higher household income was associated with the use of food labels, but not with the perceived importance of grain consumption. People less likely to use food labels and to consider grains important included smokers and those who doubted that food choices affected health.

How Was the Study Conducted?

The authors analyzed data from USDA's *Continuing Survey of Food Intakes by Individuals* (CSFII) conducted in 1994-96 and 1998. The survey also collected various economic, social, and demographic characteristics for each respondent and his/her household. The 1994-96 survey had a companion module, *The Diet and Health Knowledge Survey*, which asked adults about their information, attitudes, and practices with respect to diet and health, making the CSFII data ideal for examining the effects of knowledge and practices on food consumption. Since 1998, USDA has published two further surveys of U.S. food intake, most recently for 2003-2004. However, these surveys did not ask about dietary knowledge and practices and cannot be used to study their effects on grain consumption. When data from future surveys are analyzed, the present study will be valuable as a baseline for assessing changes in the U.S. diet and the consumption of grains and whole grains.

Introduction

Grain products are available in two basic forms, refined and whole. Whole grains contain all three key parts of the kernel—the bran, the germ, and the endosperm. Refining normally removes most of the bran and some of the germ. Grains can be labeled as whole grains if they contain the same proportions of bran, germ, and endosperm as in the original grain. Whole-grain products are noticeably darker than refined white products due to the presence of bran. Historically, there has been a belief that white flour was the food of the rich and unrefined flour the food of the hard-working peasant and the poor (Spiller, 2002). Americans tend to favor—by a substantial margin—refined grains over whole grains. The box "Sources for Information About Grains" (p.2) is for readers who are interested in learning more about refined and whole grains.

Nutritional Superiority of Whole Grains

Even though some vitamins and minerals are added back to enrich refined grains, whole grains provide greater amounts of vitamins, minerals, fiber, and other valuable substances. Responding to mounting evidence of the association between whole-grain consumption and a reduced risk of heart problems and other diseases, as well as an association with healthy weight maintenance, the U.S. Government and the food industry have been promoting grains—especially whole grains— in the American diet.

In a comprehensive review of scientific evidence, the National Research Council (1989) concluded that "Diets high in plant foods—i.e., fruits, vegetables, legumes, and whole-grain cereals—are associated with a lower occurrence of coronary heart disease and cancers of the lung, colon, esophagus, and stomach." This scientific consensus, together with subsequent research on whole-grain foods, was the basis for the whole-grains/cancer-and-heart disease health claim submitted by General Mills for its Cheerios cereals in 1999, and approved by the Food and Drug Administration (Wiemer, 2002).

The national goals specified in *Healthy People 2010* include the objective of increasing the proportion of people who consume at least six daily servings of grain products, with at least three servings of whole grains (USDHHS, 2005). During 1994-96, only half of Americans ate 6 or more servings of grain products a day, and only 1 in 10 ate 3 or more servings of whole-grain products a day (Kantor et al., 2001). The *2005 Dietary Guidelines* made the first recommendation for a specific number of whole-grain servings by caloric intake (USDA and USDHHS, 2005). The grain industry and the public health community share an interest in increasing whole-grain consumption, through both marketing strategies and public health campaigns.

Understanding U.S. Grain Consumption

Who consumes grain products, and how much do they consume? Where and at what meal occasions do Americans consume grains? What are the factors associated with low or high consumption of refined and whole grains? Which subpopulations fall particularly short of the recommendations? This study sought answers to such information, which has been very limited (Harnack et al., 2003; Kantor et al., 2001; Moutou et al., 1998).

The objectives of the study were twofold:

- To describe U.S. consumption of refined and whole grains and compare the amounts consumed against the *2005 Dietary Guidelines* recommendation by economic and demographic characteristics of consumers. This descriptive information points out a general dietary deficiency in grain consumption, paving the way for the development of intervention strategies. The descriptive statistics can serve as the baseline for monitoring national progress in meeting the Federal recommendations for whole-grain consumption.
- To conduct a regression analysis to identify social, economic, demographic, nutrition knowledge, and behavioral factors associated with consumption of refined- and whole-grain products.

To accomplish these objectives, we analyzed data from the USDA's *Continuing Survey of Food Intakes by Individuals* (CSFII) conducted in 1994-96 and 1998 (USDA, 2000). The 1994-96 survey included a companion module that asked adults about their knowledge, attitudes, and practices with respect to diet and health, making the CSFII data ideal for examining the formation of dietary knowledge/attitudes, the adoption of dietary practices, and the effects of knowledge and practices on food consumption. Even though grains are a staple in the American diet, many consumers do not eat whole grains regularly. This data characteristic—zero consumption—complicates the econometric modeling.

Sources for Information About Grains

Information on grains can be obtained from the Federal Government, the grain and food industry, and not-for-profit organizations. The Federal Government provides accurate information to help Americans choose healthy diets at www.HealthierUS.gov, in the section devoted to nutrition. The book *Whole-Grain Foods in Health and Disease* (Marquart et al., 2002) gives a comprehensive review of current whole-grain science and technology, regulatory and policy issues, dietary intake, consumer interest, and health promotion. The Whole Grains Council has a consumer guide on the benefits of whole grains (www.wholegrainscouncil.org/consumer%20guide.html). Many other not-for-profit organizations, including universities and medical schools, provide valuable information on whole grains.

USDA Food Consumption Survey Data

USDA has conducted periodic food consumption surveys in the United States since the 1930s. Data from the 1994-96 and 1998 *Continuing Survey of Food Intakes by Individuals* (CSFII) and the 1994-96 *Diet and Health Knowledge Survey* (DHKS) are analyzed in this study. A major task of the CSFII was to collect data on dietary intakes. Similar intake data were also collected in the *National Health and Nutrition Examination Survey* (NHANES) conducted by the National Center of Health Statistics of the Centers for Disease Control and Prevention (CDC). CSFII and NHANES surveys have been integrated since 2002, at which time the DHKS survey was dropped. Therefore, the 1994-96 CSFII and DHKS surveys provide the only national data for examining the relationship between dietary knowledge and attitudes and dietary/health outcomes.

The CSFII/DHKS survey was first implemented in 1989-91, and was repeated in 1994-96. Each year of the 1994-96 CSFII survey comprises a nationally representative sample of noninstitutionalized persons residing in the United States. The 1998 CSFII is a supplemental survey to increase the sample of children in the 1994-96 CSFII. The DHKS surveyed only adults, and hence was not conducted in 1998.

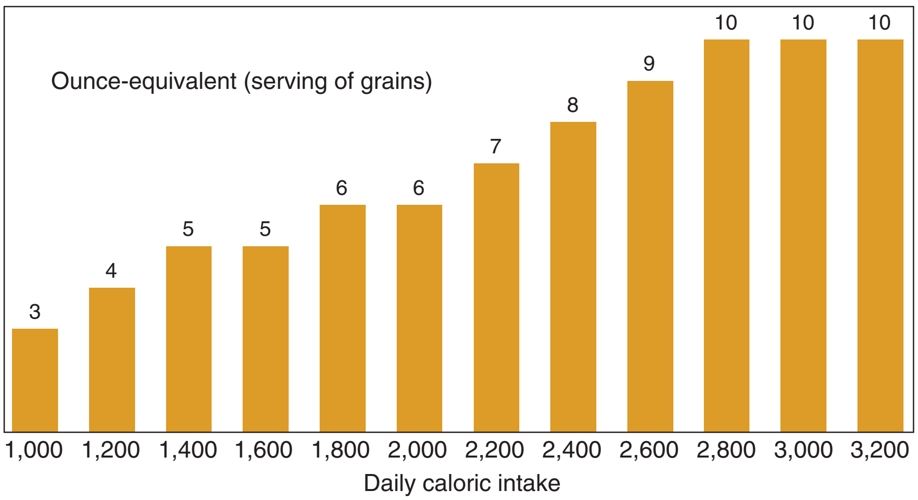
In the CSFII, 2 nonconsecutive days of dietary data were collected for individuals of all ages 3 to 10 days apart, through in-person interviews using 24-hour recall. The 1994-96 CSFII data provide information on the food intakes of 15,303 individuals, who gave a list of foods consumed, where the food was prepared and eaten, how much was eaten, and at what meal and time. After the respondents reported their first day of dietary intake, an adult 20 years or older was randomly selected from each household to participate in the DHKS. The DHKS questions cover a wide range of topics, including self-perception of the adequacy of nutrient intakes, awareness of diet-health relationships, knowledge of dietary recommendations, perceived importance of following dietary guidelines, use and perception of food labels, and behavior related to fat intake and food safety. Of the 7,842 households eligible to participate in the DHKS, respondents from 5,765 households completed the survey. The 1998 CSFII survey collected dietary data for 5,559 children up to age 9. Because only children were surveyed, the DHKS was not conducted in 1998. Various economic, social, and demographic characteristics were also collected for the CSFII respondent and his/her household.

