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NATIVE AMERICAN OBESITY:
AN ECONOMIC MODEL OF THE "THRIFTY GENE" THEORY

by:

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Abstract:

Native American obesity and the associated health conditions are generally thought to result in part from a genetic predisposition to overeating fats and carbohydrates, called the "thrifty gene." Although coined by nutritional scientists, this study maintains the origin of the thrifty gene lies in economics. Apparently harmful overconsumption and addiction constitute economically rational behavior if the increment to current utility from adding to one's stock of "consumption capital" is greater than the present value of utility lost in the future due to ill health and the costs of withdrawl. Tests of these conditions for such "rational addiction" are conducted using two-stage household production approach. The results obtained by estimating this model in a panel of Native and non-Native supermarket scanner data show that both Natives and non-Natives tend to be inherently forward-looking in their nutrient choices, but Natives tend to have far higher long-run demand elasticities for carbohydrates compared to non-Natives. Consequently, reductions in real food prices over time, primarily among foods that are dense in simple carbohydrates, leads Native Americans to over-consume potentially harmful nutrients relative to their traditional diet.

JEL Classification:

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Introduction

Health officials and epidemiologists regard the incidence of conditions such as obesity, hypertension, hyperglycemia, type-2 diabetes, and heart disease among Native American tribes as a topic of major public policy concern. In particular, the National Institute of Diabetes and Digestive and Kidney Diseases (NIDDK) reports that over "...one half of adult Pima Indians have diabetes and 95% of those with diabetes are overweight" (NIDDK). Diabetes afflicts other Native American tribes and indigenous people or "transitional societies" around the world (Vaughan; Eaton et al.). In each case, diet, lifestyle, and genetic predisposition appear to contribute to the problem. Numerous studies have documented nutritional deficiencies among Southwest Native American populations.[2] Common patterns in changes to these diets include a shift from high-protein, high-fiber and complex carbohydrate diet to one that is higher in saturated fat and sugar, and low in both complex carbohydrates and fiber. The most common explanation for the apparently disfunctional diets of many Native American groups lies in the notion that they possess a "thrifty gene" (Neel 1962). Over many generations, surviving native societies develop a means of sustaining themselves during times of famine by building up stores of energy (fat) acquired during times of relative prosperity. In modern welfare societies, however, continuous prosperity and a sharp reduction in physical activity combine to produce an over-accumulation of energy stores. In economic terms, the thrifty gene theory implies that the implicit value of potentially scarce nutrients are higher among Native Americans than among

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[2] Deficiencies are noted among the Havasupai (Vaughan *et al.*), the Pima (Ravussin *et al.*), the Hopi (Brown and Brenton), the Hualapai (Teufel and Dufor), and the Navajo (Ballew *et al.*).

non-Native Americans, so they are led to substitute toward more calorie-dense, potentially harmful nutrients. There are, however, other explanations that rely more on behavioral motivations than genetic predisposition.

Typically, health agencies respond to the problem of Native American malnutrition with education and counseling services on the assumption that poor diets are borne of pathological, irrational choices. While Schelling, Thaler and Shefrin, and Winston explain addiction as the reflection of consumers' multiple selves – the buying self and the consuming self – such explanations are of little empirical value because they admit a wide range of behaviors. Further, the thought that an entire class of individuals can make decisions without regard to their future consequences is not only untenable, but contradicts the basic tenets of economic reasoning. Several authors develop economic explanations for obesity among the general population that incorporate various assumptions about the roles of individual choice when technological change reduces the cost of food intake relative to food usage (Lakdawalla and Philipson; Philipson and Posner) or the cost of convenient food options (Cutler, Glaeser and Shapiro). Cawley, on the other hand, acknowledges that calories may simply be addictive. Using a similar line of reasoning, this paper investigates the possibility that food, or more specifically nutrient, choices among Native Americans – even apparently addictive, self destructive choices – result from fully rational, forward thinking decisions.

Becker and Murphy define addiction as a situation in which current consumption raises future demand as the consumer builds a stock of "consumption capital" or habits (Iannaccone) that increase the marginal utility of current consumption, but reduce future utility as his health deteriorates. Even when the addictive good is inherently harmful, consumption will rise so long

as the increment to current utility is greater than the present value of all future costs. Oriphanides and Zervos, as well as Suranovic, Goldfarb and Leonard, however, argue that such dynamic (or adjacent in the terminology of Becker and Murphy) complementarity may generate a form of habitual consumption, but not truly addictive behavior. Unlike the "happy addicts" of Becker and Murphy, true addicts would like to change their current situation, but find that they cannot. Adjustment costs, typically in the form of withdrawl symptoms, are necessary for addiction because the negative utility induced by attempting to reduce consumption below a habitual level makes quitting an irrational act (Suranovic, Goldfarb and Leonard). While withdrawl from alcohol or nicotine can indeed be painful, withdrawl from food can have more serious consequences. Adjustment costs, therefore, may explain why some Native American societies appear to be trapped in patterns of poor dietary outcomes habits. Most importantly, however, if the genetic difference between Native and non-Native Americans manifests itself in a rational addiction, then economic policy has a greater role than once thought in conditioning adverse nutritional outcomes in an efficient way.

The primary empirical implication of the rational addiction model is that current consumption responds to not only current and past prices, but expected future prices and consumption as well. Numerous empirical tests of the rational addiction model exist in the literature, examining addictions to cigarettes (Gruber and Koszegi; Chaloupka; Keeler *et al.*; Douglas; Becker, Grossman, and Murphy), alcohol (Grossman, Cahloupka and Sirtalan; Waters and Sloan), cocaine (Grossman and Chaloupka) and caffeine (Olekalns and Bardsley) and heroin (Bretteville-Jensen). These studies show near uniform support for the rational addiction hypothesis, but in very simple econometric models that may be consistent with many other

theoretical explanations.

A large body of empirical work has also arisen in response to the growing concern over dietary adequacy in general and the demand for specific nutrients. However, the bulk of these studies (Park and Davis; Gould and Lin; Variyam *et al.*) study the role of nutrient information in changing the observed quality of consumers' diets and do not address price-responsiveness. Gawn *et al.* also lack nutrient prices, but do find significant positive elasticities for income, wages and education for both protein and total calories. Using survey data, Adrian and Daniel find negative income elasticities for carbohydrates – a finding that may help explain observed Native consumption patterns. Chung, Lee, Moss and Brown use an empirical framework very similar to the current paper in a data set that does contain prices, but do not account for possible nutrient addiction or even habitual consumption.

