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Modelling Economic Policy Issues

Food demand and intertemporal allocation of food expenditure

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ABSTRACT

Existing studies on food consumption often ignore nonfood and fail to account for intertemporal allocation of food expenditure, which leads to a biased inference in food consumption analysis. To address this issue, the present paper proposes an integrated analysis of food demand and intertemporal food consumption via intertemporal two-stage budgeting with nonfood. A restricted indirect utility function is specified conditional on food expenditure with given nonfood, and unrestricted demand functions are derived for food and nonfood by endogenizing their expenditures with income. From intertemporal optimization with the restricted indirect utility function, Euler equations are derived for food expenditure and nonfood, and jointly estimated, using annual time series U.S. data for 1959–2019, with demand functions with nine food items and aggregate nonfood. Then restricted and unrestricted demand elasticities are estimated for food and nonfood, and various intertemporal issues are analyzed. Overall, this study provides novel and useful results relative to previous studies, and underscores the importance of an integrated analysis of food consumption.

1. Introduction

The literature on food consumption abounds with empirical studies undertaken to estimate the demand for food in order to obtain the price and income elasticities of food items[1] that are important summary measures characterizing the consumer's food consumption behavior.[2] Although these studies have greatly enhanced our understanding of food consumption behavior, there are some inherent shortcomings underlying them. They are usually conducted with no allowance for nonfood.[3] This can be justified under the assumption that food items are *weakly separable* from nonfood, which may not be an adequate portrayal of consumer behavior. These studies are essentially static in nature and do not contribute to an understanding of relevant intertemporal issues in food consumption. More importantly, they are typically concerned with optimal allocation of the consumer's given food expenditure to different food items

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[1] A good textbook discussion and an overview of demand theory with elasticities, as applied to food demand, is provided in Deaton and Muellbauer (1980a).

[2] For a survey of the theoretical literature and empirical evidence on food demand in the U.S. see Okrent and Alston, 2011, and for international evidence, see Molina, 1994, Muhammad et al., 2011, Gao, 2012, and Femenia, 2019. For recent studies on food demand, see also Angelucci et al., 2013, Zhen et al., 2014, Ulubasoglu et al., 2015, Hovhannisyan and Bozic, 2017, and Lusk, 2017.

[3] There are early studies estimating consumer demand with aggregate food and nonfood goods (see Deaton and Muellbauer, 1980b; Blundell et al., 1994). Our concern in this paper is about food demand at the disaggregate levels.

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within periods; thus food demand functions are estimated conditional on food expenditure, which is usually treated as exogenously given and left unexplained. However, to the extent that the consumer chooses food expenditure to optimally allocate wealth *across periods*, food expenditure is not exogenously given but is endogenously determined in the consumer's intertemporal optimization problem.

These issues – nonseparability of food items from nonfood, endogeneity of food expenditure, and static nature of food demand – have not received due attention in existing food consumption studies, and the failure to address them likely leads to a biased inference in food consumption analysis. It is the purpose of this study to do so to improve our understanding of the consumer's food consumption behavior with more realism. To that end, we depart from the conventional approach to food consumption analysis, and propose an integrated analysis of food demand and intertemporal food expenditure by utilizing the idea of intertemporal two-stage budgeting (Kim and McLaren, 2024) with allowance for nonfood. Intertemporal two-stage budgeting is distinctly different from more familiar, static two-stage budgeting. Intertemporal two-stage budgeting is concerned with the intertemporal (*across period*) and intratemporal (*within period*) allocations of consumption expenditure. Traditional two-stage budgeting, on the other hand, involves the *intergroup* and *intragroup* allocations of consumption expenditure *within periods*, and forms the underlying framework for studies on conditional food demands based on separability (see the papers referenced in Footnote #1.

Although intertemporal two-stage budgeting is found useful with some applications (Blundell et al., 1994; Kim et al., 2021), its operational importance has not been realized in empirical studies on food consumption. The *intratemporal* allocation of food expenditure underlies static food demand studies, while the *intertemporal* allocation of food expenditure forms the basis for intertemporal food consumption analysis, typically a macro topic of interest. Conventional studies on food consumption focus on the intratemporal allocation and fail to account for the intertemporal allocation of food expenditure. The two allocation decisions, though seemingly disjoint, are inexplicably linked together in the consumer's optimization problem (see Section 2 for a detailed discussion), and it is only when we integrate the two strands of studies on food demand and intertemporal food consumption, we can have a proper understanding of consumer behavior about food consumption. Pope (2009) clearly recognized such a need in his review on food consumption. Yet, no attempt has been made to do so in existing studies on food consumption.[4]

In this paper, we formulate and estimate an integrated model of food demand and intertemporal food expenditure via intertemporal two-stage budgeting with allowance for nonfood. We extend existing studies on intertemporal two-stage budgeting by incorporating novel features into food consumption analysis, and make three main contributions to the theoretical and empirical literature on food consumption. First of all, we improve on the traditional, static study of food demand by embedding it within an intertemporal optimization framework, with food expenditure determined endogenously together with nonfood. We relax the separability assumption of food items from nonfood by specifying consumer preferences with a *restricted* indirect utility function[5] – an indirect utility function conditional on food expenditure *with a given level of nonfood*, and derive *restricted* demand elasticities for food conditional on food expenditure *with given nonfood*. From intertemporal optimization with food expenditure and nonfood, we then derive a demand function for nonfood, which yields *unrestricted* demand elasticities for food and nonfood conditional on food expenditure *with a given nonfood price*. To allow for endogeneity of food expenditure in these elasticities, which is a key concern in food demand studies, we relate food expenditure to total – food and nonfood – expenditure and derive unrestricted demand elasticities for food and nonfood conditional on *total expenditure* with a given nonfood price. For policy analysis, unrestricted demand elasticities conditional on total expenditure are more relevant than the elasticities conditional on food expenditure.