The Agricultural Research Service (ARS) of USDA has created several technical databases, including the Pyramid Servings Database (PSD), to support use of the CSFII data. For 30 food groups, including refined and whole grains, the PSD converts the amount of food consumed into the number of servings, enabling comparison with dietary recommendations in the 2000 *Dietary Guidelines for Americans*. However, in the 2005 *Dietary Guidelines*, recommendations on food consumption are expressed in cups (for fruits, vegetables, and dairy products) and ounce-equivalents (grains and meat) instead of servings. This does not affect the measurement of grain consumption, because one ounce-equivalent is identical to one serving for grain products. Therefore, the PSD is still directly applicable to the current recommendation on grain consumption.

Grain Consumption: What Kind, By Whom, and How Much?

The 2005 *Dietary Guidelines* included several changes in the recommendations for grain consumption. The most prominent are the quantitative recommendations for consumption of whole grains. Second, the recommendations for consumption of total grains were revised slightly downward. For example, recommended total grain consumption is now five 1-ounce equivalents (servings) per day for a 1,600-calorie diet, compared with six servings recommended in 2000. Third, the new guidelines cover a much wider range of food energy intakes, from 1,000 to 3,100 calories, compared with the 1,600–2,800 calories specified in the previous guidelines (fig. 1).

Figure 1
Recommended consumption of grains: At least half the total should be whole grains



Source: *Dietary Guidelines for Americans, 2005.*

Americans Favor Refined Grains Over Whole Grains

The current recommendations for grain consumption are specified for 12 caloric levels (fig. 1). We used linear interpolation to derive recommendations for intakes that fall between the specified levels. During 1994-96 and 1998, Americans age 2 and above consumed on average 1,987 calories per day, which corresponds to a recommendation of 6.3 ounces of total grains (table 1). During this period, Americans actually consumed 6.7 ounces of total grains per day, or 106 percent of the recommendation (fig. 2). However, they overconsumed refined grains (5.6 ounces per day), averaging 77 percent over the recommended amount of 3.1 ounces, or half of total grains. It is a major challenge for Americans to meet the new guidelines for whole grains, as average consumption in the 1994-96 and 1998 surveys amounted to 1.1 ounces (34 percent of the recommended amount), and only 7 percent of consumers met the recommendation (table 1).

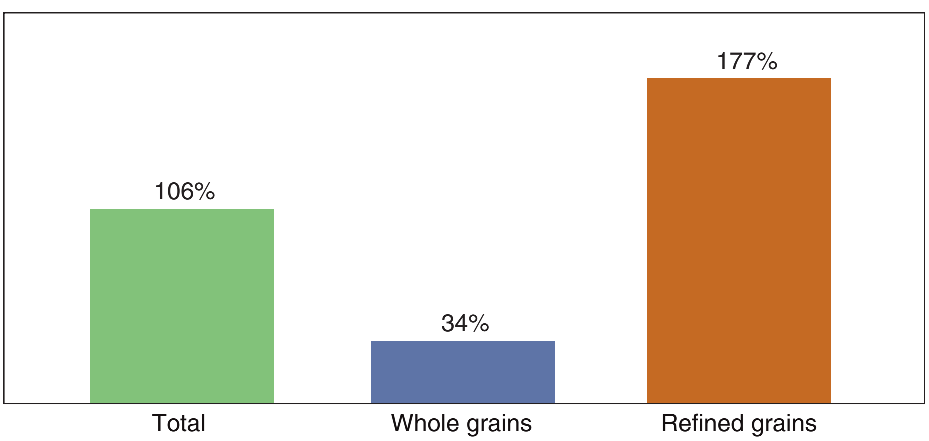
Recommendations for food consumption are based on caloric intakes, which vary by gender, age, physical activity, and body weight. On average, males

Table 1
U.S. grain consumption by gender and age

Intake and recommendation	All U.S	Females	Males	Children	All adults	Adults without children	Adults with children
Caloric intake (kcal/day)[1]	1987	1641	2349	1975	1991	1969	2020
				Ounces/day			
Recommended intake of total grains	6.30	5.40	7.24	6.28	6.31	6.21	6.42
Whole grains[2]	3.15	2.70	3.62	3.14	3.15	3.11	3.21
Actual grain consumption:							
Total grains	6.68	5.62	7.79	6.73	6.66	6.64	6.64
Whole grains	1.07	0.94	1.21	1.02	1.09	1.11	1.00
At home	0.90	0.79	1.01	0.84	0.92	0.95	0.83
Away from home	0.17	0.15	0.19	0.17	0.17	0.16	0.17
Refined grains	5.61	4.69	6.58	5.72	5.57	5.52	5.64
At home	3.69	3.18	4.24	3.76	3.67	3.61	3.65
Away from home	1.92	1.51	2.34	1.96	1.90	1.92	1.99
				Percent			
Consumption to recommendation:							
Total grains	105.54	104.21	106.94	106.53	105.17	106.45	102.87
Whole grains	34.30	34.98	33.59	32.43	35.01	36.97	30.62
Refined grains	176.79	173.44	180.29	180.63	175.34	175.92	175.11
Share of people meeting the recommendation:							
Total grains	53.45	52.94	53.99	54.80	52.95	53.74	50.93
Whole grains	7.34	7.32	7.35	5.41	8.06	8.72	6.68
Refined grains	87.42	86.75	88.12	91.28	85.97	85.59	86.89
				Ounces/1,000 kcal			
Whole-grain density[3]:							
2005 Dietary Guidelines recommendation[2]	1.64	1.68	1.60	1.63	1.64	1.64	1.65
Reported whole-grain consumption	0.56	0.58	0.53	0.52	0.57	0.60	0.49
At-home consumption	0.68	0.71	0.65	0.64	0.70	0.75	0.59
Away-from-home consumption	0.29	0.31	0.27	0.29	0.29	0.28	0.30
				Percent			
Away-from-home share of caloric intake	30.69	29.53	31.90	31.16	30.51	30.31	32.65

[1]Average of 2 days. [2]Half of total grains. [3]Whole-grain density is the recommended or reported consumption of whole grains per 1,000-calorie intake.

Figure 2
U.S. grain consumption as a percent of 2005 recommendations



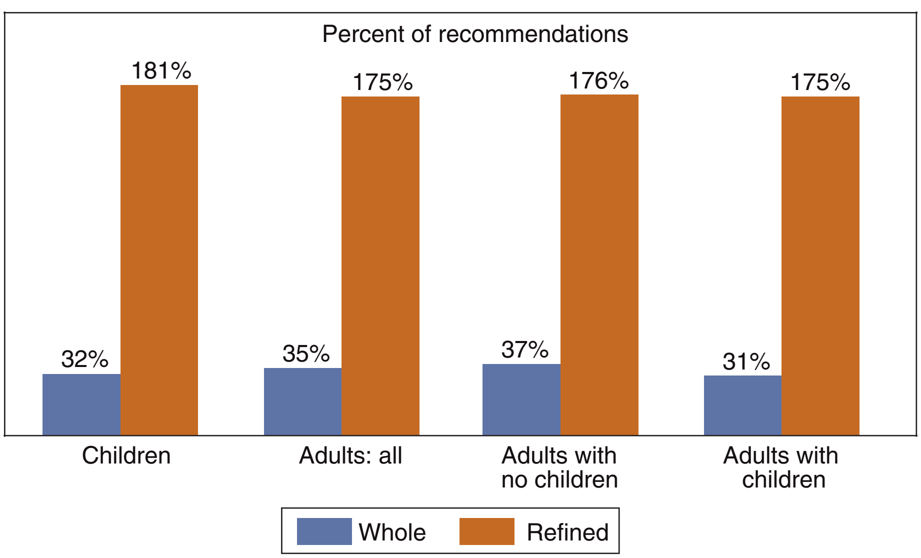
Source: CSFII 1994-96 and 1998.