In this paper, we test for a rational addiction to fats and carbohydrates among Native Americans using a two-stage approach based upon the household production model of Stigler and Becker. Because nutrient prices are not directly observable, a Generalized Leontief cost function provides shadow values for each nutrient (protein, fat and carbohydrate) in the first stage, while the second-stage nutrient demand model consists of a linear approximate AIDS model, using the first-stage shadow values as data. These models are used to generate elasticity estimates for specific foods (stage one) and nutrients (stage two) for each demographic sub-sample (Native and non-Native) so that comparisons can be made between them. The data for each sample comprises a uniquely detailed data set. Specifically, supermarket scanner data on food sales were obtained for eighteen stores of a single grocery chain in Arizona. Nine of these stores are located either on or near reservations, while the other nine in markets that are broadly

representative of the general population. Comparing shadow value and elasticity estimates between the two sub-samples provides a relatively direct, natural test whether the thrifty gene hypothesis or rational addiction models provide a better explanation for Native American dietary choices.

In estimating these models, the primary objective of this study is to provide policy makers and health care providers better information as to the likely efficacy of price and income policy in changing Native American dietary outcomes. To do so, we determine whether dietary choices by Native Americans can be explained as rational, market-driven economic decisions even though they appear addictive and self-destructive. The second section describes a theoretical model of nutrient demand based on Becker and Murphy's concept of rational addiction and extended to include adjustment costs and differences in the budget set faced by Natives and non-Natives. A dynamic, two-stage econometric model of nutrient demand designed to test the implications of the theoretical model is presented in the third section, while a fourth describes the unique store-level retail scanner data set used herein. A fifth section presents the empirical results and offers some suggestions as to how these results may lead to better nutritional policy not only for Native Americans, but for the obesity epidemic among non-Native Americans as well.

Economic Model of Rational Addiction, Withdrawl and the "Thrifty Gene"

Households (consumers) derive utility from nutrients, which they obtain from retail food purchases. In the context of a dynamic household production model of nutrient demand, the primary macronutrients (fat, protein, carbohydrates) are non-market commodities and foods and

beverages are market goods. As in Stigler and Becker and Iannacone, assume further that consumers form stocks of "consumption capital" of each commodity – stocks that rise with current consumption, but depreciate over time.[3] Consumers' optimization process consists of two stages. In the first stage, consumers choose the amount of each nutrient subject to a wealth constraint and an equation of motion that governs habit development. In the second stage, they minimize the cost of producing this fixed set of nutrient-outputs subject to the technological constraint represented by the nutrient content of all available food-inputs. In the conceptual model, we combine the two stages in one optimization problem, but separate them in the empirical application to follow.

Defining the current consumption over an i dimensional vector of nutrients (i = protein, fat, carbohydrate) at time t as $\boldsymbol{n}$ and the stock of accumulated consumption as N, the utility function is written in vector notation as: $U(\boldsymbol{n}, \boldsymbol{N})$, which is increasing and concave in nutrients ($U_{\boldsymbol{n}} > 0, U_{\boldsymbol{nn}} < 0$) and decreasing and convex in nutrient capital ($U_N < 0, U_{NN} < 0, U_{nN} > 0$). These assumptions embody the fundamental behavioral assumptions that lead to addiction. Namely, $U_{nN} > 0$ implies that the marginal utility from consuming each nutrient rises in the stock of consumption capital – reinforcing consumption habits – while $U_N < 0$ for harmful nutrients (above a threshold level required for adequate nutrition) implies that utility is lower for each consumption level at higher amounts of previous consumption (tolerance). Given these assumptions, each stock "nutrient capital" evolves according to the process:

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[3] Note that this does not literally imply that individuals accumulate stocks of nutrients, but rather the habitual consumption of them. It is appropriate and intuitive to think of habitual consumption of nutrients and not goods if we recognize that even the most addicted consumers shift among brands of cigarettes, beer or fast food while satisfying the more primative craving for nicotine, alcohol or fat. Although there is no empirical evidence of addiction to protein, the most general version of the model allows for all possible addictions. Which nutrients in fact are addictive is an empirical question.

$$\dot{N}_{it} = n_{it}(N_{it}) - \delta_i N_{it} \quad \forall \ i, \tag{1}$$

where $\dot{N}_{it}$ is the (continuous) rate of change of the stock of nutrient i and δ_i is the constant rate of

depreciation for nutrient-stock i. Allowing current additions to the stock of habits to depend on

N reflects the general concept that a household's productivity in creating commodities depends in

part on the stock of accumulated capital. Nutrient consumption is also constrained by a

household's available wealth (W_t), which accumulates over time at the rate of interest (r), but is

reduced by food purchases at a price p_j. Assume further that households minimize their

expenditure on foods to achieve fixed nutrient levels so that the net change in wealth equals

annual interest income less the optimized cost of purchasing foods subject to a fixed nutritional

constraint:

$$\dot{W}_t = rW_t - C(\boldsymbol{p}, \boldsymbol{n}), \tag{2}$$

where $C(\boldsymbol{p},\boldsymbol{n}) = \min \left[\sum_j p_j x_j \mid \boldsymbol{n} \geq \bar{\boldsymbol{n}} \right]$, where x_j are individual foods. Further, there are significant

costs associated with changing nutrient consumption levels – withdrawl symptoms, the cost of

appetite suppressant drugs, and weight loss programs are examples. However, adjustment costs

are fundamentally asymmetric because consumers can easily take in more than their habitual

amounts of each nutrient, but find it very difficult to consume less (Suranovic, Goldfarb and

Leonard). Therefore, the adjustment cost function is discontinuous at the habitual consumption

level, such that:

$$K(n_{it}) = \begin{bmatrix} K(n_{it}) > 0, & n_{it} \in [0, n_i^h] \\ K(n_{it}) = 0, & n_{it} \in [n_i^h, \infty] \end{bmatrix}, \tag{3}$$

where n_i^h is the habitual consumption level of nutrient i and the adjustment cost function is

increasing and convex so that: $K_{n_i} > 0, K_{n_i n_i} > 0$ for all i. Subject to the wealth and commodity

production constraints, consumers choose nutrients to maximize utility according to the current-

value Hamiltonian:[4]

$$H = U(\boldsymbol{n}, \boldsymbol{N}) + \lambda(\boldsymbol{n} - \delta \boldsymbol{N}) + \mu(rW - C(\boldsymbol{p}, \boldsymbol{n})) - K(\boldsymbol{n}). \tag{4}$$

Applying the maximum principle to (4) yields first-order conditions for a dynamic optimum with

respect to nutrient content (in matrix notation):

$$H_{\boldsymbol{n}} = U_{\boldsymbol{n}} + \lambda - \mu C_{\boldsymbol{n}} - K_{\boldsymbol{n}} = 0, \tag{5}$$

so the full-price of nutrient i is given by:

$$\hat{\pi}_i = U_{n_i} = \mu C_{n_i} - \lambda_i + K_{n_i}, \tag{6}$$

where the ˆ notation differentiates the dynamic, or full price of each nutrient from its static

counterpart to be introduced below. Similarly, the necessary condition with respect to the

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[4] Utility is defined over nutrients and "nutrient capital" rather than more ephemeral concepts of "health" or "fitness" (Chaloupka; Becker and Murphy) because consumers obtain utility more directly from the characteristics of the foods they eat. Modeling commodities this way, however, does not rule out adding a prior stage in which health or fitness are produced from human capital and food inputs.