The second contribution is to provide a full analytical framework to examine the consumer's intertemporal food consumption behavior with allowance for nonfood. There are some studies analyzing the intertemporal behavior of consumption using food expenditure as a proxy measure for total consumption with PSID data, based on Hall's (1977) celebrated life cycle framework (Zeldes, 1989; Runkle, 1991; Naik and Moore,1996). Notwithstanding, these studies tacitly assume that food is additively separable from nonfood with a restrictive utility function, and fail to take account of the interplay between the intratemporal and intertemporal allocation decisions of food expenditure.[6] We build on these studies and provide the microfoundational underpinnings to intertemporal analysis of food consumption by allowing for nonfood. From intertemporal optimization with the restricted indirect utility function, we derive a system of simultaneous log-linearized Euler equations for food consumption and nonfood growth, which describe the intertemporal allocations of these goods. This allows us to examine various intertemporal issues relevant to food and nonfood consumption such as time preference, risk aversion, intertemporal substitution, and precautionary behavior for food consumption. An issue of importance concerns whether falling growth rates of food consumption during recessions are due to a fall in disposable income, or they reflect uncertainty about the future (Pope, 2009). This issue cannot be examined in a food demand study, but our analysis provides a relevant framework to address it with evidence.

Our last contribution in this paper is an empirical analysis of the proposed integrated model of food consumption behavior, with

[4] In previous studies on consumption, food expenditure is often used as a measure of total consumption using PSID data (see Zeldes, 1989; Runkle, 1991). Attanasio and Weber (1995) provided a limited analysis of intertemporal two-stage budgeting using food expenditure and showed that this practice leads to biased results. Their analysis is highly aggregated with one aggregate food item and other aggregate nondurable good, and is limited to examine many issues in food demand and consumption.

[5] A detailed discussion of separability as related to the traditional food demand studies is provided in Sections 2.1 and 2.3 by addressing endogeneity of group expenditure.

[6] There are studies analyzing the intertemporal consumption behavior of farm households using aggregate consumption (Langemeter and Patrick, 1993; Phimister, 1995; Abdulkadri and Langemeier, 2000). They, however, are based on restrictive, homothetic preferences and do not account for food consumption behavior. See Sub-Sections 2.2, 2.4, and 2.5 for further discussions.

annual time series U.S. data on nine aggregate food items with an aggregate nonfood good. We employ a flexible specification of the restricted indirect utility function that places minimal restrictions on consumer preferences with respect to separability between food and nonfood. We jointly estimate the system of food and nonfood budget share equations together with the Euler equations for food consumption and nonfood. Then we present new evidence on food demand and intertemporal food expenditure relative to previous studies. An important finding is that increasing uncertainty causes consumers to reduce or defer current food consumption (of nonessential items) and other spending accompanied by an increase in (precautionary) savings, especially in times of economic weakness, as is observed during the recent coronavirus pandemic (Smith, 2020).

2. An integrated model of food consumption behavior: theory

We consider a (representative) consumer who faces an optimal consumption problem of food and nonfood goods over time. In particular, let $\mathbf{x}_s$ be an N vector of food quantities at period *s,* whose elements are $x_{is}, i = 1,...,N,$ and z_s an aggregate quantity of nonfood at period *s*. (Nonfood is treated as an aggregate or a scalar for simplicity, but it could be a vector without seriously affecting the analysis.) Given a direct utility function, $u(\mathbf{x}_s, z_s)$, which is continuous, increasing, and quasi-concave in $\mathbf{x}_s$ and z_s, the consumer's optimization problem is to choose $\mathbf{x}_s$ and $z_s, t \leq s < t + T$, so as to maximize

$$E_t\left[\sum_{s=t}^{t+T} (1+\rho)^{-(s-t)} u(\mathbf{x}_t, z_t)\right], \tag{1}$$

where E_t is the expectation operator taken over future variables conditional on information available at time *t,* and ρ is the constant rate of the consumer's time preference, subject to the intertemporal finance or budget constraint:

$$A_s = (1 + r_{s-1})A_{s-1} + Y_s - \mathbf{p}_t' \mathbf{x}_t - p_t^z z_t \text{for all} s \geq t, \tag{2}$$

where A_s is the value of financial assets at the end of period *s* to be carried into the next period, r_s is the nominal interest rate on assets that can be both bought and sold between periods *s* and $s + 1$, Y_s is labor income at period *s,*[7] $\mathbf{p}_s$ is an N vector of food prices at period *s*, whose elements are $p_{is}, i = 1, ..., N,$ and p_s^z is the aggregate price of nonfood at period *s.*

Solving the above dynamic optimization problem is, in general, a challenging task in a stochastic environment unless a simple utility function is used (see Miron, 1986, in a different context). There are $(N + 1)$ goods to solve for over time under uncertainty, which is not feasible with a general specification of consumer preferences. To circumvent this problem, we utilize intertemporal two-stage budgeting (Kim and McLaren, 2024). In this budgeting procedure, the levels of food expenditure and nonfood are chosen in the first stage, by optimally allocating wealth across periods. Then, in the second stage, each period's optimal allocation of food expenditure is distributed across food items conditioned on the level of nonfood. The two allocation problems are intimately linked together in the consumer's optimization behavior. Nevertheless, the first stage allocation problem is typically ignored in existing studies on food consumption, with no regard to the joint link between the two allocation problems. To facilitate the discussion, we assume for now that capital markets are perfect so that the consumer can freely borrow and lend against future earnings at a given interest rate to finance consumption or accumulate assets. (We will relax this assumption and allow for liquidity constraints in the empirical analysis.) The solution to the above budgeting procedure can be found by reversing the order of the two stages: first, solve the second stage problem and then the first stage problem.