(men and boys) consumed more whole grains than females (1.21 vs. 0.94 ounces), but females consumed a slightly higher percentage of the recommended level, 35 percent vs. 34 percent for males. Children age 2 to 19 consumed slightly more ounces of total grains than adults (6.73 vs. 6.66), but children appeared to favor refined grains over whole grains even more than adults did. Adults reached 35 percent of the recommended whole-grain intake, compared with 32 percent for children (fig. 3). Further, the presence of children at home appeared to affect adults' grain consumption, especially of whole grains: compared with the recommended level, adults living with children consumed the same amount of refined grains as adults without children (176 and 175 percent of the recommended level), but adults living with children consumed less whole grain than other adults (31 percent of the recommendation vs. 37 percent).

Grain-type preference varies by race and ethnicity (table 2). Asians ate more grains than others, but they registered a strong preference for refined over whole grains, consuming more than double the recommended level of refined grains (226 percent) and having the lowest whole-grain intake among all consumers (fig. 4). Hispanic consumers did better than other consumers in meeting the recommendation for whole-grain consumption, consuming 41 percent of the recommended level, compared with 35 percent for Whites, 25 percent for Blacks, and 22 percent for Asians. Eleven percent of Hispanics met the whole-grain recommendation, compared with 7 percent for Whites, 6 percent for Asians, and 4 percent for Blacks.

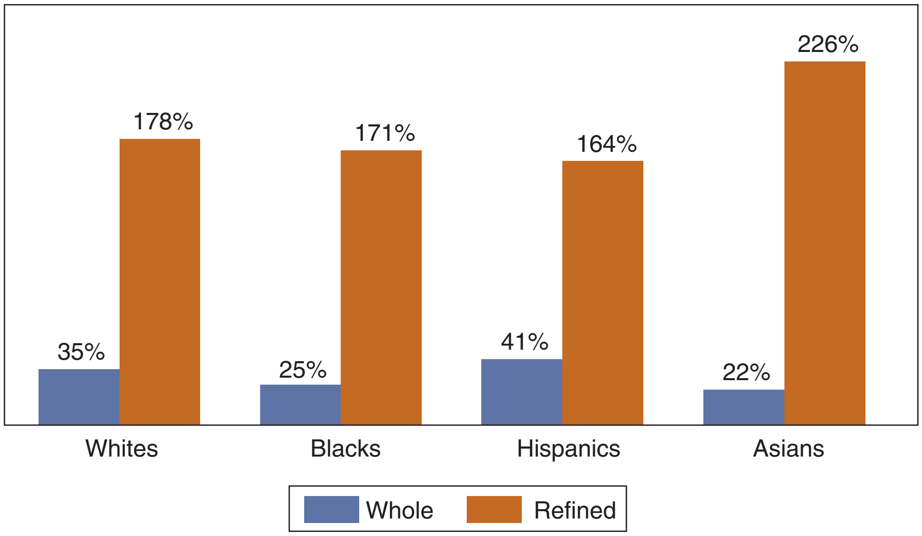
Grain consumption also varied by consumer income and education. In general, individuals with higher educational status earn higher incomes. (Household income is measured as a percentage of the Federal poverty guideline.) Consumers in the highest income bracket (300 percent of poverty or higher) ate 1.17 ounces of whole grains and 5.79 ounces of

Figure 3
U.S. grain consumption by children and adults



Source: CSFII 1994-96 and 1998.

Figure 4
U.S. grain consumption as a percent of recommendations, by race and ethnicity



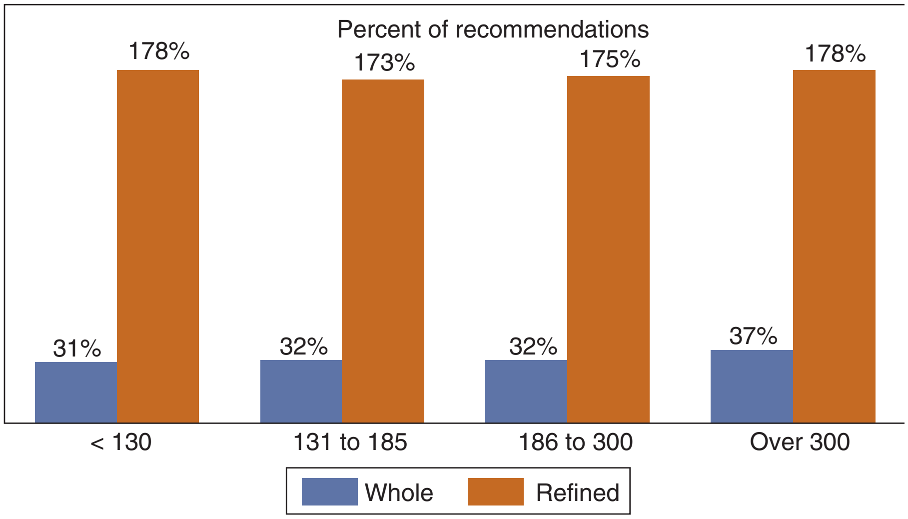
Source: CSFII 1994-96 and 1998.

Table 2
U.S. grain consumption by race and ethnicity

Intake and recommendation	Whites	Blacks	Hispanics	Asians	Others
Average caloric intake (kcal/day)[1]	2001	1963	1932	1969	1876
			Ounces/day		
Recommended intake of total grains	6.36	6.07	6.20	6.27	6.08
Whole grains[2]	3.18	3.04	3.10	3.13	3.04
Actual grain consumption:					
Total grains	6.77	6.10	6.46	7.82	6.40
Whole grains	1.11	0.72	1.29	0.72	0.87
At home	0.94	0.59	1.09	0.62	0.70
Away from home	0.17	0.13	0.21	0.09	0.17
Refined grains	5.66	5.39	5.17	7.11	5.53
At home	3.73	3.35	3.48	5.05	3.65
Away from home	1.93	2.03	1.69	2.05	1.88
			Percent		
Consumption to recommendation:					
Total grains	106.53	98.26	102.42	124.12	103.35
Whole grains	35.54	25.05	41.08	22.27	27.57
Refined grains	177.53	171.47	163.76	225.98	179.13
Share of people meeting the recommendation:					
Total grains	54.57	44.48	50.09	75.46	54.31
Whole grains	7.49	3.79	11.01	6.34	5.66
Refined grains	88.15	84.36	83.11	95.39	91.89
			Ounces/1,000 kcal		
Whole-grain density[3]:					
2005 Dietary Guidelines recommendation[2]	1.63	1.65	1.65	1.65	1.69
Reported whole-grain consumption	0.57	0.41	0.66	0.36	0.45
At-home consumption	0.71	0.51	0.75	0.41	0.52
Away-from-home consumption	0.29	0.23	0.38	0.20	0.25
			Percent		
Away-from-home share of caloric intake	30.90	31.56	29.19	27.87	28.95

[1]Average of 2 days. [2]Half of total grains. [3]Whole-grain density is the recommended or reported consumption of whole grains per 1,000-calorie intake.

Figure 5
U.S. grain consumption by income*



* as a ratio of income to poverty.
Source: CSFII 1994-96 and 1998.