accumulated stock of each nutrient is:

$$\dot{\lambda} - r\lambda = -H_N = -[U_N + \lambda(n_N - \delta)], \tag{7}$$

where $\dot{\lambda} = \partial\lambda/\partial t$ is the derivative of the shadow value of nutrient capital with respect to time.[5]

Taking the derivative of (5) with respect to time, substituting the solution for $\dot{\lambda}$ from (6) and

solving for the optimal time-path of nutrient demand gives:

$$\dot{n} = -[U_{nn} - C_{nn} - K_{nn}]^{-1}[(U_{nN} - K_{nN})\dot{N} + (r - (n_N - \delta))\lambda - U_N], \tag{8}$$

where $\dot{N}$ is the vector of optimal time-paths for each stock of nutrient capital. Substituting the

solution for λ from (8) provides an expression for nutrient demand as a function of the marginal

cost of nutrients, the gross investment in nutrient capital and parameters of the utility, cost and

cost of adjustment functions:

$$\dot{n} = -[U_{nn} - C_{nn} - K_{nn}]^{-1}[(U_{nN} - K_{nN})\dot{N} + (r - (n_N - \delta))(\mu C_n - U_n + K_n) - U_N], \tag{9}$$

This solution provides several implications for nutrient demand that define and differentiate a

rational addiction from mere myopic, or habitual consumption.

Following Iannaccone, we simplify the interpretation of (9) by assuming for now that

nutrients are separable in demand.[6] Recall that the "reinforcement" effect of past consumption

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(U_{nN}) is non-negative because previous consumption raises the marginal utility of current consumption for addictive nutrients. Therefore, taking the derivative of (9) with respect to U_{nN}, and recognizing that the first, inverted term is non-negative by the assumed concavity of utility and convexity of adjustment costs, addictive consumption rises with the level of reinforcement. This is the source of adjacent or dynamic complementarity in Becker and Murphy in which a higher stock of consumption capital generates higher levels of future consumption. Second, reinforcement is supported by a form of tolerance in which higher levels of previous consumption mean that existing levels of consumption provide lower levels of utility, or: $U_N < 0$. Because this term enters (9) in a negative way, tolerance also leads to higher rates of consumption for addictive nutrients relative to non-addictive nutrients. Third, the shadow value consumption capital, λ, represents the current value of all future costs incurred by addictive behavior – all of the negative health implications that occur later in life. Therefore, because λ is negative, greater future costs cause current consumption to fall.

Fourth, marginal adjustment costs (K_n) are positive for all n_i below the long-run average. Therefore, if n_i is falling (a consumer is dieting or, in prior years, a Native population enters a period of relative scarcity), adjustment costs cause the rate of decline to slow, or even reverse direction if sufficiently strong. Adjustment costs have two additional effects as well. In the first term of (9), $K_{nn} > 0$ effectively reduces the convexity of U below n_i^h so the rate of n_i consumption is higher than would otherwise be the case. In the second term, K_{nN} reduces the reinforcement effect for consumption levels below n_i^h to the extent where, if n_i is falling and $K_{nN} > U_{nN}$, dieting stops and eating resumes once again. Thus, adjustment costs can effectively lock in an addicted

consumer such that the "happy addict" of Becker and Murphy is more likely the bundle of regret described by Orphanides and Zervos, wanting to quit, but unable due to the high cost involved.

Fifth, notice that higher rates of discount and depreciation, combined with negative λ for addictive nutrients, increase the current costs of future damage so lead to lower rates of current consumption. However, by expressing the current value multiplier in present value form:

$$\hat{\lambda}_t = e^{-(r+\delta)t}\lambda_t,$$ higher rates of discounting and depreciation reduce the full present value cost of

future health damage, so cause consumption of the addictive commodity to rise.

Although (9) accounts for all the characteristics of a rational addiction, it does not yet differentiate rational addiction from a genetic predisposition toward overeating certain nutrients, or the thrifty gene theory. Smith describes the "genetic hardwiring" associated with the thrifty gene in terms of a model of optimal genetic selection in which the survivors are those who are able to store enough energy (body fat) in times of plenty to sustain themselves during famines. Consistent with notion that addictions can be rational because they are driven by acquired human capital, *genetic traits* are also independent of consumer preferences because they impact the *expected* budget set. Thus, the thrifty gene hypothesis implies that, although famines may not occur in modern times, those with the thrifty gene are more likely to behave as if there is a positive probability of scarcity.[7] Formally, the possibility of seasonal scarcity is incorporated into the problem by defining two states of food availability, x^i where $i = (1, 2)$ and $i = 1$ indicates famine and $i = 2$ indicates plenty. Assuming the states are Bernoulli distributed and famine occurs with a probability ρ, and "normal" times with probability $(1 - \rho)$, the marginal cost of

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[7] It is important to emphasize that over-eating does not require conscious thought, nor is it learned behavior, but is rather an ingrained self-defense mechanism much like running from danger, or drinking when thirsty.

obtaining a fixed level of a particular nutrient i will be higher the less food is available:

$$C_{n_i}^1(p,n|x^1) > C_{n_i}^2(p,n|x^2), \tag{10}$$

where $x^1 < x^2$. Therefore, the full price of nutrient i to those with the thrifty gene is greater than the full price to those without to the extent that they are genetically conditioned to expect a positive probability of famine:

$$\begin{aligned}
\hat{\pi}_i^{TG} &= \mu_1 \rho \, C_{n_i}(p,n|x^1) + \mu_2(1-\rho)\,C_{n_i}(p,n|x^2) - \lambda_i + K_{n_i} > \\
&\qquad \mu_2 C_{n_i}(p,n|x^2) - \lambda_i + K_{n_i} = \hat{\pi}_i^{NTG},
\end{aligned} \tag{11}$$

where $\hat{\pi}^{TG}$ is the full-price of nutrient i for those with the thrifty gene, and $\hat{\pi}^{NTG}$ to those without.[8]

The implication of the thrifty gene for nutrient demand is now clear. Shortages of different foods occur at different times, so the effect of random famines is likely to be nutrient-specific. To the extent that traditional Native American societies defined scarcity in terms of the hunt, equation (11) implies that the Native protein shadow value is expected to be higher than the shadow value for non-Natives. In the absence of market prices, consumption of non-market commodities is driven by relative shadow values, so if the shadow values for fats and carbohydrates are relatively low, Native Americans are expected to substitute toward these nutrients and away from protein. Further, given that elasticity rises with a good's price, the

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[8] Modeling the thrifty gene effect in terms of a random budget set is not the only alternative. Some argue that the thrifty gene theory implies a more efficient conversion of calories into body mass. However, we do not have access to body mass data so cannot test this implication directly. Nonetheless, it is a simple matter to show that the theoretical implications are similar, namely that the shadow value of nutrients that are more efficiently converted to body mass will be higher in groups with the thrifty gene than in those without.

elasticity of demand for protein will be higher, *ceteris paribus*. More elastic demand, in turn, suggests that higher relative prices over time will reduce protein consumption in favor of fats and carbohydrates. Whether this is the case, however, is an empirical question.