2.1. Restricted indirect utility and food demand functions

Given the direct utility function, $u(\mathbf{x}_t, z_t)$, the consumer's second stage optimization problem is summarized by the "restricted" indirect utility function, $\nu(C_t, \ \mathbf{p}_t, z_t)$, defined as

$$\nu(C_t, \ \mathbf{p}_t, z_t) \equiv \max_{\mathbf{x}_t}\left\{u(\mathbf{x}_t, z_t) \middle| \mathbf{p}_t' \mathbf{x}_t \leq C_t\right\}, \tag{3}$$

where C_t is the level of food expenditure to be allocated among different food items at period *t.* The above restricted indirect utility function is conditional on food expenditure *with a given quantity of nonfood*. For this indirect utility function to be well defined as a description of the consumer's within-period preferences, it needs the following regularity conditions (see Deaton and Muellbauer, 1980a for a basic discussion): it is continuous, increasing in C_t and z_t, decreasing in $\mathbf{p}_t$, homogeneous of degree zero in (C_t, $\mathbf{p}_t$), and quasi-convex in $\mathbf{p}_t$. Application of Roy's Identity to Eq. (3) yields the system of "restricted" food demand functions:

$$x_{it} = g_i^{RC}(C_t, \ \mathbf{p}_t, z_t) \equiv -\frac{\partial \nu(C_t, \ \mathbf{p}_t, z_t)/\partial p_{it}}{\partial \nu(C_t, \ \mathbf{p}_t, z_t)/\partial C_t}, \ i = 1, ..., N, \tag{4}$$

where $g_i^{RC}(C_t, \ \mathbf{p}_t, z_t)$ is the ordinary or Marshallian demand function for the *i*th ($i = 1, \ldots$, N) food item conditional on food expenditure C_t *for given nonfood* z_t.

The indirect utility function derived in (3) is specified in a general form and imposes no a priori restrictions on the underlying

[7] We consider leisure or labor supply as fixed and treat labor income as exogenous to the consumer's choice.

structure of the consumer's within-period preferences. Studies on food demand typically assume that food items are separable from nonfood (see the papers referenced in Footnote #1. Formally, the direct utility function $u(\mathbf{x}_t, z_t)$ is *weakly separable* in food items from nonfood if there exist a "subutility" function $\widetilde{u}(\mathbf{x}_t)$ and a "macro" function $\overline{u}(\widetilde{u}_t, k_t)$, which is strictly increasing in $\widetilde{u}_t$, such that $u(\mathbf{x}_t, z_t) \equiv \overline{u}(\widetilde{u}(\mathbf{x}_t), z_t)$ (see Varian, 1983). The required condition is that the marginal rate of substitution between any two food *items* is independent of nonfood. This implies that nonfood does not enter the consumer's choice problem involving food, and allows us to derive an indirect utility function for food defined by $\widetilde{\nu}(C_t,\ \mathbf{p}_t) \equiv max_{\mathbf{x}_t}\left[\widetilde{u}(\mathbf{x}_t)|\mathbf{p}_t'\mathbf{x}_t \le C_t\right]$, giving the typical food demand functions independent of nonfood, i.e., $x_{it} = \widetilde{g}_i(C_t, \mathbf{p}_t), i = 1,\ldots,$ N. Then, under weak separability, we have the following result for the indirect utility function (3):

$$\begin{aligned}\nu(C_t,\ \mathbf{p}_t, z_t) &= \max_{\mathbf{q}_t}\left\{\overline{u}[\widetilde{u}(\mathbf{x}_t), z_t]\,\middle|\,\mathbf{p}_t'\mathbf{x}_t \le C_t\right\}\\ &= \overline{u}\left\{\max_{\mathbf{q}_t}\left[\widetilde{u}(\mathbf{x}_t)\,\middle|\,\mathbf{p}_t'\mathbf{x}_t \le C_t\right], z_t\right\}\\ &= \nu[\widetilde{\nu}(C_t,\ \mathbf{p}_t), z_t]\end{aligned} \tag{5}$$

Weak separability is, therefore, a special case of the restricted indirect utility function in which the marginal rate of substitution between any two food *prices* is independent of nonfood. In the empirical analysis, we specify a flexible restricted indirect utility function that places no a priori restrictions on consumer preferences (see Sub-Section 3.1), and investigate the relevance of the separability restriction often imposed in previous studies on food demand (see Sub-Section 5.1).

Although weak separability is discussed in the context of food and nonfood, it is also the condition required for the existence of *conditional* (second stage) food demands defined for some group of food items of interest (such as meats) as functions of this group of prices and total expenditure on these food items (group expenditure, for short), in the traditional two-stage food demand studies (see, e.g., LaFrance and Hanemann, 1989; LaFrance, 1991; Edgerton,1997). As will be discussed later in Sub-Section 2.3, however, estimation of conditional food demands alone, with no regard to other food items and nonfood, engenders difficulties.

2.2. Intertemporal optimization and Euler equations for food and nonfood consumption

The above second stage optimization problem is derived under the assumption that the consumer takes, as given, food expenditure C_t and nonfood $\mathbf{z}_t$. The first stage problem of intertemporal two-stage budgeting allows us to determine them endogenously in the consumer's intertemporal optimization decision. In particular, in the first stage, the consumer faces the following asset accumulation constraint:

$$A_s = (1 + r_{s-1})A_{s-1} + Y_s - C_s - p_t^z z_t \text{for all} s \ge t. \tag{6}$$

We assume that there are shocks such as hurricane or tornados that make food and nonfood prices uncertain. Other shocks such as recession or stock market crash can make income and the interest rate treated as random. This makes wealth and, hence, food and nonfood consumption stochastic processes.

