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Is Generational Change Contributing to the Decline in Fluid Milk Consumption?

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U.S. per capita fluid milk consumption has decreased since the 1940s. This study uses data collected between 1977 and 2008 from USDA surveys to investigate whether generational change is a contributing factor. More recent generations are found to consume less whole milk and less lower-fat milk, controlling for their age at the time of the survey and other consumption determinants. These findings underscore the importance of checkoff programs, the National School Lunch Program, and other initiatives that encourage children to consume milk. Our methodology may also be adapted to analyze long-run trends in the consumption of other foods.

Key words: cohort effects, double hurdle models, generational effects, milk consumption

Introduction

The American diet is constantly evolving. To track consumption trends for fluid milk, cheese, red meat, and other foods, the U.S. Department of Agriculture (USDA) annually estimates the quantities of different foods available for consumption in the United States (USDA Economic Research Service, 2012a). These data, known as food availability data, reveal that Americans have been drinking less and less fluid milk since the mid-1940s, on average.[1] The data also reveal that, when they do drink milk, Americans have been choosing lower-fat milk products more frequently since the 1960s. Despite the importance of these trends to farmers, agribusinesses, and the diet quality of Americans, it remains unclear what drives changes in fluid milk consumption over time.

Dairy farmers and fluid milk processors operate checkoff programs to increase the consumption of dairy products, including fluid milk, through promotions, nutrition education, and research (National Dairy Promotion and Research Board, 2012). One popular promotion features athletes and other celebrities sporting a "milk mustache." Dairy farmers contribute $0.15 to checkoff programs per 100 pounds of milk they market commercially, while fluid milk processors contribute an additional $0.20 per 100 pounds they sell in consumer-type packages.[2]

The USDA also promotes dairy consumption through a variety of programs. For example, schools receiving subsidies through the National School Lunch Program (NSLP) must meet Federal nutrition requirements, one of which is serving fluid milk. Participants in the Special Supplemental Nutrition Program for Women, Infants, and Children (WIC) may receive supplemental food packages that include fluid milk.[3]

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[1] These data have not been adjusted for food spoilage and other types of food loss. Consumption trends are therefore confounded by changes in loss rates, such as those associated with the introduction of plastic over glass bottles. Loss-adjusted data are available only as far back as 1970.

[2] Only processors that market more than 3 million pounds per month contribute.

[3] Participants other than infants are generally eligible to receive fluid milk.

While dairy farmers, fluid milk processors, and the federal government promote fluid milk, they have been unable to reverse the decline in per capita consumption that started in the 1940s. This study considers a potential explanation for the ongoing decline. It is hypothesized that children may have grown up less accustomed to drinking milk over the years. Moreover, if habits learned as children continue into adulthood, then successive generations of Americans may consume less fluid milk at thirty years old, forty years old, and so on than did previous generations at the same age points. To test this hypothesis, we compile data on over 60,000 individuals who participated in one of five USDA food consumption surveys between the 1970s and the 2000s. We then propose and estimate a model to identify the impact of a consumer's decade of birth (generation) on fluid milk consumption while controlling for the effects of other demand determinants, including current age. Generations born more recently are found to consume increasingly less whole and less lower-fat fluid milk, all else constant. This finding underscores the belief expressed in the *Dietary Guidelines for Americans 2010* that consumers form the habit of drinking (or not drinking) milk as children and then carry this behavior forward into their adult lives.[4] It also underscores the importance of checkoff programs, the NSLP, WIC, and other efforts that encourage children to consume fluid milk.

Trends in Milk Consumption and Generational Change

Trends in fluid milk consumption are often disaggregated by the fat content of the milk. Whole milk has a minimum fat content of 3.25% and once accounted for most of the fluid milk consumed in the United States. However, average American consumption of whole milk has steadily decreased since the 1940s (USDA Economic Research Service, 2012a). By contrast, U.S. per capita consumption of lower-fat products increased between the early 1960s and early 1990s (*Ibid*). In this study, we define these products as fluid milk with fat content lower than whole milk, such as 2%, 1%, and skim milk. Despite drinking less whole milk, Americans have not increased their consumption of lower-fat milk since the early 1990s, on average.

Several notable developments in the American population and food marketing system have coincided with the decline in fluid milk consumption. In the mid-1940s, for example, Americans consumed less food away from home (FAFH) and much less fast food in particular. FAFH accounted for about 25% of total food expenditures and fast food represented only 10% of all FAFH sales (USDA Economic Research Service, 2012b). By the late 2000s, those shares had reached 48% and 37%, respectively (*Ibid*). Standing in line at a fast-food restaurant or walking through a supermarket, consumers face a growing array of beverage choices. Soft drinks, for example, have become increasingly available (USDA Economic Research Service, 2012a). Aging, immigration, and other population trends have changed the nation's demographics. The median age in years of the U.S. population increased from 28.1 in 1970 to 32.9 in 1990 to 37.2 in 2010 (Hobbs and Stoops, 2002; Howden and Meyer, 2011). Despite fluctuating with business cycles, household income also has tended to rise over the long run, according to the Current Population Survey (CPS).[5] Other notable changes have occurred in the incidence of lactose intolerance, the popularity of veganism, concern for animal welfare, the availability of soy-based substitutes for fluid milk, pediatric advice, and organic production. Some or all of these developments could affect fluid milk consumption.

Interest in fluid milk consumption and its long-run decline has sparked much research. Among the many studies, Schmit et al. (2002), Kaiser and Dong (2006), and Kaiser (2010) confirm that promotions sponsored by checkoff programs increase demand. Gleason and Suitor (2001) confirm a positive association between a child's participation in the NSLP and his or her consumption of

[4] The *Dietary Guidelines for Americans* are issued by the USDA and the U.S. Department of Health and Human Services (DHHS) to provide evidence-based nutrition information and advice for individuals two and older. They also serve as the basis for federal food assistance and nutrition education programs.

[5] The CPS is a monthly survey of households conducted by the U.S. Census Bureau and the Bureau of Labor Statistics. It collects data on the characteristics of the labor force, including employment and labor force participation. The March Income Supplement to the CPS further collects data on family and household income.

fluid milk. Cornick, Cox, and Gould (1994) and Gould (1996) investigate the demand for fluid milk products by fat content. Still other studies show that soft drinks can displace milk in a consumer's diet (e.g., Fisher et al., 2001). Altogether, key determinants of fluid milk consumption have been shown to include prices, promotions, availability of competing beverages, household income, and consumer demographic characteristics. For example, Cornick, Cox, and Gould (1994) find that household income is negatively associated with the demand for whole milk while identifying as black is negatively associated with the demand for lower-fat products.

Despite extensive research on the determinants of fluid milk consumption, it remains unclear exactly what drives changes in consumption over time. When investigating food demand trends, Schrimper (1979) questions whether it is sufficient to consider only the types of demographic variables commonly included in a cross-sectional analysis, such as a person's age. He instead urges researchers to consider the possibility that "cohort" effects are a contributing factor. People born around the same point in history tend to grow up consuming more similar foods than people born further apart in time and, as a result, can exhibit more similar food choices as adults. For example, Mori, Clason, and Lillywhite (2006) investigate trends in Japanese fresh fruit consumption using data from annual releases of Japan's Family Income and Expenditure Survey between 1979 and 2001. The researchers find that newer generations of Japanese people tend to consume smaller quantities of fresh apples and fresh mandarin oranges than older generations. Japanese people who grew up amidst post-World War II economic prosperity likely are accustomed to a more diverse diet than members of older generations, who came of age consuming these traditional foods. Mori and Saegusa (2010) identify similar cohort effects in Japanese fish consumption.

Cohort effects also have been identified in U.S. food demand. Using data from the Consumer Expenditure Survey collected between 1982 and 2003, Stewart and Blisard (2008) analyze spending on fresh vegetables. Households headed by members of newer generations are found to spend less money on fresh vegetables for at-home consumption than households headed by members of older generations. Fresh vegetables are a main ingredient in home-cooked meals prepared from scratch. Instead of purchasing fresh vegetables to prepare a home-cooked meal, Americans born more recently may have grown up accustomed to eating out or using convenience foods.