Empirical Model of Native American Nutrient Consumption

Despite the fact that the rational addiction model has attracted a large volume of empirical interest in recent years, nutritional addiction presents a somewhat unique application. For this reason, replicating existing empirical methods is not appropriate to test among the potential explanations for nutrient overconsumption. First, these studies define utility directly over the addictive good, for which prices are readily available. In the case of food, however, utility is defined over nutrients and not individual foods (Silberberg). Therefore, we use a two-stage econometric approach based on the household production model of Stigler and Becker wherein shadow prices for addictive, non-market nutrients are imputed in the first stage for inclusion in a second-stage model of nutrient demand. Second, these studies consider univariate consumption problems in which a representative consumer is either addicted to a particular good or not. In the case of food, however, addiction is a relative concept when a group of nutrients are all necessary for survival and, to a certain extent, substitutable. Third, each of these models is based on an assumption of quadratic utility so that simple, linear demand functions follow directly from dynamic first order conditions. However, this assumption is unnecessarily restrictive. Although such an approach ensures that the demand model is consistent with a dynamic solution, it is not consistent with any other model of optimal consumer demand. Rather, this study uses a demand

system that is based on a more restrictive model of utility maximization, but one that can nonetheless be used to test the implications of a general dynamic optimization model. In this way, we show that it is possible to provide a much richer description of addictive behavior with a flexible demand system. Fourth, the presence of a thrifty gene impacts relative shadow prices and elasticity values and cannot be represented by specific arguments of the utility function. Finally, no existing empirical models of food addiction incorporate adjustment costs as an explanation for overweight individuals who are not satisfied with their condition – an implication of the rational addiction model that is logically hard to accept (Oriphanides and Zervos). Consequently, the empirical model developed here takes each of these considerations into account.

The household production approach is a well-understood way of describing the demand for non-market commodities (Becker; Stigler and Becker; Deaton and Muellbauer; Betancourt and Gautschi). From this perspective, households maximize their nutrition-utility through a two-stage process. Households first solve a cost-minimization problem by combining inputs (market goods, or foods) and consumption capital in order to produce non-market commodities (nutrients) at a minimum cost subject to a technology constraint. For the current problem, the set of non-market commodities consists of total grams of fat, protein, and carbohydrates sold by each store, while the food-inputs include total volumetric measures of dairy, bakery, meat, produce, beverages, and snack foods sold each week. By choosing a functional form for the dual cost function described above that is both flexible and amenable to multi-product cost minimization, we account for the interaction among potentially addictive products. Specifically, a Generalized Leontief (GL) functional form is flexible and includes multiple outputs in a parsimonious way.

In addition, the GL is also strictly increasing in p and n, decreasing in N, linearly homogeneous, concave in input prices and convex in output, as required by the restrictions implied by constrained optimization. A modified GL cost function representing the solution to the first stage of the household's problem is written as:

$$C(p,n,N) = A + p^{1/2^T} B p^{1/2} + p^T C n + p^T D N + n^T E n + N^T F N, \tag{12}$$

where A, B, C, D, E, and F are conformable parameter matrices. The cost function (12) is estimated with its implied input demand functions in order to both improve efficiency and impose cross-equation restrictions implied by demand theory. Therefore, if (12) satisfies the required curvature conditions (which are imposed in estimation), it is dual to the household production technology g, so applying Shephard's Lemma to (12) provides a system of input demand equations:

$$C_p(p,n,N) = x(p,n,N) = (1/2)p^{-1/2^T} B p^{1/2} + C n + D N, \tag{13}$$

for all food categories, i. Symmetry in prices, nutrients, and capital (N) is imposed prior to estimation. While tests of the primary hypotheses of the paper concern the second-stage nutrient demand model, food input elasticities are also of considerable interest because foods are purchased directly by consumers while nutrients are not. Based on the input demands in (13), a typical element of the matrix of own- and cross-price elasticities of demand is given by:

$$\epsilon_{ij} = -(1/2)\sum_j \left(\frac{B_{ij}}{x_i} \right) \left(\frac{p_j}{p_i} \right)^{1/2}, \tag{14}$$

for foods $i = 1, 2, ... 6$ and $k = 1, 2, ... 6$. While the first-stage procedure described to this point

characterizes the demand for each food-input, the focus of this study is on the demand for the

aggregate of each nutrient these foods embody.

In the second stage of (4) above, households choose nutrients to maximize utility subject

to a lifetime wealth constraint. Nutrients are assumed to be fixed outputs in (12), so

differentiating the optimal cost function with respect to commodity quantities provides a vector

of implicit prices for each consumption good (nutrient):

$$C_{n_i}(p,n,N) = \pi_i(p,n,N).$$
(15)

for all j non-market nutrients. Further, if the household production function has constant returns

to scale, then the cost function is linearly homogeneous. Deaton and Muellbauer show that the

minimum cost to produce the desired bundle of nutrients can be found using Euler's Theorem as

the sum of "shadow expenditures" on each non-market nutrient:

$$C(\pi(p,n,N),n,N) = \sum_i \pi_i(p,n,N)n_i,$$
(16)

where π_i is the static, or myopic cost of nutrients.

With nutrient prices and total expenditure calculated in (16), it remains to define

preferences in (4) such that the joint hypotheses of rational addiction, adjustment costs and thrifty

gene may be tested In analyzing the dynamics of the rational addiction model, Becker and

Murphy suggest that there are two ways to proceed: (1) linearize the first order conditions, or (2)

define a quadratic utility function such that the first order conditions are naturally linear.

Virtually all empirical applications of the rational addiction model adopt the second approach

(Chaloupka; Becker, Grossman and Murphy; Grossman and Chaloupka; Olekalns and Bardsley and others). For current purposes, specifying utility as quadratic is not practical, nor desirable, because of the multi-product nature of the utility maximization problem. In adopting a systems approach, however, it is necessary to ensure that the resulting demand model is consistent with two-stage intertemporal budgeting. If the habit formation process is myopic (Pollak) then preferences are intertemporally separable, so the entire process can be estimated using an Euler equation for allocation over time and a general demand system for the allocation of goods within each period (MacCurdy). However, if habits or addictions are formed rationally, then preferences are inherently non-separable. Spinnewyn shows that it is possible to specify a demand model in which consumers form habits rationally if the price of consumption goods is adjusted to include the future cost of habit formation to define the full-price of each nutrient as in (6).[9] Whereas Spinnewyn provides an example of this approach using an indirect addilog utility function, Pashardes shows that the same method can be used in a more general, flexible AIDS demand specification.