In formulating an intertemporal optimization problem by endogenizing food expenditure and nonfood, it is important to note that the direct and hence indirect utility function in (3) is ordinal; thus the intratemporal allocation of food expenditure across different food items as captured by the food demand functions (4) is invariant to a monotonic transformation of the utility function (3). It should be stressed that the intertemporal allocation of food expenditure and nonfood is invariant with respect to a linear transformation of the utility function, but not to other transformations of this function. This suggests that while the indirect utility function (3) is appropriate to represent within-period or intratempoeal preferences, it is not for intertemporal preferences. To represent intertemporal preferences, we, therefore, take a Box-Cox form for $\nu(C_t, \mathbf{p}_t, z_t)$:

$$U_t = \frac{\nu(C_t,\ \mathbf{p}_t, z_t)^{1-\zeta} - 1}{1-\zeta}, \tag{7}$$

where ζ is a Box-Cox parameter, with the marginal utility of C_t and z_t given by$\nu(C_t, \mathbf{p}_t, z_t)^{-\zeta}\nu_C(C_t,\ \mathbf{p}_t, z_t)$ and $\nu(C_t, \mathbf{p}_t, z_t)^{-\zeta}\nu_k(C_t,\ \mathbf{p}_t, z_t)$, respectively, where $\nu_C(C_t,\ \mathbf{p}_t, z_t) \equiv \partial\nu(C_t, \mathbf{p}_t, z_t)/\partial C_t$ and $\nu_z(C_t,\ \mathbf{p}_t, z_t) \equiv \partial\nu(C_t, \mathbf{p}_t, z_t)/\partial z_t$.[8] We assume that the Box-Cox utility function (5) is continuous, increasing, and, more importantly, strictly concave in C_t and z_t for given $\mathbf{p}_t$. The concavity condition ensures the existence of a solution to the intertemporal optimization problem, and implies that the necessary conditions are indeed sufficient.

Now, given the Box-Cox transformation of the indirect utility function, the consumer's first stage optimization problem is to choose C_s and $z_s, t \le s < t + T$, so as to maximize

$$E_t\left[\sum_{s=t}^{t+T}(1+\rho)^{-(s-t)}\left(\frac{\nu(C_s,\ \mathbf{p}_s, z_s)^{1-\zeta} - 1}{1-\zeta}\right)\right]. \tag{8}$$

We assume that the consumer replans continuously when solving the above stochastic dynamic optimization problem (Kim and

[8] A Box-Cox transformation on consumption alone would give plain vanilla CRRA utility, with ζ interpreted as the coefficient of relative risk aversion (see Sub-Section 2.4). With the indirect utility function, we do not adopt such interpretation in our analysis and derive the risk aversion measure in a more general framework; see Sub-Section 2.4.

McLaren, 2024). Accordingly, the consumer updates his plans continuously by reoptimizing the intertemporal problem at every period s, $s \geq t$, with the new information he has. This means that the calendar time τ solutions for C_τ and z_τ should be the successive time t solutions for C_t and z_t as planning time s evolves through time, with the present always being time t.

For estimation and data analysis then, only the first-order conditions necessary for the intertemporal optimization problem (8) at the initial point in time ($s = t$) are relevant. Utilizing the Lagrange method, they are given by

$$C_t : \nu(C_t, \mathbf{p}_t, z_t)^{-\zeta} \nu_C(C_t,\ \mathbf{p}_t, z_t) = \lambda_t \tag{9}$$

$$z_t : \nu(C_t,\ \mathbf{p}_t, z_t)^{-\zeta} \nu_z(C_t,\ \mathbf{p}_t, z_t) = \lambda_t p_t^z \tag{10}$$

$$A_t : \lambda_t = E_t\left[\left(\frac{1 + r_t}{1 + \rho}\right)\lambda_{t+1}\right], \tag{11}$$

where λ_t is the Lagrange multiplier associated with the asset accumulation constraint (6) known at time t, which measures the shadow value of the wealth constraint or the marginal utility of wealth.

Eq. (9) indicates that the marginal utility of wealth is equated, at the optimum, to the marginal utility of food consumption. Eq. (10) describes a similar condition for nonfood. Eq. (11) is the standard Euler equation for consumption (Hall, 1978; Hansen and Singleton, 1983) and illustrates the intertemporal allocation of food expenditure. Defining λ_t^z by $\lambda_t^z = \nu(C_t, \mathbf{p}_t, z_t)^{-\zeta} \nu_z(C_t, \mathbf{p}_t, z_t)$, solving (10) for λ_t, and substituting it into (11), we have

$$\frac{\lambda_t^z}{p_t^z} = E_t\left[\left(\frac{1 + r_t}{1 + \rho}\right)\frac{\lambda_{t+1}^z}{p_{t+1}^z}\right], \tag{12}$$

which is a related Euler equation for nonfood describing the intertemporal allocation of nonfood. In previous studies on consumption using food expenditure as a proxy measure for total consumption, Eq. (11) is derived with a utility function specified as a function of real consumption without nonfood (Zeldes, 1989; Runkle, 1991; Naik and Moore,1996; see also Phimister, 1995 and Abdulkadri and Langemeier, 2000, who use aggregate consumption for farm households). This is valid under the assumption that within-period preferences are homothetic with the implied absence of relative prices, which is found to be inconsistent with observed behavior; see Sub-Section 5.3 for evidence.