The possibility that cohort effects contribute to the decline in U.S. fluid milk consumption has not been formally investigated to the authors' knowledge. However, there is reason to hypothesize that cohort effects do play a role. Mannino et al. (2004), for example, suggest that the habit of drinking milk forms in early childhood. They followed a group of girls between ages five and nine and determined that the girls not only maintained their milk consumption over these years but tended to keep their relative quartile positions. Those with high intakes at age five tended to maintain high intakes through age nine. Other research indicates that milk consumption begins to fall during adolescence and continues to fall at a decreasing rate throughout adulthood (e.g., Sebastian et al., 2010). The habit of drinking milk may nonetheless persist throughout a consumer's lifetime. According to the *Dietary Guidelines for Americans 2010*, "It is especially important to establish the habit of drinking milk in young children, as those who consume milk at an early age are more likely to do so as adults" (p. 38). That children may be growing up less accustomed to drinking milk is thus foreboding. Indeed, several changes in the food marketing system coincidental with declining fluid milk consumption have been shown to negatively impact a child's consumption of fluid milk. Bowman et al. (2004) identify a negative association between fast food and fluid milk consumption. Fisher et al. (2001) identify a negative association between a child's consumption of soft drinks and fluid milk.

The future of fluid milk demand in the United States may depend on whether newer generations consume as much as older generations. Compare, for example, a female consumer born in the 1970s and her parents born in the 1940s. The daughter may have been exposed to a wider variety of competing beverages when in her parents' home, at school, at a restaurant, or at a friend's home. She may then be less accustomed to drinking milk than children born into previous generations. Moreover, if habits learned as a child continue into adulthood, as stated in the *Dietary Guidelines for*

Americans 2010, she may continue to demand less milk at age thirty and at age forty than her parents did at the same ages. In general, the daughter's consumption could be characterized by a downward intercept shift from her parent's level of consumption. Fluid milk producers and processors would then face a population with increasingly less taste for their product as newer generations gradually replace older generations.

A Time Series of Cross Sections

The lack of a readily available data set may explain why no prior studies have investigated whether generational change is contributing to long-run trends in fluid milk consumption. In Deaton's (1997) terminology, one needs a "time series of cross sections." That is, one must pool surveys collected over several decades. Panel data are not necessary; each year's survey can be independent. For example, Japan's government has been administering the Family Income and Expenditure Survey annually since at least 1979. Models have been developed to analyze these data in the aggregated forms in which Japan's Statistics Bureau releases results (e.g., Mori, Clason, and Lillywhite, 2006; Mori and Saegusa, 2010).

Studies of cohort effects in the United States focus on food spending. The Bureau of Labor Statistics (BLS) has administered the Consumer Expenditure (CE) survey annually since 1982. Participating households record their spending on food and other products over a two-week period. The BLS later publishes each household's expenditures. Information is not available on the quantities of products bought, which prevents researchers from using the CE to study U.S. food consumption trends. Since households face different prices and choose heterogeneous products, a household's expenditures may not necessarily reflect the quantities of foods it consumes. Stewart and Blisard (2008) use the CE to test for cohort effects in household spending on fresh vegetables for at-home consumption. Zan and Fan (2010) use the CE to investigate cohort effects in household spending on food away from home.

Data on food consumption by Americans are available from the USDA.[6] Early surveys include the Nationwide Food Consumption Survey (NFCS) of 1977–78 and 1987–88. The 1977–78 survey collected information from households about their food use over a one-week period. Data were also collected on the diets of individual household members. Specifically, on the first day of the survey, USDA interviewed individuals about their food and beverage consumption on the previous day (a one-day dietary recall). Household members then maintained separate dairies in which they recorded all foods and beverages consumed for the next two days (a two-day diary). By contrast, in the later 1989–91 Continuing Survey of Food Intakes by Individuals (CSFII), the USDA continued to collect the one-day dietary recalls and two-day diaries but ceased to collect information on household food use. In the 1994–96 CSFII, the USDA continued to collect an initial one-day dietary recall but replaced the two-day diary with additional one-day dietary recalls on nonconsecutive days. In 2002, the CSFII was integrated with the National Health and Nutrition Examination Survey (NHANES),[7] which collects multiple one-day dietary recalls, much as the 1994-96 CSFII. The NHANES data are released every two years. When used with sample weights, all USDA surveys are nationally representative of the U.S. population at the time of their collection.

Because the USDA has consistently administered one-day dietary recalls on the first day of its food consumption surveys for more than thirty years, it is possible to study long-run trends in the American diet by pooling data from that component of the surveys. Enns, Goldman, and Cook (1997) use the 1977–78 NFCS and both CSFII to study food consumption trends between the late 1970s and the late 1990s. Cavadini, Siega-Riz, and Popkin (2000) use these same surveys to focus on dietary trends among American adolescents. Both studies use only the one-day dietary recall

[6] A history of the USDA's many surveys and documentation is available online (USDA Agricultural Research Service, 2012a,b).

[7] NHANES is administered by the U.S. Department of Health and Human Services (DHHS), while the USDA remains primarily responsible for the survey's food consumption component.

collected on the first day of each survey, excluding household food-use data from the 1977–78 NFCS, for example, in order to avoid biasing results due to the variety of data collection methods used. Both studies also omit the 1987–88 NFCS from their analysis. This survey's nonresponse rate greatly exceeded that of other USDA surveys (e.g., Guenther and Tippett, 1993).

In this study, we pool USDA surveys from the 1970s through the 2000s. Our data set is similar in structure to those previously assembled for investigating cohort effects in U.S. food spending. Stewart and Blisard (2008), for example, pool CE data from 1982, 1985, 1988, 1991, 1994, 1997, 2000, and 2003. Every third year of CE data is used. This was possible because the BLS has collected CE data continuously. However, since the USDA has collected its surveys only intermittently, we must use data for the available years. Specifically, we pool the 1977–78, 1989–91, 1994–96, 2003–04, and 2007–08 surveys. Due to changes over time in the USDA's methodology, we also restrict our analysis to the one-day dietary recall collected during each individual's initial interview. We exclude individuals from the analytical sample who did not provide a complete dietary record on day one of the survey or who provided only incomplete information on their household income and other demographic characteristics. The final sample of 62,246 individuals includes 13,732 preadolescent children (between ages three and thirteen) and 48,514 teenagers and adults.

Each survey participant's consumption of both plain and flavored fluid milk products was recorded. We excluded other dairy and non-dairy beverages, such as reconstituted dry milk, yogurt drinks, and soy beverages. Dietary records distinguished between whole milk, 2% milk, 1% milk, skim milk, and other milk types. However, some interviewees could not recall the type of milk they had consumed. Unspecified milk accounted for 12.5% of survey participants' total consumption. We imputed the missing information in these cases. For example, when participants in the 2007-08 NHANES could not recall the fat content of consumed products, we assumed that 30% of the reported quantity was whole milk, since whole milk accounted for about 30% of total consumption in 2007–08 (USDA Economic Research Service, 2012a). Consumption was measured in eight-ounce cups.[8]

Pooled USDA food consumption surveys confirm that Americans of all ages have consumed less fluid milk over time. As shown in table 1, our data reveal that 88% of preadolescent children drank some milk in their one-day dietary recall in 1977–78, compared with 81% in 1994–96 and 74% in 2007–08. On average, preadolescent children consumed about a third less fluid milk in 2007–08 than did children in the same age group in 1977–78. Teenagers and adults have also consumed less fluid milk over time. In their one-day dietary recall, 59% of Americans beyond their preadolescent years reported drinking some milk in 1977–78, compared with 50% in 1994–96 and 45% in 2007–08. Our empirical analysis hereafter focuses on these individuals. Mori and Saegusa (2010) explain that young children are not typically included in empirical tests for generational effects because children are still forming the habits that will later define their generation. As discussed earlier, the habit of consuming fluid milk develops in early childhood and likely has been formed by at least adolescence, when consumption begins to decrease.