Pashardes' AIDS model is only dynamic, however, in the sense that it includes prices that reflect the full dynamic cost of habituated goods. Ray and Alessie and Kapteyn, on the other hand, develop AIDS models that are fully consistent with rational, or forward looking consumer behavior. In this paper, we use a dynamic AIDS model similar to Alessie and Kapteyn to model second-stage nutrient allocations, but substitute the first-stage intertemporal Euler equation of Becker and Murphy and Chaloupka in order to test for any addictive behavior, whether this

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[9] Implied restrictions on the demand system include: (1) constant real rates of time preference, (2) constant relative prices over time, and (3) no liquidity constraints (Alessie and Kapteyn). Each of these are reasonable given the short time frame of the data set used here.

behavior is rational or myopic, or whether it is dominated by a thrifty gene explanation.

Specifically, begin by writing the second-stage PIGLOG nutrient expenditure function as:

$$\ln e(\hat{u}, \hat{\pi}) = (1 - \hat{u}) \ln a(\hat{\pi}) + \hat{u} \ln b(\hat{\pi}), \qquad (17)$$

where:

$$\ln a(\hat{\pi}) = \alpha_0 + \sum_i \alpha_i^* \ln \hat{\pi}_i + 1/2 \sum_i \sum_j \gamma_{ij} \ln \hat{\pi}_i \ln \hat{\pi}_j, \qquad (18)$$

and:

$$\ln b(\hat{\pi}) = \ln a(\hat{\pi}) + \beta_0 \prod_i \hat{\pi}_i^{\beta_i}, \qquad (19)$$

and $\hat{\pi}$ is a vector of full-cost, or dynamic nutrient prices defined in (6) above.[10] Further,

consistent allocation at the second stage requires symmetry: $\gamma_{ij} = \gamma_{ji}$, homogeneity:

$\sum_j \gamma_{ij} = 0 \ \forall i$, and adding up: $\sum_i \alpha_i^* = 1, \ \sum_i \beta_i = 0, \ \sum_i \gamma_{ij} = 0 \ \forall j$. Substituting (18) and (19)

into (17) and applying Shephard's Lemma provides share equations for each nutrient:

$$\hat{w}_i(\hat{\pi}, \hat{m}) = \alpha_i^* + \sum_j \gamma_{ij} \ln \hat{\pi}_j + \beta_i (\ln \hat{m} - \ln \hat{P}), \qquad (20)$$

for all i nutrients, where $\hat{w}_i$ is the budget share of nutrient i, $\hat{m}$ is the total expenditure on all

nutrients and $\hat{P}$ is a Stone's price index defined as: $\ln P = \sum_i \hat{w}_i \ln \hat{\pi}_i$. In order to test whether

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nutrient demand among Natives and non-Natives are consistent with rational addiction and if consumption is subject to adjustment costs, we substitute a modification of Becker and Murphy's dynamic solution for α_i^* into (20), which allows the budget share for each nutrient to vary with lagged share, future share, the stock of accumulated nutrient demand and negative periodic deviations from mean budget share:

$$\alpha_i^* = \alpha_{i0} + \alpha_{i1}w_{i,t-1} + \alpha_{i2}w_{i,t+1} + \alpha_{i3}N_{i,t} + \alpha_{i4}\min[(w_{i,t} - \bar{w}_i), 0], \qquad \textbf{(22)}$$

for each nutrient. If the coefficient on lagged share is significantly different from zero, then current consumption depends on past consumption, which can be consistent with either habitual or myopic addictive behavior. If, however, the coefficient on future consumption and the current stock of nutrients are different from zero, then this uniquely identifies a rational addiction. If negative budget-share deviations have a significant effect on nutrient demand, then adjustment costs may also play a role in driving addictive behavior as well. Based on the argument expressed in equation (9), it is expected that this effect will be negative.

Unlike the test for rational addiction, there are no economic variables that can be used to test directly for the thrifty gene. Rather, as equation (11) indicates, we can infer the impact of genetic variation on shadow values and, hence, price elasticities and levels of consumption. If Native Americans do indeed possess a thrifty gene, then the shadow value of nutrients they perceive to be in short supply should be inflated. According to nutritionists who have studied Pima Indians in both Arizona and their native Mexico, the nutrient most commonly absent during scarce times is protein (Ravussin, *et al.*). Therefore, the thrifty gene implies relatively high

protein shadow values and substitution away from proteins toward foods rich in fat and

carbohydrates. Further, differentiating the linear-approximate AIDS price-elasticity expression

with respect to price shows that higher prices are associated with higher own-price elasticities of

demand, *ceteris paribus*.[11] Consequently, testing for the thrifty gene involves comparing both

shadow values and own price elasticities between Native and non-Native sub-samples. Casting

the model in a systems framework also allows for another explanation that calorie-based theories

of obesity cannot. While some substitution among nutrients is likely to occur, it is also expected

that some nutrients may also be complements, given that they all contribute to the body's

fundamental need for caloric energy. If the relative shadow value of fat and carbohydrates are

lower for Native Americans due to the thrifty gene, then increased consumption of one may in

fact reinforce higher consumption of the other. Moreover, given that technological progress has

reduced the relative price of food in general over time (Philipson and Posner; Lakdawalla and

Philipson) and processed foods rich in both fats and highly refined carbohydrates in particular,

then Natives will be more likely to consume more calorie-dense nutrients than is optimal for their

body type. No prior studies have been able to conduct such a comparison between genetically

distinct groups due to a lack of comparable food-purchase data.

Data Description

In contrast, the data used in this study provide a unique and highly detailed means of comparing

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[11] Chalfant shows that the appropriate price-elasticity for a linear-approximate AIDS model is:
$\epsilon_{ij} = -\delta_{ij} + (\gamma_{ij} - \beta_i w_j)/w_i,$ where δ_i is Kronecker's delta.

food consumption patterns between Native and non-Native Americans. Specifically, we use retail supermarket scanner data on food prices and purchase-volumes recorded over a thirteen-week period in 2001 for nine stores of the same chain (Basha's Supermarket) located on or near Native American reservations in Arizona (the Native subsample) and for nine stores located in other areas throughout the state (non-Native sub-sample). Basha's Supermarket holds a dominant market position in rural regions and is a major competitor in urban retail markets, and follows chain-wide pricing strategies so there is no scope for price-discrimination within the state. Further, non-Native stores are selected so that they demographic profile of the local market mirrors the Arizona population as a whole as closely as possible, providing a natural control group against which Native store sales can be compared.[12] Table 1 presents a listing of the stores and the demographic characteristics for the local market served by each store.