Eqs. (11) and (12) form the underlying framework for intertemporal analysis (see Sub-Section 2.5). For empirical analysis, it is convenient to work with these equations in a ratio form represented by

$$E_t\left[\left(\frac{1 + r_t}{1 + \rho}\right)\frac{\lambda_{t+1}}{\lambda_t}\right] = 1 \tag{13}$$

and

$$E_t\left[\left(\frac{1 + r_t}{1 + \rho}\right)\left(\frac{p_t^z}{p_{t+1}^z}\right)\frac{\lambda_{t+1}^z}{\lambda_t^z}\right] = 1. \tag{14}$$

2.3. Unrestricted indirect utility and food and nonfood demand functions

Dividing (10) by (9), we have

$$p_t^z = \psi(C_t,\ \mathbf{p}_t, z_t) = \frac{\nu_z(C_t,\ \mathbf{p}_t, z_t)_t}{\nu_C(C_t,\ \mathbf{p}_t, z_t)}, \tag{15}$$

where $\psi(C_t,\ \mathbf{p}_t, z_t)$ is an inverse Marshallian demand function for nonfood conditional on food expenditure. The right-hand side expression in (15) is the marginal rate of substitution of food consumption for nonfood, which is the dollar amount of food consumption the consumer is willing to forgo or pay for having one more unit of nonfood. This equation states that, at the optimum, the price of nonfood is equated to the consumer's marginal willingness to pay for this good. Eqs. (4) and (15) taken together jointly determine the demands for food items and nonfood conditional on food expenditure.

Implicitly solving the inverse demand for nonfood in (15) for $\mathbf{z}_t$, we obtain an "unrestricted" demand function for *nonfood* conditional on food expenditure C_t with given p_t^z:

$$z_t = z^{UC}(C_t,\ \mathbf{p}_t, p_t^z). \tag{16}$$

Substituting it into (4) gives unrestricted demand functions for *food* conditional on food expenditure *with given* p_t^z:

$$x_{it} = g_i^{UC}(C_t,\ \mathbf{p}_t, p_t^z) = g_i^{RC}\left[C_t,\ \mathbf{p}_t, z^{UC}(C_t,\ \mathbf{p}_t, p_t^z)\right],\ i = 1, ..., N. \tag{17}$$

With the unrestricted demands for nonfood and food, we can derive and estimate corresponding elasticities of these goods conditional on food expenditure (see Readers' Appendix B for derivation). We concede that food expenditure is not exogenous as food expenditure is expected to adjust in response to a change in income or total purchasing power allocated to food and nonfood expenditure. Hence, it is more appropriate to measure the unrestricted elasticities by conditioning them on total consumption expenditure.

From (6), we can define a static budget constraint with respect to total consumption expenditure M_t expressed by $M_t \equiv \mathbf{p}_t'\mathbf{x}_t + p_t^z z_t = C_t + p_t^z z_t$, which gives $C_t = M_t - p_t^z z_t$. Substituting this expression into (15) leads to

$$p_t^z = \psi(M_t - p_t^z z_t, \mathbf{p}_t, z_t), \tag{18}$$

Solving (18) implicitly for z_t, we have an unrestricted nonfood demand function conditional on *total expenditure* M_t :

$$z_t = z^{UM}(M_t,\ \mathbf{p}_t, p_t^z), \tag{19}$$

and substituting this expression into $C_t = M_t - p_t^z z_t$, we obtain

$$C_t = M_t - p_t^z z^{UM}(M_t,\ \mathbf{p}_t, p_t^z) = C^{UM}(M_t,\ \mathbf{p}_t, p_t^z). \tag{20}$$

Further, substitution of (19) and (20) into (4) results in

$$x_{it} = g_i^{UM}(M_t, \mathbf{p}_t, p_t^z) = g_i^{RC}\left[C^{UM}(M_t, \mathbf{p}_t, p_t^z), \mathbf{p}_t, z^{UM}(M_t,\ \mathbf{p}_t, p_t^z)\right],\ i = 1, \ldots, N, \tag{21}$$

which is a system of unrestricted demand functions for food conditional on *total expenditure*. Eqs. (19) and (21) can be used to derive unrestricted elasticities for food and nonfood conditional on total expenditure (see Readers' Appendix B for derivation).

As indicated before, most studies on food demand invoke weak separability and estimate conditional demand systems for some food group of interest. In these studies, group expenditure is typically treated as exogenous. However, group expenditure is not exogenous but is endogenously determined, which produces biased demand elasticities if it is not accounted for. This has been recognized in the food demand literature (see LaFrance, 1991). Notably, Manser (1976) specified a Translog indirect utility function and estimated the demand for several aggregate food items. To allow for endogeneity of food expenditure, she adjusted the food expenditure elasticities by making food expenditure as a function of total consumption expenditure or income. Edgerton (1997) examined the relation between conditional and unconditional demand elasticities with allowance for expenditure endogeneity, and estimated these elasticities for food. Thompson (2004) specified an Almost Ideal Demand System for meat, and estimated a separable meat demand system, together with a meat expenditure function expressed as a function of income, an aggregate price index for meat, and CPI. He pointed out, though, that this procedure may result in the violation of theoretical restrictions, such as symmetry. In our analysis, we work with a nonseparable demand system with nonfood, and provide a theoretically consistent framework to take account of endogeneity of food expenditure as well as nonfood in food demand analysis; see also Readers' Appendix B for a related discussion of elasticities.

2.4. Risk aversion under nonhomothetic preferences

In the presence of uncertainty, the consumer's attitude toward risk, measured by the degree of risk aversion, determines his decisions about occupation, asset allocation, health-related conduct, and moving and job change decisions (Guisoand Paiella, 2008). Risk aversion is also relevant in food consumption because food is a necessity with a subsistence level, and food consumption can reflect the consumer's risk aversion behavior, especially in developing countries. Ogaki and Zhang (2001) found that the degree of relative risk aversion decrease with consumption for low-income households with subsistence.