Testing whether cohort effects contribute to the trends in table 1 can be accomplished by estimating a model of food consumption that includes explanatory variables for a consumer's decade of birth (generation) along with other variables for income, demographic characteristics, and survey date. Extensive research has been conducted on methods for specifying this type of model. For example, Johnson (1980), Deaton (1997), and Stewart and Blisard (2008) examine strategies for specifying the key explanatory variables.

Assembling Deaton's (1997) "time series of cross sections" makes it empirically possible to identify the effects of a consumer's generation separately from the effects of other demand determinants. This would not be feasible with data from only one survey. For example, among participants in the 1977–78 NFCS, we observe some consumers who were born in the 1960s. Each of these participants was no older than a teenager at that time. The effects of being a teenager

[8] USDA food surveys report consumption in grams. We converted grams to eight-ounce cups under the assumption that one cup weighs 243.8 grams.

Table 1. Fluid Milk Consumption by Americans, 1970s to 2000s, Daily Averages

	Number of Cups Consumed			Proportion of Individuals Consuming		
Years	**Whole**	**Lower-Fat**	**Total Milk**	**Whole**	**Lower-Fat**	**Total Milk**
Children Aged 3 to 12 Years Old						
1977–78	1.31	0.40	1.71	0.77	0.42	0.88
	(0.02)	(0.01)	(0.02)	(0.006)	(0.007)	(0.005)
1989–91	0.79	0.83	1.62	0.51	0.48	0.85
	(0.03)	(0.03)	(0.04)	(0.01)	(0.01)	(0.01)
1994-96	0.56	0.86	1.42	0.39	0.54	0.81
	(0.02)	(0.03)	(0.03)	(0.01)	(0.01)	(0.01)
2003–04	0.60	0.82	1.42	0.41	0.49	0.77
	(0.04)	(0.05)	(0.06)	(0.02)	(0.02)	(0.02)
2007–08	0.36	0.74	1.10	0.31	0.54	0.74
	(0.02)	(0.03)	(0.04)	(0.02)	(0.02)	(0.02)
Overall	0.72	0.75	1.47	0.47	0.50	0.82
	(0.01)	(0.01)	(0.02)	(0.006)	(0.006)	(0.005)
Teenagers and Adults						
1977–78	0.59	0.25	0.83	0.48	0.32	0.59
	(0.008)	(0.005)	(0.01)	(0.004)	(0.004)	(0.004)
1989–91	0.27	0.46	0.73	0.23	0.34	0.54
	(0.01)	(0.01)	(0.01)	(0.006)	(0.006)	(0.007)
1994–96	0.20	0.48	0.68	0.17	0.36	0.50
	(0.008)	(0.01)	(0.01)	(0.005)	(0.006)	(0.006)
2003–04	0.18	0.51	0.69	0.13	0.33	0.45
	(0.01)	(0.02)	(0.02)	(0.006)	(0.01)	(0.01)
2007–08	0.14	0.46	0.60	0.11	0.35	0.45
	(0.01)	(0.02)	(0.02)	(0.006)	(0.009)	(0.01)
Overall	0.26	0.44	0.70	0.22	0.35	0.51
	(0.004)	(0.006)	(0.007)	(0.002)	(0.003)	(0.003)

Notes: Cups are eight-ounce cups, assuming that one cup weighs 243.8 grams. Standard deviations of means and proportions are in parentheses. Source: USDA surveys of food intakes by individuals administered in 1970s, 1980s, 1990s, and 2000s.

are then perfectly collinear with the effects of being born in the 1960s. The two effects cannot be separately identified. However, pooling the 1977–78 NFCS with later USDA surveys facilitates identification. As illustrated in table 2, the pooled surveys in this study include information on the generations at several age points. For example, we observe consumers born in the 1960s in their teens in 1977–78, in their twenties in 1989–91, in their thirties in 2003–07, and approaching their forties in 2007–08. That age and generation are no longer perfectly collinear is confirmed by the pairwise correlation coefficients between a consumer's age and binary indicator variables for being born in the 1930s (+0.24), 1940s (+0.05), 1950s (-0.17), 1960s (-0.36), 1970s (-0.29), 1980s (-0.31), and 1990s (-0.19).[9]

Using a time series of cross sections, it is also possible to identify survey-year effects. The popularity of fast food, the availability of competing beverages, and other conditions in the food marketing system were different when, for example, the 1994–96 CSFII and the 2007–08 NHANES were collected. These effects may have caused participants in these two surveys to make different

[9] Each generation appears at different age points in our pooled surveys. However, we still tend to observe earlier generations at older ages and newer generations at younger ages. It will likely be possible to further reduce this collinearity in the future. For example, future USDA surveys will contain information on the food choices of generations born since the 1980s and 1990s at older ages.

Table 2. Number of Teenage and Adult Participants in USDA Food Consumption Surveys by Decade of Birth

Survey	Decade of Birth								Total
	Pre-1930s	1930s	1940s	1950s	1960s	1970s	1980s	1990s	Participants
1977–78 NFCS	5,830	2,171	3,069	3,261	2,068				16,399
1989–91 CSFII	2,453	1,087	1,607	2,145	1,946	1,285			10,522
1994–96 CSFII	1,283	949	1,452	1,903	1,974	1,586	553		9,700
2003–07 NHANES	421	564	759	1,022	1,053	1,037	1,017	123	5997
2007–08 NHANES	279	398	669	1,034	1,075	887	1,048	505	5,896
All Surveys	10,267	5,170	7,556	9,365	8,116	4,795	2,618	628	48,514

Notes: Shares includes only teenage and adult participants.

food choices independently of differences in consumption due to their generations, ages, and other demographic characteristics. Most generations appear in most of our surveys. The exceptions are consumers born in the 1980s and 1990s, who only appear in more recent surveys as teenagers or adults. Pairwise correlation coefficients between binary indicator variables for a consumer's generation and survey date likewise tend to be small. The largest are between being born in the 1980s and participating in the 2003–07 NHANES (+0.36) as well as between being born in the 1990s and participating in the 2007–08 NHANES (+0.26).

Overall, the surveys assembled for this study appear sufficient to facilitate estimation of an empirical model, though collinearity may still increase the variance of parameter estimates. In the event that the estimated parameters are mostly insignificant, Belsley, Kuh, and Welsch (1980) recommend the use of diagnostic tools like the condition number to judge whether collinearity may have been responsible. Conversely, if parameter estimates are mostly significant, then collinearity has caused no problem. "These cases serve to exemplify the pleasantly pragmatic philosophy that collinearity does not hurt so long as it does not bite" (p. 116).

Modeling Fluid Milk Consumption Over One Day

In some ways, our model is similar to models of fluid milk consumption in previous studies. Cornick, Cox, and Gould (1994), for example, model household spending on fluid milk, disaggregated by fat content, over a thirteen-month period. We similarly propose to model whole and lower-fat fluid milk consumption by Americans. One key difference is the inclusion of additional explanatory variables to test for cohort effects. Another key difference is the focus on consumption by individuals over twenty-four hours. Most individuals eat only a relatively small number of foods on any given day. Our USDA survey data likewise contain many zero observations. Below, we look at the explanatory variables used in the study. We then extend the Cornick, Cox, and Gould (1994) multivariate tobit model to overcome problems associated with zero-censoring.

Variables Used in the Analysis

Theoretically identifying cohort effects in a demand model is possible using a time series of cross-sectional surveys as previously discussed. Following methods outlined in Johnson (1980), Deaton (1997), and Stewart and Blisard (2008), we define the explanatory variables included in the study. An individual's income and demographic characteristics are included in the model based on the findings of past research on fluid milk demand. We also include explanatory variables for a consumer's generation and survey date. Definitions and mean values are provided in table 3.