The scanner data consists of dollar sales and unit volume on a weekly basis for each major product category: dairy, bakery, snack foods, and beverages. Only total dollar sales are available for meats and produce. Unit value indices, a proxy for price, are calculated as the ratio of category sales to unit volumes for all product categories, except meat and produce. Because unit volumes reflect a simple number-count of items sold within the category as a whole, the implicit assumption is that the product-mix remains the same from week to week. Although violations of this assumption are likely to occur, individual product prices are not available. For meats and produce, unit volumes are calculated by dividing total sales by an estimate of the local

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[12] The non-Native stores were selected by solving an integer programming blending problem, where constraints were placed on the average demographic characteristics of the optimal sample, so that it would resemble the state averages.

market price. For meat, the estimate was taken from a monthly retail price from the Bureau of

Labor Statistics and converted to a weekly series using a cubic spline extrapolation method. For

fresh produce, total dollar values and unit volumes for all sample stores were obtained from

FreshLook Marketing of Chicago, Illinois and were used to calculate weekly unit prices for each

store.

Nutrient quantities were inferred from observed food purchases using nutrient tables and

food consumption data published with the USDA CSFII survey. Using the consumption share of

each food product as weight, average food nutrient profiles were constructed for each category.

With the nutrient content of each food category known, the weekly nutrient consumption in each

market area is computed as a Stones quantity index, where $n_j = \sum_k s_k \ln n_{jk}$ is the content of

nutrient j in food category k; s_k is the share of expenditures on food category k measured at each

store on a weekly basis.

Total weekly food expenditure is the dependent variable in the first-stage of the

econometric model. At this stage, the modified Generalized Leontief cost function is estimated

using non-linear three-stage least squares with symmetry, concavity in prices and fixed inputs,

and convexity in outputs (nutrients) imposed. Initial tests revealed significant autocorrelation, so

each equation was estimated using the Prais-Winsten autocorrelation correction procedure. In

the second stage, each dynamic linearized AIDS model was also estimated using non-linear

three-stage least squares with symmetry and homogeneity imposed. Instruments at this stage

consist of lead and lagged nutrient shadow values, lagged food input prices and quantities, lagged

expenditure and a time trend. All models were estimated using a fixed-store-effect approach to

control for unobserved store-based heterogeneity.

Results

Estimates of the two-stage nutrient demand system are used to test four primary hypotheses of this paper: (1) protein shadow values are expected to be relatively high among Native Americans relative to non-Native Americans, causing substitution away from proteins to fat- and carbohydrate based foods and higher price-elasticities of demand, (2) consumption of fats and carbohydrates can be addictive, (3) addictions are formed in a rational, or forward-looking way, and (4) adjustment costs explain the existence of food-addicts who regret their situation, despite its apparent rationality. If the first hypothesis is found to be true, then expectations of future protein price increases will cause a more dramatic shift away from proteins toward cheaper, and more harmful, fats and simple carbohydrates.

Before testing specific hypotheses regarding individual nutrient shadow values, it is first necessary to test whether members of each sub-sample differ in their consumption behavior. Because the data period and product selection are the same for all stores, each sub-sample is nested within a larger, combined sample. Therefore, comparisons between samples are made using likelihood ratio tests. With 70 restrictions, the critical chi-square value at a 5% level of significance is 90.531, while the estimated likelihood ratio value is 185.876. Consequently, we reject the null hypothesis that the Native and non-Native samples share the same cost function and estimate nutrient shadow values and food elasticities with separate cost function models. For each sub-sample, table 2 provides the shadow values for each nutrient and nutrient stock as well

as the input demand elasticity for each food category.

The thrifty gene theory suggests that the full-price of nutrients deemed essential for long-term survival will be higher for those possessed of the gene than for those who are not. Diamond provides a convincing recent explanation as to why individuals of European origin are not likely to be affected by the thrifty gene, whereas Native Americans are. Based on the results in table 2, our estimates provide some empirical support for the economic implications of the thrifty gene theory. Indeed, protein, the nutrient nutritionists cite as the primary component of a traditional Native American diet, has a relative shadow value many times greater than among non-Native Americans. Specifically, while the ratio of the protein and fat shadow prices in the Native sample is 1.57, the same ratio among non-Natives is 0.38. A similar relationship holds among the protein and carbohydrate shadow prices. Because shadow prices drive behavior for non-market commodities, Native Americans have an incentive to reduce protein consumption in favor of fats and simple carbohydrates. Essentially, if Native Americans are genetically conditioned to expect a shortage of a key nutrient in their diet, then their implicit valuation will reflect a higher scarcity value than non-Native Americans ascribe to the same nutrient. This point is underscored by the positive value of accumulated protein consumption stocks for Native Americans. While all other stocks have negative shadow values, which is a necessary condition for a nutrient to be deemed "harmful" or in overconsumption (Becker and Murphy), a positive value of λ_i reflects an expectation of positive utility throughout the planning horizon, or that the addiction, if it exists, is a "beneficial" one.

[table 2 in here]

Although diet-related health problems are tied to the overconsumption of particular

nutrients (Wright, *et al.*), the demand for different types of food is important as food is, of course, the primary medium for nutrient delivery. As such, any policy designed to modify nutrient intake would have to be implemented through food. In this regard, the results in table 2 provide some important insights into differences in the structure of demand between the Native and non-Native samples. Specifically, the elasticity of demand for fresh produce among Natives is far below that of non-Natives. Therefore, as fruit and vegetable prices decline over time, Native American demand will rise less than for other groups. Similarly, the higher demand elasticities for beverages and snacks suggest that lower prices for these products will induce a large consumption response. This result is consistent with observed dietary patterns among many Native American communities. Further, given recent upward trends in meat prices, the relatively high meat demand elasticity can explain some of the shift in consumption away from meats to lower-priced foods. Nonetheless, a more direct analysis of the underlying cause of nutrient imbalance requires an examination of the ultimate demand for specific macronutrients.

Cawley finds that consumers can form a rational addiction for calories. Whether the same is true for individual nutrients is an empirical question. In table 3, the LAIDS demand parameter estimates show that, although non-Natives exhibit no evidence of an addiction to either protein or carbohydrates, there is some evidence of a forward-looking, or rational addiction to fat.[13] Nor do adjustment costs appear to influence non-Native consumption of either protein or carbohydrates. If fat consumption falls below trend, however, there is a strong tendency for adjustment costs to force non-Natives to return to average levels. Natives, on the other hand,

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[13] Although the coefficient on future share is negative, the effect of current stocks is positive and significant, as would be expected if non-Natives are rationally addicted to fats.

appear to exhibit habitual behavior with respect to all nutrients (at a 10% level of significance) but accumulated consumption is only significant for protein and, at a 10% level, carbohydrates. Because none of the future-consumption parameters are significantly different from zero, these results provide little evidence for a rational addiction to any nutrient. Adjustment costs, however, appear to be particularly strong for Native Americans. For each nutrient, negative deviation from trend exhibits the greatest statistical impact on current consumption, suggesting that breaking existing habits will be particularly costly and, therefore, less likely. Once differences in habit are accounted for, the thrifty gene theory suggests that differences in consumption patterns may also be due to differences in shadow values and elasticities.