The degree of relative risk aversion (RRA) is typically measured with the well-known power or CRRA (constant relative risk aversion) utility function, $u(c_t) = \frac{c_t^{1-\zeta}-1}{1-\zeta}$ where c_t is the level of real consumption and the coefficient ζ is the estimate of RRA (see Hansen and Singleton, 1983; Mehra and Prescott, 1985).[9] Recall that this measure is derived from (7) under the assumptions that preferences are homothetic and non-food item (z_t) are excluded. We now generalize this measure by relaxing the aforesaid assumptions; it should give us a more realistic description of the consumer's risk behavior than the traditional measure based on power utility.

The well-known measures of risk aversion a la Arrow and Pratt are, essentially, static concepts constructed under the assumption that initial wealth is non-random or the consumer has full access to the capital market. Since the consumer cares about utility derived from consumption, which is directly related to wealth, the indirect utility function in (3) can be deployed to construct operational measures of risk aversion (Deschamps, 1973). While the demand functions are determined by an ordinary utility function, a risk aversion function is determined by a cardinal utility function. To allow for this, we take the Box-Cox transformation of the indirect utility function given in (7), which gives the marginal utility of food consumption at time t as $U_C(C_t,\ \mathbf{p}_t, z_t) \equiv \frac{\partial U_t}{\partial C_t} = \frac{\nu_C(C_t, \mathbf{p}_t, z_t)}{\nu(C_t, \mathbf{p}_t, z_t)^{\zeta}}$, so that

$$U_{CC}(C_t,\ \mathbf{p}_t, z_t) \equiv \frac{\partial U_C(C_t,\ \mathbf{p}_t, z_t)}{\partial C_t} = \frac{\nu_{CC}(C_t, \mathbf{p}_t, z_t)}{\nu(C_t, \mathbf{p}_t, z_t)^{\zeta}} - \zeta\frac{[\nu_C(C_t, \mathbf{p}_t, z_t)]^2}{\nu(C_t, \mathbf{p}_t, z_t)^{(\zeta+1)}}. \tag{22}$$

Given (22), the coefficient of relative risk aversion is defined as

$$RRA(C_t, \mathbf{p}_t, z_t) \equiv -\frac{\partial \ln U_C(C_t,\ \mathbf{p}_t, z_t)}{\partial \ln C_t} = -\frac{C_t U_{CC}(C_t,\ \mathbf{p}_t, z_t)}{U_C(C_t,\ \mathbf{p}_t, z_t)}. \tag{23}$$

[9] The CRRA is also used to measure the risk aversion for farm households (Abdulkadri and Langemeier, 2000).

The concavity of the intertemporal utility function with respect to C_t implies that $U_{CC}(C_t,\ \mathbf{p}_t, z_t) > 0$ hence $RRA(C_t, \mathbf{p}_t, z_t) > 0$.

The measure of RRA in (23) is based on the condition that nonfood (z_t) and food consumption (C_t) are exogenous. When they are allowed to vary, it has to be redefined by allowing for endogeneity of these variables. A detailed derivation is provided in Readers' Appendix C, and a modified measure of RRA is given by

$$RRA\left(M_t,\ \mathbf{p}_t, p_t^z\right) \equiv -\frac{\partial \ln U_M\left(M_t,\ \mathbf{p}_t, p_t^z\right)_t}{\partial \ln M_t} = -\frac{M_t U_{MM}\left(M_t,\ \mathbf{p}_t, p_t^z\right)}{U_M\left(M_t,\ \mathbf{p}_t, p_t^z\right)}, \tag{24}$$

with $RRA\left(M_t,\ \mathbf{p}_t, p_t^z\right) > 0$. The risk aversion measure based on $RRA\left(M_t,\ \mathbf{p}_t, p_t^z\right)$ is more appropriate than $RRA\left(C_t,\ \mathbf{p}_t, p_t^z\right)$ because food expenditure adjusts in response to a change in income or total consumption expenditure.

2.5. Intertemporal allocation: food and nonfood consumption growth equations

While we derived the unrestricted demands for food consumption and nonfood in (19) and (21) under static conditions, it is not feasible to obtain structural or closed forms of these functions from the intertemporal optimization problem, even for simple utility functions when the environment is stochastic. To circumvent this problem, it is instead a common practice to work with an Euler equation in studies on consumption and saving (Hall, 1978; Hansen and Singleton, 1983; Abdulkadri and Langemeier, 2000), which is adopted here. To do so, we use the Euler equations for food consumption (13) and nonfood (12), and exploit a lognormal property (Hansen and Singleton, 1983; Ludvigson and Paxson, 2001).[10] Following Kim et al. (2021), we derive the following log-linearized Euler equations for food consumption and nonfood growth:

$$\Delta \ln C_{t+1} = d_{rt}^c \ln[(1 + r_t)\,/\,(1 + \rho)] + \sum_{j=1}^{N} d_{jt}^c \Delta \ln p_{it+1} + d_{kt}^c \Delta \ln z_{t+1} + d_{\sigma t}^c \sigma_{ct+1}^2 + u_{t+1}^c, \tag{25}$$

and

$$\Delta \ln z_{t+1} = d_{rt}^z \ln[(1 + r_t)\,/\,(1 + \rho)] + \sum_{j=1}^{N} d_{jt}^z \Delta \ln p_{it+1} + d_{zt}^z \Delta \ln p_{zt+1} + d_{ct}^z \Delta \ln C_{t+1} + d_{\sigma t}^z \sigma_{zt+1}^2 + u_{t+1}^z, \tag{26}$$

where σ_{ct+1}^2 and σ_{zt+1}^2 are conditional variances for marginal utility growth of C_{t+1} and z_{t+1}, and u_{t+1}^c and u_{t+1}^z are expectation errors for C_{t+1} and z_{t+1} at time $t + 1$ that are uncorrelated with variables known at time t.[11]