Fluid milk consumption depends on a consumer's income and demographic characteristics, including his or her age (*AGE*). Consumption is expected to decrease in the natural logarithm of *AGE* based on existing research that shows it falls at a decreasing rate as consumers age (e.g.,

Table 3. Definitions, Units, and Means of Explanatory Variables

Variable	Definition	Units	Mean
Income and Demographic Characteristics			
INCOME	Per capita household income (thousands of 2003 dollars)	no.	18.28
AGE	Age of person	no.	42.21
WEEKEND	Reported consumption for a Saturday or Sunday	0/1	0.26
DIETING	Consumer was on a diet	0/1	0.07
MALE	Consumer is a male	0/1	0.46
COLLEGE	One or more heads of household completed college	0/1	0.29
BLACK	Consumer is Black	0/1	0.11
HISPANIC	Consumer is Hispanic	0/1	0.09
OTHER RACE	Consumer is neither White, Black, nor Hispanic	0/1	0.04
Consumer's Decade of Birth (Generation)			
C2	Consumer was born in the 1930s	0/1	0.10
C3	Consumer was born in the 1940s	0/1	0.15
C4	Consumer was born in the 1950s	0/1	0.19
C5	Consumer was born in the 1960s	0/1	0.18
C6	Consumer was born in the 1970s	0/1	0.13
C7	Consumer was born in the 1980s	0/1	0.07
C8	Consumer was born in the 1990s	0/1	0.02
Survey Year			
TIME2	Reported consumption in 1989–91 CSFII	0/1	0.20
TIME3	Reported consumption in 1994–96 CSFII	0/1	0.35
TIME4	Reported consumption in 2003–04 NHANES	0/1	0.14
TIME5	Reported consumption in 2007–08 NHANES	0/1	0.15

Notes: Data set created by pooling selected USDA surveys from the 1970s, 1980s, 1990s, and 2000s.

Sebastian et al., 2010). We also include household per capita income (*INCOME*). It is expected that the natural logarithm of *INCOME* is negatively associated with drinking whole milk but positively associated with consuming lower-fat products (e.g., Cornick, Cox, and Gould, 1994). Also consistent with past studies, we include variables to control for gender, race, ethnicity, and level of education. The interested reader is referred to the cited studies for the expected effects of these variables. Lastly, we account for whether survey participants were on a diet as well as whether they reported consumption for either a Saturday or Sunday. Notably, USDA food consumption surveys do not include information on prices paid by households. Publically available NHANES data also lack information on the region of the nation in which an individual lives. Regional differences in tastes and preferences as well as differences in consumption due to spatial variation in prices are left in the error terms.

The explanatory variables of primary interest account for individuals' decade of birth. Changes in the U.S. food marketing system, such as the rising popularity of fast food and the introduction of competing beverages, have coincided with declining fluid milk consumption. We hypothesize that if these developments have caused successive generations of Americans to complete their childhood years less and less accustomed to drinking milk, then the consumption of each successive generation could be characterized by a downward intercept shift from the previous generation's level of consumption. To begin, we allow for the possibility that these shifts could have started with Americans born in the 1930s. This is because consumers born in the 1930s were still children when fluid milk consumption peaked in the 1940s. We next create seven explanatory variables. The first, *C2*, indicates that a consumer was born in the 1930s. Similarly, *C3* indicates birth in the 1940s, and so on in ten-year intervals. Our final variable, *C8*, indicates birth in the 1990s. By including *C2* through *C8* in the model, we can calculate the expected differences in consumption between each subsequent generation and Americans born prior to 1930. Evidence of successive downward consumption shifts associated with *C2* through *C8* would confirm that cohort effects contribute to consumption trends. By contrast, finding no consistent tendency for consumption to change across the generations would refute the hypothesis that generational change was a part of the trend.

Finally, we include four indicator variables to identify the particular USDA survey in which individuals participated. The first time variable, *TIME2*, indicates consumers from the 1989–91 CSFII, while *TIME3* identifies participants from the 1994–96 CSFII and *TIME4* and *TIME5* identify participants from the 2003-04 NHANES and the 2007–08 NHANES. Our estimated time effects therefore represent the expected differences in consumption between participants in the omitted 1977–78 NFCS and each of the subsequent surveys, where all other factors remain constant. Unlike *C2* through *C8*, which capture variations among the generations due to their different experiences as children, we hypothesize that *TIME2* through *TIME5* capture the contemporaneous impacts on all individuals from fast food, the availability of competing beverages, and other aspects of the food marketing system. Given that fluid milk consumption has been trending downward (table 1), we might expect the effects of these variables to be negative and increasingly large in magnitude from the older to the newer surveys. However, results may also differ for whole and lower-fat milk products. Lower-fat products have become increasingly available over time. Most food stores now sell a range of milk products, and the NSLP has encouraged schools to offer lower-fat milk.[10]

Econometric Model

An obstacle in studying cohort effects in U.S. food consumption is assembling the necessary data set. This study relies on intermittent USDA surveys collected over a thirty-year period. Information is available on each individual's consumption over twenty-four hours, but most individuals eat a relatively small number of foods on any given day. Our data likewise contain a large number of zero observations. Cornick, Cox, and Gould (1994) have previously used a multivariate tobit model to investigate fluid milk demand. The advantage of this model is that, if nonzero, cross-equation correlations exist, it will be more efficient than estimating independent tobit models for each type of milk.[11] However, in the tobit framework, all zero-purchase observations are corner solutions. That is, the Kuhn-Tucker conditions cannot be satisfied at positive levels of consumption, given prevailing prices and a consumer's income, since the marginal utility associated with consumption is less than the marginal cost. Because 49% of teenagers and adults participating in the USDA's food surveys reported no milk consumption in their one-day dietary recall (see table 1), we extend the multivariate tobit model in Cornick, Cox, and Gould (1994) to allow for additional reasons for zero-consumption observations.

There are at least two reasons why an individual might not consume a food or beverage on a given day. First, prices and income may lead to a corner solution. Second, noneconomic factors may be responsible. From the standpoint of utility maximization, milk is not always in a consumer's utility function. Some individuals may not consider drinking milk as frequently as daily, while others may be lactose intolerant or vegans.

Pudney (1989) extends a univariate tobit model to allow for the possibility that both corner solutions and noneconomic factors generate zero observations. In his discussion of these double-hurdle models, Pudney (1989) argues that neither income nor prices influences whether noneconomic factors are responsible for zero observations; rather, the model's first hurdle accounts for whether a good is in a consumer's utility function and is unconnected to the levels of economic variables. If a consumer passes this hurdle, then economic factors determine consumption quantities.

[10] Regulatory changes adopted in 2012 require schools to offer 1% or skim milk.

[11] The gain in efficiency is analogous to gains associated with estimating a seemingly unrelated regressions model over ordinary least squares for the case of noncensored data.

Corner solutions occur when a consumer passes the first hurdle, but the Kuhn-Tucker conditions are not satisfied at positive levels of consumption.

Following Pudney's (1989) lead, we add a hurdle to the multivariate tobit model for whether noneconomic factors prevent the consumption of all types of milk on a given day:

$$D_i = \begin{cases} 1 \text{ if } D_i^* > 0 \\ 0 \text{ if } D_i^* \leq 0 \end{cases}, \tag{1}$$

where D_i^* is a function of the explanatory variables, Z_i, and a stochastic error term, e_i, such that $D_i^* = Z_i\alpha + e_i$, where α is a vector of coefficients on Z_i to be estimated. The probability that an individual did not drink fluid milk because he or she failed to pass this first hurdle is $P(D_i = 0)$. This single latent variable determines whether milk of any fat content is in a consumer's utility function on the day of participation in a survey according to the following preference relation:

$$u_i = D_i U^*(m_{i1}, \ldots, m_{ij}, q_i) + (1 - D_i)U^{**}(q_i), \tag{2}$$

where $U^*(\cdot)$ and $U^{**}(\cdot)$ are the utility functions of potential consumers and non-consumers, m_{ij} represents the amount of milk type j consumed, and q_i is a vector containing the quantities of all other goods consumed.