Table 3
U.S. grain consumption by income

Intake and recommendation	Income-poverty ratio < 130%	131-185%	186-300%	> 300%
Average caloric intake (kcal/day)[1]	1937	1925	1946	2023
		Ounces/day		
Recommended intake of total grains:	6.02	6.16	6.20	6.48
Whole grains[2]	3.01	3.08	3.10	3.24
Actual grain consumption:				
Total grains	6.44	6.31	6.43	6.96
Whole grains	0.95	0.98	0.98	1.17
At home	0.82	0.84	0.82	0.97
Away from home	0.13	0.15	0.15	0.20
Refined grains	5.49	5.33	5.45	5.79
At home	3.76	3.65	3.66	3.70
Away from home	1.73	1.68	1.79	2.09
		Percent		
Consumption to recommendation:				
Total grains	104.53	102.37	103.42	107.57
Whole grains	31.27	32.18	32.20	36.84
Refined grains	177.80	172.55	174.63	178.30
		Percent		
Share of people meeting the recommendation:				
Total grains	50.09	51.82	52.37	55.58
Whole grains	7.11	6.83	6.37	7.94
Refined grains	85.67	87.32	87.50	88.08
		Ounces/1,000 kcal		
Whole-grain density[3]:				
2005 Dietary Guidelines recommendation[2]	1.66	1.64	1.64	1.63
Reported whole-grain consumption	0.51	0.52	0.52	0.59
At-home consumption	0.61	0.64	0.62	0.74
Away-from-home consumption	0.26	0.25	0.27	0.31
		Percent		
Away-from-home share of caloric intake	26.86	28.32	29.92	33.03

[1]Average of 2 days. [2]Half of total grains. [3]Whole-grain density is the recommended or reported consumption of whole grains per 1,000-calorie intake.

refined grains, reaching 37 percent and 178 percent of the recommended whole-grain and refined-grain servings, compared with 31 and 178 percent for individuals in the lowest income bracket (130 percent of poverty or lower, see table 3). College-educated individuals consumed 38 percent of the whole-grain recommendation, compared with 32 percent for those without a high school diploma, 30 percent for high school graduates, and 35 percent for those who attended college without completing a degree (table 4).

Detecting the Source of Whole-Grain Deficiency by Density Measurement

With an average intake of 1,987 calories a day during 1994-96 and 1998, Americans needed to consume 3.15 ounces of whole grains in order to meet the 2005 recommendation. Therefore, each 1,000 calories of energy intake needed to incorporate 1.64 ounces of whole grains. Whole-grain density, measured as ounces of whole grains consumed per 1,000-calorie intake, is a useful yardstick for comparing whole-grain consumption across population subgroups, as well as for detecting sources of dietary deficiency.

Table 4
U.S. grain consumption by educational level

Intake and recommendation	< High school	High school	Some college	College
Average caloric intake (kcal/day)[1]	1996	1981	2072	1949
		Ounces/day		
Recommended intake of total grains	6.16	6.31	6.47	6.27
Whole grains[2]	3.08	3.15	3.24	3.14
Actual grain consumption:				
Total grains	6.68	6.46	6.82	6.76
Whole grains	0.97	0.93	1.12	1.17
At home	0.85	0.79	0.91	0.98
Away from home	0.12	0.14	0.21	0.19
Refined grains	5.71	5.53	5.70	5.59
At home	3.81	3.68	3.56	3.72
Away from home	1.90	1.85	2.14	1.87
		Percent		
Consumption to recommendation:				
Total grains	106.41	102.40	104.99	107.47
Whole grains	31.90	30.08	35.42	37.51
Refined grains	180.91	174.73	174.56	177.43
Share of people meeting the recommendation:				
Total grains	106.41	102.40	104.99	107.47
Whole grains	31.90	30.08	35.42	37.51
Refined grains	180.91	174.73	174.56	177.43
		Ounces/1,000 kcal		
Whole-grain density[3]:				
2005 Dietary Guidelines recommendation[2]	1.65	1.65	1.62	1.64
Reported whole-grain consumption	0.52	0.49	0.57	0.61
At-home consumption	0.64	0.60	0.69	0.75
Away-from-home consumption	0.22	0.26	0.30	0.33
		Percent		
Away-from-home share of caloric intake	27.32	30.47	34.24	30.63

[1]Average of 2 days. [2]Half of total grains. [3]Whole-grain density is the recommended or reported consumption of whole grains per 1,000-calorie intake.

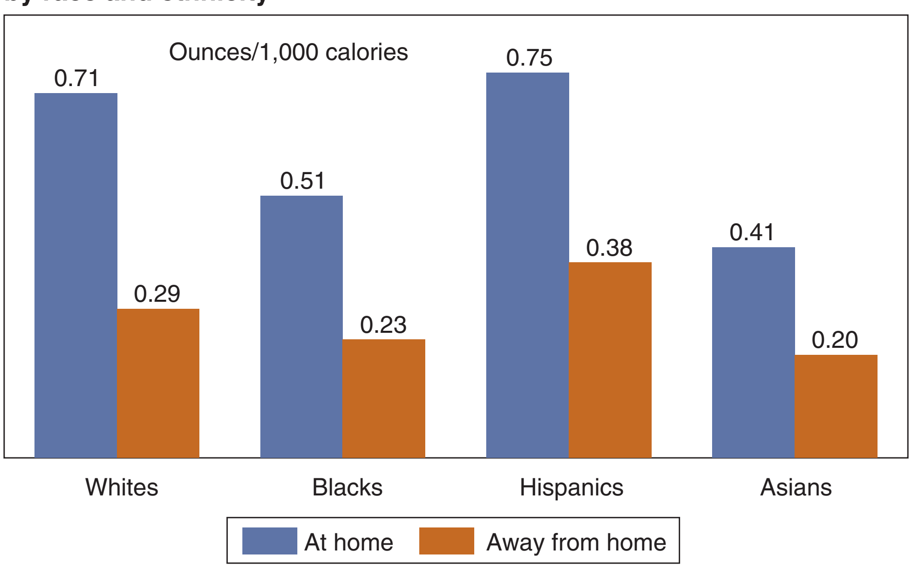
During 1994-96 and 1998, Americans consumed only 0.56 ounce of whole grains per 1,000 calories, slightly above one-third of the recommendation (table 1). Judging from the whole-grain density, females did better than males (0.58 vs. 0.53 ounce), adults did better than children (0.57 vs. 0.52 ounce), and Asians and Blacks were behind other consumers (0.36 and 0.41 ounce vs. 0.57 ounce for Whites and 0.66 ounce for Hispanics) in reaching whole-grain recommendations (table 2). Whole-grain density rose with educational achievement and household income (tables 3 and 4), consistent with the consumption-to-recommendation ratios.

Eating Out Poses a Challenge to Whole-Grain Consumption

The most significant lifestyle change of the past two decades in the United States is probably the increase in dining out. Americans consumed about a third of their calories from food prepared away from home during 1994-96 and 1998, up from less than a fifth in 1977-78 (USDA/ERS, 2007a). But when people order items from menus, whole grains seldom make the list. The whole-grain density for food prepared away from home is low compared with that for food prepared at home (0.29 vs. 0.68 ounce per 1,000 calories; see table 1). Therefore, the rising popularity of eating out could present a barrier to incorporating more whole grains into our diets.