Eqs. (25) and (26) constitute a system of two simultaneous equations to solve for $\Delta \ln C_{t+1}$ and $\Delta \ln z_{t+1}$ in terms of exogenous variables. In a reduced form, they are expressed as

$$\Delta \ln C_{t+1} = \phi_{rt}^c \ln[(1 + r_t)\,/\,(1 + \rho)] + \sum_{j=1}^{N} \phi_{jt}^c \Delta \ln p_{it+1} + \phi_{zt}^c \Delta \ln p_{zt+1}^z + \phi_{\sigma t}^c \sigma_{ct+1}^2 + \upsilon_{t+1}^c, \tag{27}$$

and

$$\Delta \ln z_{t+1} = \phi_{rt}^z \ln[(1 + r_t)\,/\,(1 + \rho)] + \sum_{j=1}^{N} \phi_{jt}^z \Delta \ln p_{it+1} + \phi_{zt}^z \Delta \ln p_{zt+1} + \phi_{\sigma t}^z \sigma_{zt+1}^2 + \upsilon_{t+1}^z. \tag{28}$$

These equations can be used to examine the growth of the food demands in (4). In previous studies on consumption using food expenditure as a proxy measure for total consumption (Zeldes, 1989; Runkle, 1991; see also Phimister, 1995 and Abdulkadri and Langemeier, 2000, who use aggregate consumption for farm households), Eq. (27) is estimated with no allowance for nonfood under the assumption that within-period preferences are homothetic with well-known power utility (see above). In these studies, conditional variance is also not accounted for.

Eqs. (27) and (28) identify the variables governing the intertemporal allocations of food and nonfood consumption. The variables of focal interest in intertemporal analysis are the time preference rate, the interest rate, and conditional variances. Ceteris paribus, a higher time preference rate implies a higher propensity to consume now rather than in the future with less saving, resulting in negative expected food and nonfood consumption growth. A change in the interest rate has the opposite effect of the time preference rate. In particular, the elasticity of intertemporal substitution (EIS) for consumption measures the effect of the interest rate on consumption

[10] It is customary to approximate the Euler equation with a lognormal distribution (Hansen and Singleton, 1983) or a second-order Tayler series expansion (Dynan, 1993). For CRRA utility, under the assumption that consumption growth is normally distributed, a log-linearized Euler equation derived from it is the same as that obtained by a second-order Tayler series expansion of the Euler equation (Ludvigson and Paxson, 2001; Gourinchas and Parker, 2001). Previous studies are, however, based on homothetic preferences and do not allow for relative prices.

[11] As discussed in Footnote #7, weak separability of food from nonfood implies that intratemporal allocation of food expenditure is independent of nonfood, but the intertemporal allocation of food expenditure is not; hence food consumption growth is not independent of nonfood growth, even though food is separable from nonfood.

growth. In (27) and (28), the coefficients ϕ_{rt}^{c} and ϕ_{rt}^{z} identify the elasticities of intertemporal substitution for food and nonfood consumption, that is, $\phi_{rt}^{c}=\partial\Delta\ln C_{t+1}/\partial\ln(1+r_t)$ and $\phi_{rt}^{z}=\partial\Delta\ln k_{t+1}/\partial\ln(1+r_t)$.[12] Given the EIS, ceteris paribus, the relation between the time preference rate and the interest rate determines the growth of food and nonfood consumption, with the result that a high interest rate relative to the time preference rate increases food and nonfood consumption growth.

The variables σ_{zt+1}^{2} and σ_{zt+1}^{2} are conditional variances of food and nonfood consumption, which are measures of uncertainty of these variables. The associated coefficients $\phi_{\sigma t}^{c}$ and $\phi_{\sigma t}^{z}$ capture the effect of uncertainty on food and nonfood consumption. In the absence of insurance or risk sharing opportunities, uncertainty, in general, motivates consumers to engage in precautionary saving in the form of safe or liquid assets to buffer against unforeseen future events (Dynan, 1993; Gourinchas and Parker, 2001). The more uncertainty there is about consumption and the more risk averse the consumer is, the greater is precautionary saving. This leads consumers to decrease current consumption in exchange for an increase in future consumption, resulting in higher expected consumption growth. However, in the face of uncertainty, the precautionary motive for food consumption may take on a different form (Pope, 2012). If consumers are uncertain about the future, they may temporarily increase food purchases by stocking up on food in order to prepare for the uncertain future, while reducing non-essential spending.[13] This can be regarded as a precautionary motive for hoarding food and is certainly the consumer's prudent behaviour. In fact, "Nearly every natural disaster is accompanied by "runs on grocery stores" by the imprudent and ready storage of food by the prudent" (Pope, 2012, p. 137). In general, the precautionary motive for hoarding arises for goods that are necessities and storable in nature. This is clearly evidenced by the current coronavirus pandemic.

From the above discussions, it is clear that any change in the time preference rate, the interest rate, and uncertainty will have an effect on current food and nonfood consumption, C_t and z_t, and, in turn, on the demands for food in (4) indirectly. Food and nonfood prices, which determine their demands, also influence food and nonfood consumption. This implies that the consumer's intratemporal and intertemporal allocations of food consumption with nonfood are inexplicably linked together. Thus, food demand cannot be analyzed in isolation of intertemporal food consumption, as is done in previous studies. Rather, they have to be analyzed in an integrated framework with allowance for nonfood for a proper understanding of food consumption behavior.

3. An empirical model

The theoretical model developed in the foregoing section forms the basis for empirical analysis.

To carry out an empirical analysis, we formulate an empirical model and discuss the estimation procedures in this section.