Given that a consumer passes the first hurdle, we assume that economic factors decide the latent levels of demand for all types of milk $j = 1, \ldots, J$, as they do in a traditional multivariate tobit model. Specifically, the latent level of consumption of milk type j, M_{ij}^*, is a function of the explanatory variables, X_{ij}, and a stochastic error term, ε_{ij}: $M_{ij}^* = X_{ij}\beta_j + \varepsilon_{ij}$, where β_j is a vector of coefficients on X_{ij} to be estimated. Notably, even if an individual passes the first hurdle, he or she may still reach corner solutions and not consume any type of milk. This occurs with probability $P(D_i = 1 \cap M_{ij}^* \leq 0 \; \forall \; j)$.

Overall, the quantity of milk type j consumed on a given day depends both on whether noneconomic factors prevent consumption and on whether the Kuhn-Tucker conditions can be satisfied at a positive quantity:

$$M_{ij} = \begin{cases} M_{ij}^*(X_{ij}) \text{ if } M_{ij}^*(X_{ij}) > 0 \text{ and } D_i^*(Z_i) > 0, \\ 0 \text{ otherwise} \end{cases}, \tag{3}$$

where the sets of variables in X_{ij} may be identical and Z_i may include all of the same variables except for economic ones such as income.

To derive an empirical model, we further assume that the stochastic errors in the hurdle and level equations can be represented by the outcomes of a trivariate normal density function:

$$\begin{bmatrix} e \\ \varepsilon_1 \\ \varepsilon_2 \end{bmatrix} \sim N\left(\mu = \begin{bmatrix} 0 \\ 0 \\ 0 \end{bmatrix}, \Sigma = \begin{bmatrix} 1 & \rho_1\sigma_1 & \rho_2\sigma_2 \\ \rho_1\sigma_1 & \sigma_1^2 & \rho\sigma_1\sigma_2 \\ \rho_2\sigma_2 & \rho\sigma_1\sigma_2 & \sigma_2^2 \end{bmatrix}\right). \tag{4}$$

where ρ is the correlation coefficient between the errors in the two level equations, ε_1 (for whole milk) and ε_2 (for lower-fat milk), and ρ_1 and ρ_2 are the correlation coefficients between each of these errors and the error in the hurdle equation, e. The standard errors in the two-level equations are σ_1 and σ_2. The standard error in the hurdle equation is assumed to be 1.

The complete likelihood function and derivation of the marginal effects along with other information are provided in the appendix.

Model Estimation

The model was estimated using one-day dietary recalls for 48,514 teenagers and adults. In keeping with our goal to extend the multivariate tobit model, we allowed for a non-zero correlation, ρ, between the errors in the two level equations, ε_1 and ε_2, though we assumed that each of these errors was independent of the error in the hurdle equation (i.e., $\rho_1 = \rho_2 = 0$). Standard errors for both the parameters and marginal effects were calculated using a bootstrap method with 250 replications. Efron and Tibshirani (1994, p. 52) report that 100 replications "gives quite satisfactory results" and "very seldom" are more than 200 replications needed.[12] Each replication includes 48,514 observations drawn from the analytical sample with replacement and a probability proportional to the sample weight (Efron and Tibshirani, 1994; Lee and Forthofer, 2006).

Before interpreting our estimation results, we checked for robustness. Collinearity is generally present in demand models with cohort effects and, as previously discussed, we have identified nonzero pairwise correlations between a survey participant's generation, age, and survey date. To first gauge the size of any potential increase in the variance of our parameter estimates, we calculated the condition number. Belsley, Kuh, and Welsch (1980) report that values between 30 and 100 indicate the presence of moderate to strong collinear relationships within a set of variables (p. 105). The value is 97 for the explanatory variables in this study. However, despite the high value of the condition number, we found that most variables were statistically significant. We next checked whether our results were robust to changes in the data. All consumers born in either the 1980s or 1990s were dropped from the analytical sample.[13] This reduced the value of the condition number to 31. In another experiment, we checked whether our results were robust to the specification of our key explanatory variables.[14] Specifically, we defined the variable *COHORT*, which equals zero for generations born in 1929 or earlier. *COHORT* then equals one for individuals born in 1930, two for people born in 1931, and so on. That is, *COHORT* equals the number of years after 1929 that a person was born. We then used this continuous variable to capture ongoing changes in fluid milk consumption from one generation to the next instead of the separate indicator variables *C2* through *C8*. This further reduced the value of the condition number to 29.[15] Despite large differences in the condition number, our results on cohort effects were qualitatively unchanged in both of these estimations.[16]

Estimated coefficients for the primary model using data on survey participants of all generations are reported in table 4. Marginal effects are provided in table 5.

Generational Change among the Contributing Factors

Our model appears to describe fluid milk consumption by individuals over a twenty-four-hour period better than a traditional multivariate tobit model would have. Some consumers failed to pass the first hurdle (i.e., noneconomic reasons were responsible for their zero consumption). Others reached corner solutions. Using the coefficient estimates in table 4, we calculated the probability that each individual $i = 1, \ldots, 48,514$ failed to pass the first hurdle, $P(D_i = 0)$, and reached corner solutions for both types of fluid milk, $P(D_i = 1,\ M^*_{i1} \leq 0, M^*_{i2} \leq 0)$. The average probability of failing to pass the first hurdle is 20% (i.e., $\frac{1}{N}\sum_{i=1}^{N} P(D_i = 0) = 0.20$). The average probability of reaching a corner solution for both types of milk is 30%. Finally, the overall probability of not consuming milk for either set of reasons is 50%, consistent with the proportion of individuals in our data set who did not consume milk (see table 1).

Results on our income and demographic variables are consistent with results reported in previous studies. Estimated coefficients on the natural logarithm of *AGE* are all negative and statistically significant. Of course, each variable's marginal effect depends on the sign and magnitude of all

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[12] Estimates of the standard errors in this study changed very little after 100 replications.

[13] Pairwise correlation coefficients between a consumer's generation, age, and survey date were generally largest for survey participants born in the 1980s and 1990s.

[14] Individuals born in the 1980s and 1990s were reintroduced to our analytical data set for this experiment.

[15] Using *COHORT* to specify an individual's generation adds information to the model. *C2* through *C8* specify an individual's decade of birth whereas *COHORT* further identifies the exact year.

[16] Results are available upon request.

Table 4. Coefficient Estimates

	Noneconomic Hurdle		Whole Milk		Lower-fat Milk	
Variable/Statistic	**Coefficient**	**Std. Error**	**Coefficient**	**Std. Error**	**Coefficient**	**Std. Error**
Constant	6.31***	0.45	2.96***	0.39	0.50	0.36
LN(INCOME)			−0.24***	0.02	0.10***	0.01
LN(AGE)	−1.24***	0.11	−0.59***	0.09	−0.35***	0.09
WEEKEND	−0.10***	0.04	−0.06	0.04	−0.10***	0.03
DIETING	−0.02	0.07	−0.62***	0.06	0.26***	0.05
MALE	−0.26***	0.04	0.46***	0.03	0.27***	0.03
COLLEGE	0.23***	0.05	−0.51***	0.03	0.26***	0.03
BLACK	−0.39***	0.05	0.48***	0.05	−1.23***	0.05
HISPANIC	0.21***	0.06	0.59***	0.05	−0.71***	0.05
OTHER RACE	−0.26***	0.08	0.56***	0.08	−0.58***	0.08
C2	−0.82***	0.10	−0.17***	0.06	−0.19***	0.05
C3	−1.31***	0.11	−0.20***	0.07	−0.24***	0.06
C4	−1.77***	0.12	−0.15	0.09	−0.29***	0.08
C5	−2.05***	0.17	−0.10	0.13	−0.41***	0.10
C6	−2.86***	0.17	0.00	0.15	−0.15	0.13
C7	−3.27***	0.22	−0.08	0.18	0.16	0.16
C8	−3.21***	0.28	−0.28	0.24	0.23	0.22
TIME2	1.01***	0.07	−1.56***	0.05	0.23***	0.05
TIME3	0.99***	0.08	−1.82***	0.05	0.38***	0.05
TIME4	0.98***	0.10	−1.91***	0.08	0.54***	0.07
TIME5	1.25***	0.11	−2.16***	0.09	0.44***	0.07
Variance-Covariance Matrix						
σ_1^2	3.77***	0.08				
σ_2^2	3.16***	0.05				
ρ	−0.46***	0.01				