[table 3 in here]

Indeed, elasticity estimates derived from the nutrient AIDS model shown in tables 3 and 4 provide some support for the thrifty gene hypothesis. Namely, if protein shadow prices are high among Native Americans, then we would expect to see the relatively high protein-demand elasticities reported in table 4. Highly elastic demand, in turn, implies larger reductions in consumption over time as high protein foods become relatively more expensive than processed foods that are high in simple sugars, fats and low in dietary fiber. Furthermore, given that the results in table 4 show protein and carbohydrates to be relatively strong substitutes among Native Americans, rising protein shadow prices are likely to cause a reallocation toward carbohydrates from proteins. In addition, the relatively high-price elasticity of demand for carbohydrates among Native Americans means that a lower shadow price will cause a larger increase in consumption than among non-Natives. These results are all consistent with survey data reported by Teufel and Dufour and Vaughan who find relatively high carbohydrate consumption levels

among different tribes of Native Americans living in the U.S. Southwest. Further, some suggest that income differences may explain some of the "obesity gap" among groups within the same society (Chou, et al.). In this case, non-Natives are more likely to consume increasing amounts of protein and fat as incomes rise, while Natives consume more protein and carbohydrates. For both groups, however, finding protein to be a "luxury" and carbohydrate a "staple" suggests that rising incomes should contribute to both groups consuming a more protein-intensive diet and less fat and carbohydrates as a proportion of total calories.

[table 4 in here]

The implications of these results for the nutrition and health care communities are clear. First, to the extent that rising consumption of fats among non-Native Americans can be described as a rational addiction, then policies that impact consumers' expectations of future nutrient prices, and costs of their addiction, will be more effective than information or behavioral intervention. Second, the same policies will likely not be as effective among Native Americans. Rather, if overconsumption of harmful nutrients is myopically-habitual and genetic in origin, then Native consumers fail to internalize future costs as the rational addiction model suggests. As a result, the appropriate policy may be to address current behavior through an intervention that addresses differences between *current* market prices and implicit valuations of each nutrient. Further, given the importance of adjustment costs in contributing to habituated consumption of all nutrients, reducing the cost of "withdrawl" by providing healthy alternatives may also play a critical role.

Conclusions

This study examines whether or not the alarming incidence of obesity and type 2 diabetes among Native American societies is of economic origin. Relative to non-Native communities, survey evidence finds that Natives tend to consume a disproportionate amount of both total calories, and the proportion of calories from fat and carbohydrates – both calorie-dense relative to protein – despite well-understood, long-term negative health implications. Becker and Murphy claim that such apparently addictive behavior can be the result of a rational decision making process wherein the addict values current consumption more than the cost of future health implications. Including the fact that that deviating from habitual consumption patterns imposes a significant adjustment cost, nutrient addictions can be justified on economic grounds alone. Nutritionists and anthropologists, on the other hand, suggest that such behavior may be due to a "thrifty gene" whereby Native Americans are genetically predisposed to place a higher implicit demand on nutrients that were once necessary for survival, but often found to be in short supply. This paper tests among these explanations for observed Native American dietary patterns.

Empirical tests of these hypotheses are possible due to a unique, highly detailed panel data set that describes comparable Native and non-Native food purchases from a single supermarket grocery chain. With nine stores serving predominantly Native customers (approx. 95%) and nine with a representative non-Native sample, comparisons between each sample reveal stark differences in food purchases and, hence, nutrient valuations. Econometric tests using these data are developed within a dynamic household production framework in which the shadow value of each nutrient – protein, fat and carbohydrate – is estimated using a first-stage, dual cost function and the structure of nutrient demand is then estimated using a second-stage dynamic AIDS specification. Contrary to most previous research on potentially addictive

products, this study finds little support for the rational addiction model in either the Native or non-Native samples. Nutrient demand among Native Americans, however, is consistently habitual, driven largely by dietary "adjustment costs," or withdrawl symptoms in non-economic terms. Perhaps more importantly, however, comparisons of nutrient shadow values between Native and non-Native samples show that the full-price, or dynamic shadow value, of protein is far greater among Natives than among non-Natives. Consequently, Natives have an incentive to substitute away from protein toward more calorie-dense, and potentially harmful, carbohydrates. Combining all potential explanations in the same demand model, therefore, this study finds considerable support for the thrifty gene theory rather than the rational addiction model as an explanation for Native American obesity.

Typically, studies that find support for a rational addiction to cigarettes, alcohol or caffeine suggest that policies designed to increase addicted consumers' expectations of future prices will be particularly effective in changing current behavior. However, if nutrient-addiction is instead myopically addictive and driven largely by adjustment costs, then current prices and consumption behavior become more important in changing future patterns of consumption. Moreover, if over-consumption is indeed genetic in origin, then price-based interventions will be less effective, unless targeted to the upward bias in implicit prices for more healthy nutrients.

Although this study provides important insights into the structure of Native American nutrient demand and its likely causes, a more definitive analysis of the problem would benefit from data on health outcomes – either instances of diabetes, or variation in body mass over time or among individuals. Further, because the data used in this study cannot be used to generate reliable per capita consumption figures, we are unable to analyze the demand for per capita

calories as well as the allocation of calories among macro-nutrients. Controlling for both in a consistent, two-level demand framework would provide better information on the factors that drive overall caloric intake as well as its composition among nutrients.

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Table 1. Summary of Native and non-Native Store Location Demographic Characteristics.

Sample/ Store	Location	Tribe	Native American	White	Black	Hispanic	Median Household Income	Household Size	Households with Children	Average Age HH Head
			.... *Percent of Population*				*$*	*No.*	*%*	*Years*
Native American Store Locations										
1	Peridot, AZ	Apache	94.1	2.7	0.0	2.4	30,250	4.3	47.2	23.9
2	Sells, AZ	Tohono O'odham	96.6	2.3	0.1	2.8	18,048	3.7	38.2	25.3
3	Whiteriver, AZ	Apache	95.0	3.5	0.1	1.7	19,807	4.1	54.8	21.7
4	Kayenta, AZ	Navajo	94.5	4.3	0.1	1.0	22,911	3.8	51.1	23.2
5	Tuba City, AZ	San Juan Southern Paiute (Navajo)	93.2	4.6	0.1	2.1	36,192	3.9	49.5	24.0
6	Chinle, AZ	Navajo	95.1	3.5	0.1	1.3	21,201	3.8	49.2	22.4
7	Pinon, AZ	Navajo	97.3	2.4	0.0	0.8	13,797	4.0	50.3	22.0
8	Window Rock, AZ	Navajo	93.6	4.5	0.2	1.7	37,206	3.5	49.8	26.3
9	Crownpoint, NM	Navajo	94.6	4.2	0.2	0.9	21,276	3.6	48.9	24.2
	Sub-sample Average		94.9	3.5	0.1	1.7	24,521	3.9	48.8	23.7
Non-Native American Store Locations										
10	Gilbert, AZ	*N/A*	0.5	88.0	1.9	11.0	63,735	3.1	50.2	30.5
11	Mesa, AZ	*N/A*	1.4	76.1	2.4	30.0	41,137	3.0	40.7	28.1
12	Phoenix, AZ	*N/A*	3.8	76.2	5.0	25.0	36,150	2.2	22.3	36.0
13	Phoenix, AZ	*N/A*	5.3	69.3	4.6	30.2	32,234	2.2	23.2	33.0
14	Phoenix, AZ	*N/A*	3.4	74.3	3.8	29.2	37,031	2.2	21.4	35.1
15	Phoenix, AZ	*N/A*	1.7	82.1	3.3	18.7	40,105	2.6	31.9	32.1
16	Phoenix, AZ	*N/A*	1.4	76.1	2.4	30.0	41,137	3.0	40.7	28.1
17	Scottdale, AZ	*N/A*	1.9	86.3	1.7	14.2	40,686	2.2	20.6	38.6
18	Tucson, AZ	*N/A*	3.4	70.1	3.5	32.4	23,047	2.3	25.9	32.6
	Sub-sample Average		2.5	77.6	3.2	24.5	39,474	2.5	30.8	32.7
	State Average		5.0	75.5	3.1	25.3	40,558	2.6	32.2	34.2