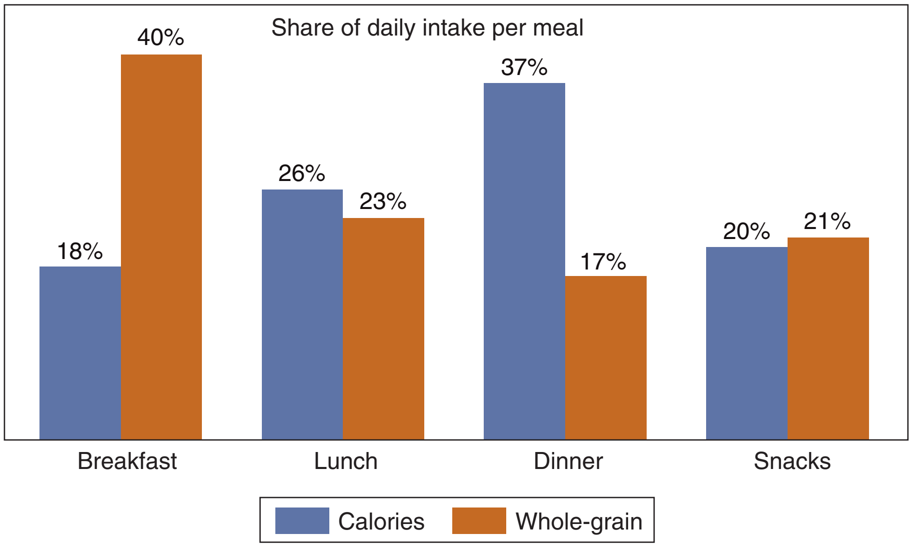
Females did better than males in including whole grains in their diets, both at home and away from home. There were few differences in the whole-grain density in the away-from-home foods consumed by children and adults, but greater variation in foods prepared at home. Compared with all other consumers, Hispanics did much better in incorporating whole grains in their meals when they ate out (with a density of 0.38 ounce per 1,000 calo-

Figure 6
Whole-grain content in U.S. meals prepared at home and away, by race and ethnicity



Source: CSFII 1994-96 and 1998.

Figure 7
Breakfast provided more whole grains than other meal occasions



Source: CSFII 1994-96 and 1998.

ries, vs. 0.29 ounce for Whites, 0.23 ounce for Blacks, and 0.2 ounce for Asians) (fig. 6 and table 2). College-educated adults did better than other adults in incorporating whole grains into meals eaten both at home and away from home (table 4).

CSFII respondents reported the meal occasion and time for each food eaten. Meal time was classified into four categories: breakfast (breakfast and brunch eaten before 10 a.m.), lunch (brunch after 10 a.m. and lunch), dinner, and snacks. Breakfast accounted for 18 percent of Americans' daily caloric intake, but contributed 40 percent of whole-grain consumption (fig. 7). Lunch contributed 26 percent of caloric intake and 23 percent of whole-grain consumption. On the other hand, dinner—the main meal of the day, with 37 percent of daily energy intake during the survey period—contributed the least (17 percent) to whole-grain consumption. Snacks accounted for 20 and 21 percent of caloric and whole-grain intake, respectively.

An Econometric Model of Grain Consumption

An objective of this study was to estimate the factors affecting U.S. consumption of refined and whole grains. Due to the nature of the data and the model specification, we estimated a censored demand system with endogenous regressors. The econometric model, which is quite technical, is included in the appendix.

We specified a four-equation demand system to estimate factors affecting the consumption of refined and whole grains. Even though grains are staple foods in American diets, the U.S. consumption of whole grains is low, and many consumers do not eat whole grains on a given day. CSFII respondents reported their dietary intakes for 2 nonconsecutive days. During 1994-96 and 1998, among those age 2 and above, 24 percent did not eat any whole grains over the 2 dietary recall days. This is the source of the censored dependent variable in demand estimation.

The food demand literature has shown that food and nutrient intakes are affected by dietary knowledge. Since the passage of the 1990 Nutritional Labeling and Education Act (NLEA) and the release of the 1994–96 DHKS data, researchers have paid increasing attention to the effects of dietary knowledge, attitude, and food-label use on the intake of foods and nutrients and on diet quality. The NLEA mandates that the Nutrition Fact Panel be affixed to packaged foods. Use of the panel has been found to affect the intake of fat (Kreuter and Brennan, 1997; Neuhouser et al., 1999) and cholesterol, sodium, and fiber (Kim et al., 2000).

Dietary knowledge and attitudes have been linked to consumption of fats and oils (Kim and Chern, 1995), fat-modified foods (Coleman and Wilson, 1994), eggs (Brown and Schrader, 1990; Kan and Yen, 2003; Yen et al., 1996), meat (Kaabia et al., 2001; Kinnucan et al., 1997), and 25 food groups consumed at and away from home (Lin et al., 2003). There are reported links between knowledge and intake of fiber (Variyam et al., 1996), energy and nutrient density (Bhargava, 2004), and fat and cholesterol (Variyam et al., 1997, 1999a). Dietary knowledge and attitude have also been linked to the diet quality of children (Variyam et al., 1999b), the elderly (Howard et al., 1998), and women household heads (Ramezani and Roeder, 1995).

In the last *Nationwide Food Consumption Survey*, conducted in 1987-88, USDA collected data on both household food use and individual food intake. In the household food use component of the survey, data on both quantity and spending were collected for foods purchased by each household. Since 1987/88, the household food use questions have been discontinued, and only data on individual food intake have been collected. Consequently, only food intake—but not spending, and hence not unit value—is available in recent food consumption surveys. Our demand specification thus suffers from missing price variables, even though regional and seasonal variables are included to capture some systematic price variations across regions and seasons.

The belief that white flour was the food of the rich and unrefined flour the food of hard-working peasants and the poor is a plausible explanation for the low consumption of whole grains relative to refined grains in the United States. Low consumption could also be attributed to lack of availability, tastes and preferences, and/or higher prices. Historically, some whole-grain products have been more expensive because they were specialty items produced in smaller quantities (Buzby et al., 2005). Therefore, the higher cost of manufacturing and marketing whole grains relative to the cost of refined grains, which benefit from economies of scale, further dampens the demand for whole grains.

An analysis of supermarket scanner data by Frazao and Allshouse (1996) found that the average price of whole-grain products was higher than the price of refined-grain products ($1.80 vs. $1.36 per pound) in 1995. Whole-grain bread and brown rice were sold at $1.19 and $1.13 per pound, compared with $0.99 and $0.68 for refined-grain bread and white rice. Similar price differentials have been reported more recently (Buzby et al., 2005; Kantor et al., 2001). If the price differential is indeed due to economies of scale, then an expanding whole-grain market—sparked by greater demand—would ease existing price differentials and further increase the demand for whole grains.

In this study, we hypothesize that consumer knowledge and attitudes and food-label use affect the consumption of refined and whole grains. Unlike sociodemographic factors, consumer knowledge, attitudes, and behavior are likely to be determined by the same factors that determine consumption. We accommodate this data feature by treating knowledge and attitudes as endogenous choice variables in a censored demand system. Such an econometric specification is new to the applied literature.

Data and Model Estimation

CSFII collected socioeconomic and demographic data for the sample households and their members. The socioeconomic and demographic variables that are hypothesized to affect grain consumption in this study include household income, household size, household structure, gender, age, race/ethnicity, household region, and season (table 5).

We hypothesize that the use of nutrition labels and the perceived importance of consuming plenty of grain products also affect grain consumption, and these two variables are also treated as endogenous in the censored demand system. In addition to income, gender, age, and race/ethnicity, the use of nutrition labels and perceived importance of grain consumption are hypothesized to be affected by education, exercise, smoking status, whether the respondent is a meal planner, and whether anyone in the household is on a special diet.