Notes: Triple asterisks (***) indicate significance at the 1% level. Standard errors are estimated using a bootstrap method with 250 replications. Each replication included 48,514 observations drawn from original sample of teenagers and adults with replacement and a probability proportional to the sample weight.

coefficients in both the first hurdle and level equations. Table 5 shows the expected changes in whole (-0.006 cups) and lower-fat fluid milk (-0.006 cups) consumption per day associated with a unit (one-year) increase in *AGE*.[17] By simple extrapolation, we would expect a person's daily consumption of each type of milk to decrease by about 0.12 cups, respectively, over each twenty years of life. We also find that higher income levels are negatively and positively associated with the consumption of whole and lower-fat fluid milk, respectively. Overall, Americans' fluid milk consumption varies due to differences in their incomes and demographic characteristics. This heterogeneity could also contribute to long-run trends in milk demand. As discussed previously, the median age of the U.S. population increased from 28.1 years in 1970 to 37.2 years in 2010 (Hobbs and Stoops, 2002; Howden and Meyer, 2011). It then follows from our results that aging may reduce the population-average level of consumption over time.

Of primary interest are the results on our cohort variables. On this matter, we find evidence that generational change contributes to fluid milk consumption trends. As discussed, the marginal effects of *C2* through *C8* represent the expected consumption differences between an individual born before 1930 and subsequent generations, all else constant. For example, we find that Americans born in the 1960s are expected to consume 0.13 cups less whole milk and 0.28 cups less lower-fat milk per day

[17] Although the model was estimated using the logarithms of *INCOME* and *AGE*, we report marginal effects for these two variables in levels.

Table 5. Marginal Effects of Explanatory Variables

	Whole Milk		Lower-Fat Milk	
Variable	**Marginal Effect**	**Std. Error**	**Marginal Effect**	**Std. Error**
Income and Demographic Characteristics				
INCOME	−0.003***	0.0002	0.002***	0.0002
AGE	−0.006***	0.0004	−0.006***	0.0007
WEEKEND	−0.02***	0.01	−0.04***	0.01
DIETING	−0.13***	0.01	0.09***	0.02
MALE	0.09***	0.01	0.05***	0.01
COLLEGE	−0.10***	0.01	0.12***	0.01
BLACK	0.08***	0.01	−0.33***	0.01
HISPANIC	0.19***	0.01	−0.18***	0.01
OTHER RACE	0.12***	0.02	−0.18***	0.02
Consumer's Decade of Birth (Generation)				
C2	−0.06***	0.02	−0.09***	0.02
C3	−0.09***	0.02	−0.14***	0.02
C4	−0.11***	0.02	−0.21***	0.03
C5	−0.13***	0.02	−0.28***	0.03
C6	−0.23***	0.03	−0.37***	0.04
C7	−0.29***	0.03	−0.41***	0.04
C8	−0.30***	0.03	−0.39***	0.06
Survey Year				
TIME2	−0.24***	0.02	0.19***	0.01
TIME3	−0.30***	0.02	0.24***	0.01
TIME4	−0.32***	0.02	0.30***	0.02
TIME5	−0.36***	0.02	0.29***	0.02

Notes: Triple asterisks (***) indicate significance at the 1% level. Standard errors are estimated using a bootstrap method with 250 replications. Each replication included 48,514 observations drawn from the original sample with replacement and a probability proportional to the sample weight.

at age twenty, at age thirty, and so on than Americans born before 1930 at each of these same ages. This finding follows from our results for *C5*. Moreover, Americans born in the 1980s are expected to consume 0.16 cups less whole milk and 0.13 cups less lower-fat milk per day than those born in the 1960s. This finding follows from our results for *C5* and *C7*. Notably, the effects of aging twenty years (based on the marginal effect of *AGE*) and being born twenty years later in history (based on the marginal effects of *C5* and *C7*) are similar in magnitude. However, while the median age of the U.S. population may have increased by about ten years over a forty-year period, younger generations are continuously and entirely replacing older generations.

Finally, we find that American teenagers and adults likely would have consumed less whole milk but more lower-fat milk between the 1970s and the 2000s, if there had not been generational change or changes in the income and demographic mix of the U.S. population. As discussed earlier, our results on *TIME2* through *TIME5* represent changes in expected consumption between each subsequent survey and the omitted 1977–78 NFCS. We hypothesize that these time variables primarily capture changes in the environment in which consumers make food choices, such as the assortment of competing beverage products available. Given that fluid milk consumption has trended downward, as shown in table 1, we expect the effects of these variables to be generally negative and increasingly large in magnitude from the older to the newer surveys. However, we also expect that results might differ for whole and lower-fat milk products, since the latter also have become increasingly available over the years. Indeed, we find that the marginal effects of *TIME2* through

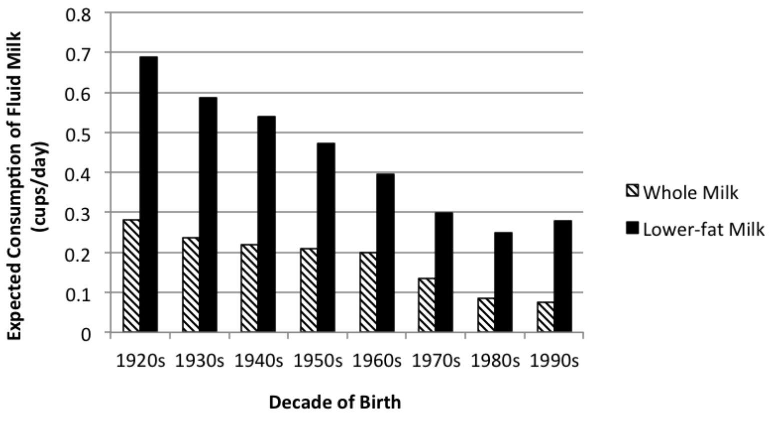

Figure 1. Expected Daily Fluid Milk Consumption by Decade of Birth Year, Age and Other Variables Constant

Notes: Simulations conducted using estimation results. Since *TIME2* through *TIME5* capture the mix of competing beverage products available and other aspects of the marketing environment, we chose the most recent survey year for the basis of our simulation. *TIME2*, *TIME3*, and *TIME4* were likewise set to 0. Simulations were conducted with *MALE* and *TIME5* (indicator variables for gender and the 2007–08 NHANES) equal to one. All other explanatory variables were set at their sample mean. Our simulations predict the differences in consumption between otherwise similar individuals born decades apart, if members of these generations could all be the same age at the same time in history and all other covariates could be held constant.

TIME5 are positive for lower-fat milk products and increasing in size over time. Moreover, the magnitude of the increase in lower-fat milk consumption is similar to the magnitude of the decrease in whole milk consumption. Americans consumed 0.29 cups more lower-fat milk and 0.36 cups less whole milk per day in 2007-08 than in 1977–78, when all other variables in our model remain constant.

Simulation Results

To better illustrate the relationship between a person's generation and intake of fluid milk, we used our estimation results to predict whole and lower-fat milk consumption by males born during each of the decades at thirty years old. All other variables were held constant to isolate the effects of *C2* through *C8*.[18] Thus, our simulations predict the differences in consumption between otherwise similar individuals belonging to different generations, if these men could all be the same age at the same time in history and all other covariates could be held constant. Results are reported in figure 1. Successively younger generations tend to consume less fluid milk. These large decreases in consumption between individuals born several decades apart will gradually reduce the population-average level of consumption over time as younger generations slowly replace older generations and account for a steadily larger share of the overall population.