Source: U.S. Census, 2000 U.S. Census, ZIP code areas.

Table 2. Food Demand Elasticities and Shadow Values: Native and non-Native Americans, Generalized Leontief Cost Function Estimates

	Non-Native Sample		Native Sample	
	Estimate	**t-ratio**	**Estimate**	**t-ratio**
	Own-Price Elasticities			
ϵ^P	-0.361*	-19.213	-0.212*	-8.977
ϵ^M	-0.125*	-8.944	-0.235*	-7.461
ϵ^B	-0.576*	-8.541	-0.264*	-5.181
ϵ^V	-0.314*	-18.828	-0.745*	-19.820
ϵ^D	-0.144*	-7.496	-0.182*	-6.801
ϵ^S	-0.231*	-4.482	-0.356*	-7.089
	Nutrient-Stock Shadow Values			
$\hat{\lambda}_P$	-34.178*	-5.449	70.773*	6.967
$\hat{\lambda}_F$	-28.612*	-5.056	-68.882*	-7.922
$\hat{\lambda}_C$	-7.886*	-5.334	-5.248*	-4.314
	Nutrient-Consumption Shadow Values			
π_P	80.384*	3.542	1,325.932*	17.579
π_F	278.101*	17.950	732.174*	9.909
π_C	327.376*	10.238	700.582*	18.848

[1] In this table, ϵ^i is the price elasticity of demand for market-good i, where P = fresh produce, M = meat, B = bread, D = dairy products, V = beverages, and S = snacks. $\hat{\lambda}_j$ is the present-value stock-shadow value for non-market nutrient j, where P = protein, F = fat and C = carbohydrate. π_j is the consumption shadow value for non-market nutrient j, where P = protein, F = fat and C = carbohydrate. A single asterisk indicates significance at a 5% level.

Table 3. LAIDS Demand Parameter Estimates: Non-Native and Native Samples

	Protein		Fat		Carbohydrate	
	Non-Native Sample					
	Estimate[a]	**t-ratio**	**Estimate**	**t-ratio**	**Estimate**	**t-ratio**
α_0	-0.586*	-5.308	-1.105*	-7.848	3.422*	29.700
w_{t-1}	-0.031	-0.785	0.032	1.574	-0.002	-0.080
w_{t+1}	0.077	1.496	-0.039	-1.391	0.008	0.210
Δw_t	0.094	0.675	-0.620*	-6.994	-0.090	-0.646
$\ln(N)$	-0.001	-0.189	0.006*	3.051	-0.013*	-2.956
$\ln(\hat{\pi}_P)$	0.088*	9.010	-0.057*	-6.549	-0.006	-0.314
$\ln(\hat{\pi}_F)$	-0.057*	-6.549	0.150*	10.790	-0.093*	-5.456
$\ln(\hat{\pi}_C)$	-0.006	-0.314	-0.093*	-5.456	0.100*	3.213
$\ln(\hat{m}/\hat{P})$	0.122*	9.823	0.251*	9.299	-0.529*	-20.230
R^2	0.957		0.976		0.946	
D.W.	2.279		2.051		2.269	
	Native Sample					
	Estimate	**t-ratio**	**Estimate**	**t-ratio**	**Estimate**	**t-ratio**
α_0	-0.032	-0.125	0.779*	2.205	1.331*	3.764
w_{t-1}	0.176*	2.929	0.116	1.729	0.115	1.750
w_{t+1}	0.001	0.020	-0.085	-1.680	0.005	0.068
Δw_t	-1.647*	-7.116	-1.443*	-4.758	-1.858*	-11.180
$\ln(N)$	0.005*	2.597	0.001	0.329	0.005	1.650
$\ln(\hat{\pi}_P)$	-0.026	-0.436	-0.042*	-3.280	0.068	1.118
$\ln(\hat{\pi}_F)$	-0.042*	-3.280	0.095*	7.867	-0.053*	-4.153
$\ln(\hat{\pi}_C)$	0.068	1.118	-0.053*	-4.153	-0.015	-0.236
$\ln(\hat{m}/\hat{P})$	0.084	1.676	-0.119	-1.705	-0.178*	-2.359
R^2	0.688		0.903		0.729	
D.W.	2.081		2.053		2.067	

[a] A single asterisk indicates significance at a 5% level. In this table, α_0 is a constant term, w_{t-1} is the share of each nutrient lagged one period, w_{t+1} is the share of each nutrient lead one period, Δw_t is the deviation in expenditure share from the sample mean, N is the stock of past consumption of each nutrient, p_i is the shadow price of nutrient i, $i = P, F, C$. X is the total expenditure on all nutrients and P is a Stone's price index defined over all nutrients. Store-specific dummy variable estimates are excluded for brevity.

Table 4. Nutrient Demand Elasticity Estimates: Non-Native and Native Samples

Nutrient Quantities	Nutrient Shadow Values		
	Protein	**Fat**	**Carbohydrate**
	Non-Native Sample		
Protein[a]	-0.144 (-1.294)	-0.376* (-8.777)	0.006* (2.093)
Fat	-0.922* (-9.321)	-0.539* (-8.098)	0.003 (1.163)
Carbohydrate	-1.019* (-4.386)	-1.269* (-9.881)	-0.328* (-5.306)
Expenditure	2.356* (17.063)	2.185* (17.149)	0.243* (6.503)
	Native Sample		
Protein	-1.165* (-5.778)	-0.026 (-0.156)	0.243 (1.805)
Fat	-0.178* (-3.299)	-0.321* (-4.403)	-0.044 (-1.333)
Carbohydrate	0.078 (0.403)	0.048 (0.203)	-0.851* (-6.210)
Expenditure	1.266* (7.981)	0.299 (0.728)	0.652* (4.425)

[a] A single asterisk indicates significance at a 5% level. All elasticities are defined as Marshallian elasticities, evaluated at the sample means of each variable.