In the *1994-96 Diet and Health Knowledge Survey* (DHKS), respondents were asked about the perceived importance of choosing a diet with plenty of breads, cereals, rice, and pasta. The answers were grouped into important (very or somewhat) and not important (not too or not at all). The respondents were also asked if, when they buy foods, whether they often, some-

Table 5
Variable definitions and sample statistics (n = 5,501)

Variable	Definition	Mean
Endogenous variables:		
Label use	Use the short phrases on the label like 'low fat' or 'light' or 'good source of fiber': 1 = often or sometimes; 0 = rarely or never.	0.61
Importance	Perceived importance in choosing a diet with plenty of breads, cereals, rice, and pasta: 1 = very or somewhat; 0 = not too important or not at all	0.74
Whole grains	Daily consumption of whole grains (servings), 2-day average	0.28 (0.34)
	Consuming sample (n = 4003)	0.38 (0.34)
Refined grains	Daily consumption of refined grains (servings), 2-day average	1.34 (0.61)
Household (HH) characteristics: continuous exogenous variables:		
Income	Household income as percent of poverty	160.90 (137.10)
HH size	Number of persons in the household	2.56 (1.46)
Binary exogenous variables (yes = 1; no = 0)		
Household characteristics:		
HH type 1	Household is dual-headed, with children	0.28
HH type 2	Household is dual-headed, without children	0.36
HH type 3	Household is single-headed, with children	0.08
HH type 4	Household is single-headed without children (reference)	0.28
Special diet	A family member is on a special diet	0.27
Individual characteristics:		
Male	Respondent is male	0.50
Age 20–30		0.14
Age 31–40		0.18
Age 41–50		0.18
Age 51–60		0.18
Age > 60	Age 61 or older (reference)	0.32
Black	A non-Hispanic Black	0.11
Hispanic	Of Hispanic origin	0.08
Asian	Asian/Pacific Islander	0.02
Other race	None of the above nor White	0.01
White	Non-Hispanic White (reference)	0.78
Quarter 1	Dietary recalls taken in January-March	0.23
Quarter 2	Dietary recalls taken in April-June	0.26
Quarter 3	Dietary recalls taken in July-September	0.28
Quarter 4	Dietary recalls taken in October-December (reference)	0.24
Midwest	Resides in a Midwestern State	0.25
South	Resides in a Southern State	0.35
West	Resides in a Western State	0.20
Northeast	Resides in a Northeastern State (reference)	0.19
Rural	Resides in a rural area	0.27
Suburb	Resides in a suburb	0.44
City	Resides in the central city (reference)	0.30
< high school	Did not complete high school (reference)	0.22
High school	Completed high school education	0.34
Some college	Attended college for less than 4 years	0.21
College	Had 4 or more years of college education	0.23
Meal planner	Main meal planner of household	0.70
Exercise	Exercised vigorously: at least twice a week	0.48
Smoker	Currently smoking cigarettes	0.26
Pessimistic	Agrees with statement that some are born to be fat and some thin	0.43

Note: Standard deviations in parentheses.

times, rarely, or never use the information in (1) the short phrases on the label like “low fat” or “light” or “good source of fiber,” (2) the list of ingredients, (3) the nutrition panel listing the amount of nutrients, and (4) claims for health benefits of nutrients or foods. These four possible answers are grouped into “use” (often or sometimes) and “do not use” (rarely or never). The four types of label use are examined in the model estimation.

Two of the endogenous variables (perception and label use) and many exogenous variables come from the DHKS, which surveyed only adults; hence, our analysis is limited to the adult sample in the 1994-96 CSFII. Excluding observations with missing values, the final sample for the regression analysis contains 5,501 adults. Of the sample, 72.8 percent consumed whole-grain products, while almost all individuals (99.8 percent) consumed refined-grain products. Sample means are reported in table 5, along with the variable definitions.

Empirical Results

The four-equation system, consisting of binary equations for food label use and perceived importance of grains and censored equations for whole and refined grains, was estimated by maximizing the likelihood function described in the appendix. Four alternative variables represent food labels—the list of ingredients, short phrases, nutrition panel, and health claims. These alternative specifications of label use produce similar results. For brevity, we present only the results from reading short phrases. This is because a short-phrase example used in the interview is related to the fiber content of foods. Whole grains are known for their rich fiber content.

The empirical results suggest that use of food labels and consumer attitude should both be treated as endogenous, and that the two binary equations and two consumption equations should be estimated as a system. Maximum-likelihood estimates for the system are reported in table 6. At the 10-percent-or-better level of significance, two-thirds of the variables are significant in the label-use and whole-grain equations, and about half are significant in the perceived importance and refined-grain equations.

Findings

Empirical results suggest that adults who perceive grain consumption as important tend to consume more of both refined and whole grains than adults who do not, and those who use labels tend to consume more whole grains, but not more refined grains, than adults who do not (table 6). Adults who perceive grain consumption as important tend to consume 0.21 ounce more of refined grains per day than those who do not. (Effects on whole-grain consumption are discussed later because many consumers do not consume whole grains, so whole-grain consumption is censored.)

Over the 2-day survey period, 27 percent of adults reported consuming no whole grains. As explained in the appendix, this censoring data characteristic is handled by using the Tobit approach. Consequentially, we derive the marginal effects of explanatory variables on (1) the probability of being a whole-grain eater, (2) a conditional effect—the effect on consumption among whole-grain eaters, and (3) an unconditional effect—the combined effects of changing probability and consumption (table 7).

Both label use and perception of importance significantly affect whole-grain consumption, with perception having a bigger impact than label use. Relative to others, individuals who saw eating enough grains as important were 36 percent more likely to consume whole grains. Among whole-grain eaters, those who saw eating enough grains as important consumed 0.17 more serving of whole grains per day than those who did not think grain consumption mattered (table 7). The corresponding marginal effect on the unconditional level suggests that, overall, individuals who see eating enough

Table 6

Parameter estimates of demands for whole and refined grains with endogenous food label use and perceived importance

	Label use		Importance of grains		Whole grains		Refined grains	
Variable	Coeff.	S.E.	Coeff.	S.E.	Coeff.	S.E.	Coeff.	S.E.
Constant	0.186***	0.070	0.484***	0.070	–0.208***	0.054	1.190***	0.070
Income	0.487***	0.146	–0.211	0.155	0.094	0.059	0.060	0.074
Male	–0.481***	0.043	0.010	0.043	0.042***	0.017	0.148***	0.024
Age 20–30	–0.061	0.061	0.149***	0.060	–0.061***	0.022	0.156***	0.028
Age 31–40	0.023	0.056	0.122**	0.057	–0.054***	0.022	0.124***	0.028
Age 41–50	0.074	0.055	0.123**	0.055	–0.065***	0.020	0.053**	0.027
Age 51–60	0.114**	0.054	0.069	0.054	–0.055***	0.019	0.046*	0.025
Black	0.007	0.059	–0.208***	0.056	–0.118***	0.022	–0.091***	0.029
Asian	0.171	0.155	–0.124	0.149	–0.253***	0.054	0.487***	0.054
Other race	0.251	0.181	0.269	0.196	–0.117**	0.060	–0.037	0.077
Hispanic	0.117*	0.068	–0.070	0.068	0.028	0.023	0.048	0.032
Special diet	0.224***	0.041	0.051	0.042	0.021	0.016	–0.018	0.020
High school	0.168***	0.051	0.067	0.047				
Some college	0.190***	0.058	0.125**	0.055				
College	0.323***	0.061	0.368***	0.060				
Meal planner	0.075*	0.045	0.133***	0.043				
Exercise	0.126***	0.037	0.134***	0.035				
Smoker	–0.273***	0.042	–0.163***	0.040				
Pessimistic	–0.153***	0.037	–0.058*	0.035				
Midwest					0.043**	0.019	–0.041*	0.025
South					–0.005	0.018	–0.087***	0.023
West					0.137***	0.020	–0.191***	0.027
Rural					–0.034**	0.016	–0.077***	0.023
Suburban					–0.025*	0.015	–0.010	0.020
HH type 1					–0.055**	0.026	0.008	0.035
HH type 2					–0.027*	0.017	0.002	0.022
HH type 3					–0.095***	0.028	–0.031	0.042
Quarter 1					0.015	0.017	0.031	0.023
Quarter 2					0.003	0.017	–0.027	0.023
Quarter 3					–0.023	0.016	–0.044**	0.022
HH size					0.078	0.063	0.050	0.088
Label use					0.168***	0.061	–0.059	0.088
Importance					0.421***	0.059	0.210**	0.094
Std. dev. (i)					0.451***	0.011	0.592***	0.008
Error correlation								
Importance	0.163***	0.025						
Whole grains	–0.169**	0.083	–0.510***	0.065				
Refined grains	0.068	0.088	–0.156*	0.087	–0.178***	0.023		

Note: Log-likelihood value = –14611.412. Asterisks ***, **, and * indicate significance at 1%, 5%, and 10% levels, respectively.
HH = household.

grains as important consume 0.24 more serving of whole grains per day than others.