Concluding Remarks

Contributing to the decline in fluid milk consumption since the 1940s is a tendency for successively newer generations to exhibit a lower level of demand than the preceding generation. This bodes poorly for the future of U.S. fluid milk consumption. Generational change may reduce the population-average level of consumption as newer birth cohorts replace older ones. This also helps

[18] Since *TIME2* through *TIME5* capture the mix of competing beverage products available and other aspects of the marketing environment, we chose the most recent survey year for the basis of our simulation. *TIME2*, *TIME3*, and *TIME4* were likewise set to zero. Simulations were conducted with *MALE* and *TIME5* (0/1 indicator variable for the 2007–08 NHANES) equal to one. All other explanatory variables were set at their sample mean.

to explain why fluid milk consumption continues to fall despite the efforts of dairy farmers, fluid milk processors, and the federal government to promote it.

Dairy farmers are concerned about the long-run decline in fluid milk consumption because it reduces sales of their product. To date, the overall demand for U.S.-produced milk continues to rise. Food availability data show that population gains have thus far been large enough to offset reductions in per capita consumption (USDA Economic Research Service, 2012a). Data also show that an increasing quantity of U.S.-produced milk is being used in manufactured products, especially cheese (*Ibid*).

Declining fluid milk consumption also threatens to reduce the diet quality of Americans. The *Dietary Guidelines for Americans 2010* recommends three cups of dairy products daily.[19] Consuming enough of these foods can improve bone health and lower blood pressure, among other health benefits. However, by age four, most Americans do not consume enough dairy products (p. 38). Moreover, other dairy products like cheese may not be a good substitute for fluid milk, since cheese tends to have more solid fat and therefore more calories than lower-fat milk.

Studies like Kaiser and Dong (2006) and Gleason and Suitor (2001) suggest that, if not for checkoff programs and the NSLP, fluid milk consumption would have decreased even more rapidly between the 1970s and the 2000s. These studies may identify only a lower-bound estimate of each program's impact. They focus on the immediate effects that the programs had on demand but do not account for the possibility that habits formed in childhood may last a lifetime. To best mitigate or halt the downward trend in fluid milk consumption, policymakers and checkoff program managers may find it fruitful to maintain a focus on children, since habit formation implies that childhood food choices can affect long-run behavior. For example, Rafferty et al. (2009) report on an initiative to make milk more appealing to elementary and secondary school students. They found that milk consumption rose with enhanced packaging and merchandising.

Studies of cohort effects in U.S. food demand have heretofore employed the Consumer Expenditure Survey to examine food spending trends. This study demonstrates that USDA food consumption surveys also can be pooled to create Deaton's (1997) "time series of cross sections." However, it may be necessary to adapt existing econometric models when using information on an individual's consumption over a twenty-four-hour period. In this study, we followed Pudney (1989) to extend a multivariate tobit model. This same approach could be adapted to consider long-run consumption trends for other types of foods, such as beef or poultry. Alternatively, discrete choice models might be used to investigate differences in the probability of consuming a particular type of food across generations.

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[19] Applies to people above eight years of age. Recommended daily quantities are 2 cups for children two to three years of age and 2.5 cups for children four to eight years of age.

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Appendix

USDA surveys pooled for this study report individuals' fluid milk consumption over twenty-four hours. However, because most consumers eat only a small number of foods on any given day, our data contain many zero observations. Following Pudney (1989), we extend the traditional multivariate tobit model to allow for two reasons for nonconsumption on a given day. First, fluid milk may not have been in a consumer's utility function. Second, as in a traditional multivariate tobit model, the Kuhn-Tucker conditions may not have been satisfied at positive levels for any type of milk. The quantity of milk type j consumed by individual i, M_{ij}, then becomes:

$$\text{(A1)} \qquad M_{ij} = \begin{cases} M^*_{ij}(X_{ij}) \text{ if } M^*_{ij}(X_{ij}) > 0 \text{ and } D^*_i(Z_i) > 0, \\ 0 \text{ otherwise} \end{cases},$$

where D^*_i is a function of the explanatory variables, Z_i, and a stochastic error term, e_i, such that $D^*_i = Z_i\alpha + e_i$, where α is a vector of coefficients. The probability that fluid milk is in i's utility function (i.e., this consumer passes the first hurdle) is $P(D_i = 1)$. The same consumer's latent level of consumption of milk type j, M^*_{ij}, is a function of the explanatory variables, X_{ij}, and a stochastic error term, ε_{ij}, such that $M^*_{ij} = X_{ij}\beta_j + \varepsilon_{ij}$, where β_j is a vector of coefficients. The sets of variables in X_{ij} may be identical and Z_i may include all of the same variables except for economic ones such as income.

To derive an empirical model, we further assume that the stochastic errors in the hurdle and level equations can be represented by the outcomes of a trivariate normal density function:

$$\text{(A2)} \qquad \begin{bmatrix} e \\ \varepsilon_1 \\ \varepsilon_2 \end{bmatrix} \sim N\left(\mu = \begin{bmatrix} 0 \\ 0 \\ 0 \end{bmatrix}, \Sigma = \begin{bmatrix} 1 & \rho_1\sigma_1 & \rho_2\sigma_2 \\ \rho_1\sigma_1 & \sigma_1^2 & \rho\sigma_1\sigma_2 \\ \rho_2\sigma_2 & \rho\sigma_1\sigma_2 & \sigma_2^2 \end{bmatrix}\right).$$

where ρ is the correlation coefficient between the errors in the two level equations, ε_1 (for whole milk) and ε_2 (for lower-fat milk), and ρ_1 and ρ_2 are the correlation coefficients between each of these errors and the error in the hurdle equation, e. The standard errors in the two-level equations are σ_1 and σ_2. The standard error in the hurdle equation is assumed to be 1.

Applying the proposed model to whole and lower-fat milk consumption, a consumer's reported intakes must belong to one of four regimes: he or she drank 1) no milk, 2) both types of milk, 3) only whole milk, or 4) only lower-fat milk.

Consider a consumer in the first regime who drank no milk of any type. The probability that noneconomic factors are responsible is:

$$\text{(A3)} \qquad P(D=0) = \int_{-\infty}^{-Z\alpha}\int_{-\infty}^{+\infty}\int_{-\infty}^{+\infty} \phi_3(e,\varepsilon_1,\varepsilon_2)d\varepsilon_2 d\varepsilon_1 de,$$

where $\phi_k(\cdot)$ denotes a k-variate normal density function. This probability can be simplified as:

$$\text{(A4)} \qquad \begin{aligned} P(D=0) &= \left[\int_{-\infty}^{+\infty}\int_{-\infty}^{+\infty} \phi_2(\varepsilon_1,\varepsilon_2|e)d\varepsilon_2 d\varepsilon_1\right]\int_{-\infty}^{-Z\alpha} \phi_1(e)de, \\ &= \int_{-\infty}^{-Z\alpha} \phi_1(e)de, \end{aligned}$$

where $\phi_1(e)$ is the marginal distribution of e and $\phi_2(\varepsilon_1,\varepsilon_2|e)$ is the distribution of ε_1 and ε_2 conditional on e. A second event also associated with the first regime occurs when the consumer passes the first hurdle. Noneconomic factors do not prevent consumption, but the consumer still reaches a corner solution for both whole and lower-fat milk. This event occurs with probability:

$$\text{(A5)} \qquad P(D=1 \cap M^*_1 \leq 0 \cap M^*_2 \leq 0) = \int_{-Z\alpha}^{+\infty}\int_{-\infty}^{-X_1\beta_1}\int_{-\infty}^{-X_2\beta_2} \phi_3(e,\varepsilon_1,\varepsilon_2)d\varepsilon_2 d\varepsilon_1 de.$$

Since the two events associated with the first regime are mutually exclusive, the relevant likelihood function for this regime is based on the sum of events' respective probabilities:

$$\text{(A6)} \qquad \text{L1}(\alpha,\beta_1,\beta_2,\Sigma) = \int_{-\infty}^{-Z\alpha} \phi_1(e)de + \int_{-Z\alpha}^{+\infty}\int_{-\infty}^{-X_1\beta_1}\int_{-\infty}^{-X_2\beta_2} \phi_3(e,\varepsilon_1,\varepsilon_2)d\varepsilon_2 d\varepsilon_1 de.$$