Effects on grain consumption can be separated into direct and indirect effects because label use and perception are treated as explanatory as well as dependent variables. The variables of income, gender, age, and race/ethnicity affect grain consumption, label use, and perception, and have direct as well as indirect effects (channeled through label use and perception) on grain consumption. The variables of education and lifestyle, which are used to explain label use and perception but not grain consumption, have only indirect effects on grain consumption.

Household income was found not to directly affect grain consumption (table 6). But as household income rises, nutrition labels are more likely to be read during shopping. Hence, income has an indirect positive effect on whole-grain consumption, but no effect on refined-grain consumption. Compared with women, men consume more refined and whole grain, but are less likely to use food labels. Younger adults (age 20-60) consume less whole grain but more refined grain than older adults (over 60).

Asians have a stronger preference for refined grains over whole grains than do other ethnic groups. In fact, marginal effects (table 7) suggest that being of Asian descent is one of the most influential factors in grain consumption.

Table 7

Marginal effects of explanatory variables on the probability, conditional level, and unconditional level of whole-grain consumption

	Probability		Conditional level		Unconditional level	
Variable	Effect	S.E.	Effect	S.E.	Effect	S.E.
Income /10^3	0.077	0.048	0.044	0.028	0.063	0.039
HH size	0.063	0.051	0.036	0.029	0.052	0.042
Male	0.034	0.014	0.020***	0.008	0.028***	0.011
Age 20–30	–0.050***	0.018	–0.028***	0.010	–0.039***	0.014
Age 31–40	–0.045***	0.018	–0.025***	0.010	–0.035***	0.014
Age 41–50	–0.054***	0.017	–0.030***	0.009	–0.042***	0.013
Age 51–60	–0.045***	0.016	–0.025***	0.009	–0.036***	0.012
Black	–0.099***	0.020	–0.052***	0.009	–0.074***	0.013
Asian	–0.220***	0.048	–0.101***	0.018	–0.142***	0.025
Other race	–0.099*	0.052	–0.051**	0.024	–0.072**	0.034
Hispanic	0.022	0.018	0.013	0.011	0.019	0.016
Special diet	0.017	0.013	0.010	0.007	0.014	0.011
Midwest	0.034**	0.015	0.020**	0.009	0.029**	0.013
South	–0.004	0.014	–0.002	0.008	–0.003	0.012
West	0.106***	0.015	0.068***	0.010	0.096***	0.014
Rural	–0.028**	0.013	–0.016**	0.007	–0.023**	0.011
Suburban	–0.020*	0.012	–0.012*	0.007	–0.017*	0.010
HH type 1	–0.045**	0.022	–0.025**	0.012	–0.036**	0.017
HH type 2	–0.022*	0.014	–0.013*	0.008	–0.018*	0.011
HH type 3	–0.080***	0.024	–0.042***	0.012	–0.060***	0.017
Quarter 1	0.012	0.014	0.007	0.008	0.010	0.011
Quarter 2	0.003	0.013	0.001	0.008	0.002	0.011
Quarter 3	–0.019	0.013	–0.011	0.008	–0.015	0.011
Label use	0.138***	0.051	0.077***	0.027	0.110***	0.039
Importance	0.355***	0.041	0.174***	0.021	0.243***	0.028

Note: Asterisks ***, **, and * indicate significance at the 1%, 5%, and 10% levels.
HH = household.

Relative to Whites, Asians are 22 percent less likely to consume whole grains. Those Asians who do eat whole grains consume 0.1 fewer servings per day than White whole-grain eaters. Compared with Whites, Blacks are less likely to perceive grain consumption as important, and they tend to consume less of both refined and whole grains (table 6). There are few differences between Whites and Hispanics in terms of refined- and whole-grain consumption. Adults who live with a family member with special dietary needs are more inclined to use food labels, and hence to consume more whole grains.

Regional differences are evident, with Midwestern and Western residents consuming more whole grains than individuals in other parts of the United States, and individuals in the Midwest, South, and West consuming fewer refined grains than those in the Northeast. Urbanization also plays a role, with rural residents consuming less of both whole and refined grains, and suburban residents consuming fewer whole grains, than individuals in cities.

Household structure is classified into four categories: dual- or single-headed and with or without children, with single-person households the reference group. Respondents from households with children (dual- or single-headed) eat fewer servings of whole grains. This is consistent with past findings that children prefer white bread (Harnack et al., 2003; Moutou et al., 1998).

Conclusion: Increasing Whole-Grain Consumption Is an Uphill Battle

Despite longstanding Government efforts to promote the consumption of whole grains, the American diet is still far short of the goals. Americans consume about 2,000 calories a day and need to eat 6 servings of grains, with at least 3 as whole grains. This translates into at least 1.5 servings of whole grains per 1,000 calories. During the study period, Americans ate only 0.56 serving of whole grains in that quantity of calories.

The American fondness for eating out, a fast-growing trend, may be an obstacle. Whole grains are particularly lacking in meals eaten in food establishments. Over the study period, there was only 0.29 serving of whole grains in each 1,000 calories consumed outside the home. With the current whole-grain content in away-from-home foods, Americans need to eat over 10,000 calories per outside meal to get the recommended 3 servings of whole grains prescribed for each 1,000 calories. Thus, unless appealing whole-grain dishes become more available in restaurants, the popularity of eating out could further erode the whole-grain base in American diets.

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Appendix: Econometric Model of Grain Consumption

Econometric Model

We developed an estimation procedure for an econometric system with censored dependent variables and endogenous regressors. In the equations that follow, observation subscripts are suppressed for brevity. The endogenous regressors, food label use (y_1) and nutrition knowledge (y_2), are both binary, and therefore specified as probit:

$$y_i = 1(z'\alpha_i + u_i > 0), \quad i = 1,2 \tag{1}$$

The censored equations for whole grains (y_3) and refined grains (y_4) are

$$y_i = \max(0, x'\beta_i + \gamma_{i1} y_1 + \gamma_{i2} y_2 + u_i), \quad i = 3,4 \tag{2}$$

In the above, $1(\cdot)$ is a binary indicator function, z and x are exogenous vectors of explanatory variables, α_i and β_i are conformable vectors of parameters, γ_{i1} and γ_{i2} are scalar parameters, and the error terms $e \equiv [u_1, u_2, u_3, u_4]'$ are distributed as $e \sim \mathcal{N}\left(0, \Sigma\right)$ with probability density function (pdf) $f(u_1, u_2, u_3, u_4)$. The covariance matrix Σ is defined with error correlations ρ_{ij} and standard deviations σ_i so that $\sigma_1^2 = \sigma_2^2 = 1$; these parametric restrictions on σ_1 and σ_2 are necessary because variables y_1 and y_2 are both binary.

The model considered here is an extension of the Tobit system of Amemiya (1974), in that endogenous variables are present in Equation (2). It also generalizes the multiple- and double-selection models (Catsiapis and Robinson, 1982; Tunali, 1986) and multiple-treatment models (Keane and Moffitt, 1998) in that there are multiple outcomes in Equation (2), and that, in addition, these outcome variables are censored.

The Log-Likelihood Function

In this study, three different likelihood functions were constructed for different 'sample regimes,' characterized by zero/positive outcomes of whole grains and refined grains, as described below.