Consider next consumers in the second regime. These individuals passed all hurdles in our model, drinking both whole and lower-fat milk. The relevant likelihood function is then:

(A7) $$\mathrm{L2}(\alpha,\beta_1,\beta_2,\Sigma)=\int_{-Z\alpha}^{+\infty}\phi_3(e,\varepsilon_1,\varepsilon_2)de.$$

Following Pudney's (1989, p. 327–28) application of Bayes' theorem, we can rewrite this expression as:

(A8) $$\mathrm{L2}(\alpha,\beta_1,\beta_2,\Sigma)=\phi_2(\varepsilon_1,\varepsilon_2)\int_{-Z\alpha}^{+\infty}\phi_1(e|\varepsilon_1,\varepsilon_2)de,$$

where $\phi_1(e|\varepsilon_1,\varepsilon_2)$ is the distribution of e given ε_1 and ε_2. This conditional distribution is defined using the original trivariate normal density in (A2):

(A9) $$\begin{bmatrix} e \\ \varepsilon_1 \\ \varepsilon_2 \end{bmatrix} \sim N\left(\mu=\begin{bmatrix} 0 \\ 0 \\ 0 \end{bmatrix}, \Sigma=\begin{bmatrix} 1 & \Sigma_{e12} \\ \Sigma_{e21} & \Sigma_{1122} \end{bmatrix}\right),$$

where $\Sigma_{1122}=\begin{bmatrix} \sigma_1^2 & \rho\sigma_1\sigma_2 \\ \rho\sigma_1\sigma_2 & \sigma_2^2 \end{bmatrix}$, $\Sigma_{e21}=\begin{bmatrix} \rho_1\sigma_1 \\ \rho_2\sigma_2 \end{bmatrix}$, and $\Sigma_{e12}=\begin{bmatrix} \rho_1\sigma_1 & \rho_2\sigma_2 \end{bmatrix}$. As shown by Greene (1997, p. 90), for example, it follows that the conditional distribution $\phi_1(e|\varepsilon_1,\varepsilon_2)$ is normal with mean $\sum_{e12}\sum_{1122}^{-1}\binom{\varepsilon_1}{\varepsilon_2}$ and variance $1-\sum_{e12}\sum_{1122}^{-1}\sum_{e21}$.

Consumers in the third regime drank only whole milk. Noneconomic reasons do not prevent consumption, but these consumers still reached a corner solution for lower-fat products. The relevant likelihood function is:

(A10) $$\mathrm{L3}(\alpha,\beta_1,\beta_2,\Sigma)=\int_{-Z\alpha}^{+\infty}\int_{-\infty}^{-X_2\beta_2}\phi_3(e,\varepsilon_1,\varepsilon_2)d\varepsilon_2 de.$$

Again applying Pudney's (1989) partition, we have:

(A11) $$\mathrm{L3}(\alpha,\beta_1,\beta_2,\Sigma)=\phi_1(\varepsilon_1)\int_{-Z\alpha}^{+\infty}\int_{-\infty}^{-X_2\beta_2}\phi_2(e,\varepsilon_2|\varepsilon_1)d\varepsilon_2 de,$$

where $\phi_2(e,\varepsilon_2|\varepsilon_1)$ is the distribution of e and ε_2 given ε_1, which is also normal with mean $\sum_{e1}\sum_{11}^{-1}\varepsilon_1$ and variance $\sum_{e22}-\sum_{e1}\sum_{11}^{-1}\sum_{1e}$, where $\Sigma_{e22}=\begin{bmatrix} 1 & \rho_2\sigma_2 \\ \rho_2\sigma_2 & \sigma_2^2 \end{bmatrix}$, $\Sigma_{e1}=\begin{bmatrix} \rho_1\sigma_1 \\ \rho\sigma_1\sigma_2 \end{bmatrix}$, $\Sigma_{1e}=\begin{bmatrix} \rho_1\sigma_1 & \rho\sigma_1\sigma_2 \end{bmatrix}$, and $\Sigma_{11}=\begin{bmatrix} \sigma_1^2 \end{bmatrix}$.

The relevant likelihood function for individuals in the fourth regime (consumed only lower-fat milk) can be derived similarly as for consumers in the third regime. That is:

(A12) $$\mathrm{L4}(\alpha,\beta_1,\beta_2,\Sigma)=\phi_1(\varepsilon_2)\int_{-Z\alpha}^{+\infty}\int_{-\infty}^{-X_1\beta_1}\phi_2(e,\varepsilon_1|\varepsilon_2)d\varepsilon_1 de,$$

where $\phi_2(e,\varepsilon_1|\varepsilon_2)$ is the conditional distribution of e and ε_1 given ε_2, with mean $\sum_{e2}\sum_{22}^{-1}\varepsilon_2$ and variance $\sum_{e11}-\sum_{e2}\sum_{22}^{-1}\sum_{2e}$, where $\Sigma_{e11}=\begin{bmatrix} 1 & \rho_1\sigma_1 \\ \rho_1\sigma_1 & \sigma_1^2 \end{bmatrix}$, $\Sigma_{e2}=\begin{bmatrix} \rho_2\sigma_2 \\ \rho\sigma_1\sigma_2 \end{bmatrix}$, $\Sigma_{2e}=\begin{bmatrix} \rho_2\sigma_2 & \rho\sigma_1\sigma_2 \end{bmatrix}$, and $\Sigma_{22}=\begin{bmatrix} \sigma_2^2 \end{bmatrix}$.

Finally, the weighted likelihood function for the full sample of $i=1,\ldots,N$ individuals is:

(A13) $$\mathrm{L}(\alpha,\beta_1,\beta_2,\Sigma)=\Pi_{i=1}^{N}L_i^{w_i},$$

where w_i and L_i are the sample weight and the relevant likelihood function for individual i. Estimates of model parameters can be obtained by maximizing the weighted log-likelihood:

(A14) $$\ln L(\alpha,\beta_1,\beta_2,\Sigma)=\sum_{i=1}^{N}w_i\ln L_i.$$

Marginal Effects

Given the parameter estimates from equation (A14), a consumer's expected intake of whole milk is:

(A15)
$$\begin{aligned} E(M_1) &= P(M_1 > 0) \times E(M_1 | M_1 > 0) \\ &= P(D = 1,\ M_1^* > 0) \times E(X_1\beta_1 + \varepsilon_1 | Z\alpha + e > 0, X_1\beta_1 + \varepsilon_1 > 0) \end{aligned}$$

and, by analogy, his or her expected consumption of lower-fat milk is:

(A16)
$$\begin{aligned} E(M_2) &= P(M_2 > 0) \times E(M_2 | M_2 > 0) \\ &= P(D = 1,\ M_2^* > 0) \times E(X_2\beta_2 + \varepsilon_2 | Z\alpha + e > 0,\ X_2\beta_2 + \varepsilon_2 > 0) \end{aligned}$$

If we assume independence between e_i and the errors in the level equations, the marginal effects in (A15) and (A16) can be simplified as:

(A17)
$$E(M_1) = \Phi(Z\alpha)\Phi\left(\frac{X_1\beta_1}{\sigma_1}\right)X_1\beta_1 + \Phi(Z\alpha)\sigma_1\phi\left(\frac{X_1\beta_1}{\sigma_1}\right)$$

and

(A18)
$$E(M_2) = \Phi(Z\alpha)\Phi\left(\frac{X_2\beta_2}{\sigma_2}\right)X_2\beta_2 + \Phi(Z\alpha)\sigma_2\phi\left(\frac{X_2\beta_2}{\sigma_2}\right),$$

where $\Phi(\theta)$ is the standard normal cdf evaluated at θ.

Marginal effects for continuous explanatory variables can be obtained by evaluating the gradients of the above equations at the specific values of Z_i and X_{ij} for each individual $i = 1, \ldots, N$. We can then calculate the weighted average change in predicted consumption for each type of milk across all individuals. Marginal effects for discrete explanatory variables can be similarly estimated by averaging over each individual's predicted changes in consumption when the above equations are evaluated at different levels of the explanatory variable.