When Both Whole Grains and Refined Grains Are Censored

This is the least observed case in which an individual does not consume either refined or whole grains. To facilitate description of the estimation procedure, define dichotomous indicators $\kappa_1 = 2y_1 - 1$, $\kappa_2 = 2y_2 - 1$, a diagonal matrix $D = \text{diag}(\kappa_1, \kappa_2, -1, -1)$ and vector $r = [r_1, r_2, r_3, r_4]$, where $r_i = z'\alpha_i$ for *i* = 1,2 and $r_i = x'\beta_i + \gamma_{i1}y_1 + \gamma_{i2}y_2$ for *i* = 3,4. The sample regime is characterized by inequalities $e^* \leq Dr$, where $e^* = -De \; = [u_1^*, u_2^*, u_3, u_4]' \sim \mathcal{N}(0, \Omega)$ so that $\Omega = D\Sigma D'$, for which the likelihood contribution is

$$\begin{aligned} L_1 &= \int_{-\infty}^{\kappa_1 r_1} \int_{-\infty}^{\kappa_2 r_2} \int_{-\infty}^{-r_3} \int_{-\infty}^{-r_4} f(u_1^*, u_2^*, u_3, u_4)\, du_4 du_3 du_2^* du_1^* \\ &= \int_{e^* \leq Dr} f(e^*)\, de^* \end{aligned} \qquad (3)$$

When Whole Grains Are Censored

This is the most frequently observed case, in which an individual consumed refined grains but not whole grains. Using Equations (1) and (2) and following a procedure similar to developing Equation (3), the likelihood contribution can be expressed as

$$L_2 = g(u_4) \int_{-\infty}^{\kappa_1 r_1} \int_{-\infty}^{\kappa_2 r_2} \int_{-\infty}^{-r_3} h(u_1^*, u_2^*, u_3 \mid u_4)\, du_3 du_2^* du_1^* \qquad (4)$$

Where $g(u_4)$ is the marginal density of u_4, $h(u_1^*, u_2^*, u_3 \mid u_4)$ is the conditional density, and $u_4 = y_4 - (x'\beta_4 + \gamma_{i1}y_1 + \gamma_{i2}y_2)$. The likelihood contribution for a regime with refined grains censored follows from Equation (4) with equation subscripts 3 and 4 reversed.

When Whole Grains and Refined Grains Are Both Consumed

The likelihood contribution is

$$L_3 = g(u_3, u_4)\int_{-\infty}^{\kappa_1 r_1}\int_{-\infty}^{\kappa_2 r_2} h(u_1^*, u_2^* \mid u_3, u_4)du_2^* du_1^* \quad (5)$$

where $u_i = y_i - (x'\beta_i + \gamma_{i1}y_1 + \gamma_{i2}y_2), i = 3,4$, and moments of the marginal distribution $g(u_3, u_4)$ and conditional distribution $h(u_1^*, u_2^* \mid u_3, u_4)$ are similar to those in Equation (4), with partition of e^* and its covariance matrix Ω at the second row.

The sample likelihood function for the system is the product of the likelihood contributions L_1, L_2 or L_3 over the sample, depending on the regime for each observation. The integrals in Equations (3), (4), and (5) can be evaluated by simulation or quadrature. The model reduces to an exogenous model when error correlations are zero between the two binary equations (food-label use and nutrition knowledge) and those of the consumption equations. The corresponding parametric restrictions are

$$\rho_{i,j} = 0 \quad \forall \quad i = 3,4;\ j = 1,2 \quad (6)$$

and a test for these parametric restrictions amounts to one for the joint endogeneity of y_1 and y_2. The restricted model implied by Equation (6) can be estimated by a bivariate probit for Equation (1) and Amemiya's (1974) Tobit system for Equation (2). Further, when all error correlations are equal to zeros, that is,

$$\rho_{ij} = 0 \quad \forall \quad i > j \quad (7)$$

the model reduces to one with separate probit and Tobit models from Equations (1) and (2).

Tests of these restricted models against the unrestricted model can be carried out by likelihood-ratio tests.

Unlike instrumental variable estimation, for which exclusion restrictions are often needed, in ML estimation the nonlinear identification criteria (i.e., linear independence of the first derivatives of the likelihood function with respect to parameters) are met, due to the functional form and distributional assumptions for the current system.

However, to avoid overburdening the nonlinear functional forms for parameter identification, we make a priori assumptions in that regard. First, while it is hard to contemplate how education per se might affect grain consumption, the educational variables are more likely to affect label use and perceived importance of grains, so they are only included in the probit equations, through which they affect consumption indirectly. Other variables used solely in the probit equations include being a meal planner and behavioral variables such as amount of exercise and being a smoker, and the attitudinal variable ‘pessimistic.’ On the other hand, because grain consumption is more likely to vary across regions, household types, seasons, household size, and urbanization categories than label use and perceived importance of grains, these variables are used only in the consumption equations.

To examine the marginal effects of explanatory variables, we derive relevant probabilities, conditional means, and unconditional means of the dependent variables. We partition the error vector e at the second row so that $e = [e_1', e_2']' = [u_1, u_2 \mid u_3, u_4]'$, with corresponding partitioning in the covariance matrix

$$\Sigma = \begin{bmatrix} \Sigma_{11} & \Sigma_{12} \\ \Sigma_{21} & \Sigma_{22} \end{bmatrix} \tag{8}$$

Then, by using properties of the multivariate normal distribution (Kotz et al., 2000), e_2 can be expressed, conditional on e_1, as

$$e_2 = \Sigma_{21}\Sigma_{11}^{-1}e_1 + \varepsilon \tag{9}$$

so that ε is independent of e_1 and x, $e_1 = [y_1 - z'\alpha_1, y_2 - z'\alpha_2]'$, and $\varepsilon \sim N(0, \Sigma_{22} - \Sigma_{21}\Sigma_{11}^{-1}\Sigma_{12})$. Substituting Equation (9) into Equation (2) gives the conditional Tobit system

$$y_i = \max\{0, x'\beta_i + \gamma_{i1}y_2 + \gamma_{i2}y_2 + \varepsilon_i^*\} \tag{10}$$

Where:

$$\begin{aligned} \varepsilon^* &= [\varepsilon_3, ..., \varepsilon_m]' = \Sigma_{21}\Sigma_{11}^{-1}e_1 + \varepsilon \\ &\sim N(0, \Sigma_{21}\Sigma_{11}^{-1}\Sigma_{11}^{-1}\Sigma_{12} + \Sigma_{22} - \Sigma_{21}\Sigma_{11}^{-1}\Sigma_{12}) \\ &\equiv N(0, \Omega) \end{aligned} \tag{11}$$

The covariance of ε^* in the second line of Equation (11) follows from the independence of ε and e_1. The motivation for writing the conditional Tobit system as Equation (10) is that parameters estimated consistently with 'unobserved heterogeneity' due to omission of $\Sigma_{21}\Sigma_{11}^{-1}e_1$. By denoting the univariate standard normal cdf as $\Phi(\cdot)$ and the standard deviation of ε_i^* as ω_i, which is the squared root of the *i*th diagonal element of Ω in Equation (11), the probabilities, conditional means, and unconditional means of y_i (for $i = 1, 2$) can be expressed as

$$\Pr(y_i > 0) = \Phi[(x'\beta_i + \gamma_{i1}y_1 + \gamma_{i2}y_2) / \omega_i] \tag{12}$$

$$\begin{aligned} E(y_i \mid y_i > 0) = {} & x'\beta_i + \gamma_{i1}y_1 + \gamma_{i2}y_2 \\ & + \omega_i \frac{\phi[(x'\beta_i + \gamma_{i1}y_1 + \gamma_{i2}y_2) / \omega_i]}{\Phi[(x'\beta_i + \gamma_{i1}y_1 + \gamma_{i2}y_2) / \omega_i]} \end{aligned} \tag{13}$$

$$
\begin{aligned}
E(y_i) = {} & \Phi[(x'\beta_i + \gamma_{i1}y_1 + \gamma_{i2}y_2)/\omega_i] \\
& \times (x'\beta_i + \gamma_{i1}y_1 + \gamma_{i2}y_2) \\
& + \omega_i \phi[(x'\beta_i + \gamma_{i1}y_1 + \gamma_{i2}y_2)/\omega_i]
\end{aligned} \tag{14}
$$

Marginal effects of explanatory variables x, y_1, and y_2 can be derived by differentiating Equations (12), (13), and (14). The effects of each discrete variable can be calculated as the changes in these probabilities and means resulting in a finite change (e.g., from 0 to 1) in the variable, while holding all other variables constant.