3.1. Specification of the restricted indirect utility function

The restricted indirect utility function (3) plays a central role in the integrated analysis of food demand and intertemporal food consumption. For empirical analysis, the specification of an appropriate parametric form for this function is essential that is flexible while satisfying the requisite regularity conditions for within-period and intertemporal preferences. The PIGLOG (Price Independent Generalized Logarithmic) form, popularized by Deaton and Muelbauer's (1980b) Almost Ideal Demand System (AIDS), has been widely used in food demand analysis despite some drawbacks (Piggott, 2003). When there are substantial changes in real income or consumption, the implied budget share equations for this system violate the required monotonicity and curvature conditions (Cooper and McLaren, 1992). More importantly, as noted by Oulton (2012) and Cooper et al. (2015), the PIGLOG form is inflexible in modelling the income effects for welfare changes; this may cause serious problems when it is used in general equilibrium modelling applications, particularly in situations where a model may be subjected to large shocks.

In this study, we have adapted Cooper et al.'s (2015) augmented MPIGLOG form as a functional representation of the restricted indirect utility function (3). This specification is based on a modified PIGLOG (MIGLOG) form proposed by Cooper and McLaren (1992), augmented by some extraneous variable, for example, nonfood quantity in our analysis. An MPIGLOG specification allows easier imposition of regularity conditions in the form of effective global regularity (Cooper and McLaren, 1996; McLaren and Wong, 2009), and gives tractable Euler equations for food consumption and nonfood.[14]

With the augmented MPIGLOG specification, the restricted indirect utility function (3) is given by

$$\nu(C_t,\ \mathbf{p}_t,z_t)=\frac{R(C_t,\ \mathbf{p}_t,z_t)}{1-\phi z_t}\left[\frac{C_t^{\eta}}{P_B(\mathbf{p}_t)}\right], \tag{29}$$

where $R(C_t,\ \mathbf{p}_t,z_t)=\left\{(1-\varphi)\ln\left[\frac{C_t}{P_A(\mathbf{p}_t)}\right]+\varphi\ln(z_t-\gamma)\right\}$, and γ, φ, η and ϕ are parameters with $0\leq\eta,\ \varphi\leq1,\ \phi\geq0$. $P_A(\mathbf{p}_t)$ and $P_B(\mathbf{p}_t)$ are

[12] For any utility function separable over time and states, it is well known that the EIS equals the reciprocal of the coefficient of RRA (Hall, 1988); thus risk aversion and intertemporal substitution are inseparable. For power or CRRA utility, the EIS is given by $1/\zeta$ (Abdulkadri and Langemeier, 2000). Epstein and Zin (1991) proposed a nonexpected or recursive utility function to disentangle risk aversion and intertemporal substitution (see Lence, 2000, for an application in agriculture). However, this result holds with power utility when there is only one consumption good or goods are separable. In our analysis, there are two goods – food and nonfood, which are treated as nonseparable.

[13] A stockpiling behavior also arises from intetemporal variations in prices (see Handel and Nevo, 2006; Wang et al., 2017). We do not address this behavior in our analysis.

[14] The augmented MPIGLOG form is of a rank 2 which is less flexible than a typical rank 3 model. Although demands for individual households appear to be of rank 3, there is evidence that aggregate demands may be adequately modeled as rank 2 (see Lewbel, 1991, for a further discussion).

price indexes that are positive, increasing, and concave in $\mathbf{p}_t$ with P_A and P_B being homogenous of degree 1 and η in $\mathbf{p}_t$, respectively. We assume that $P_A(\mathbf{p}_t)$ and $P_B(\mathbf{p}_t)$ take the forms:

$$\mathrm{P}_A(\mathbf{p}_t) \equiv \left(\sum\nolimits_{j=1}^{N} \alpha_j p_{jt}^{\tau_A}\right)^{1/\tau_A} \quad with \sum\nolimits_{j=1}^{n} \alpha_j = 1, \alpha_j \geq 0, j = 1, .., N, \tau_1 \geq 0 \tag{30}$$

and

$$P_B(\mathbf{p}_t) = \prod_{j=1}^{N} p_{jt}^{\beta_j} \; with \sum\nolimits_{j=1}^{N} \beta_j = \eta, \beta_j \geq 0, j = 1, .., N. \tag{31}$$

The augmented MPIGLOG indirect utility function (29) places no a priori restrictions on the consumer's within-period preferences. Furthermore, it is general enough to nest a number of well-known functional forms. For instance, the restriction $\varphi = 0$ allows us to derive an MPIGLOG indirect utility function of the form $v(C_t, \mathbf{p}_t) = \log\left[\frac{C_t}{P_A(\mathbf{p}_t)}\right]\left[\frac{C_t^{\eta}}{P_B(\mathbf{p}_t)}\right]$ which is independent of z_t and implies that food items are weakly separable from nonfood. On the other hand, setting $\eta = \beta_i = 0 \ \forall$ i gives an indirect utility function $v(C_t, \mathbf{p}_t) = \log(C_t / P_A)$ which is homothetic and produce a rank 1 demand system with only one price index of food items $P_A(\mathbf{p}_t)$ (see Lewbel, 1991). Additionally, the imposition of $\eta = 0$ generates an augmented form of the PIGLOG indirect utility function.

Given (29) together with associated price indexes (30) and (31), we obtain the following derivatives:

$$\frac{\partial v(C_t, \ \mathbf{p}_t, z_t)}{\partial C_t} = \frac{C_t^{\eta-1}}{P_B(\mathbf{p}_t)}[(1-\varphi) + \eta R(C_t, \ \mathbf{p}_t, z_t)], \tag{32}$$

$$\frac{\partial v(C_t, \ \mathbf{p}_t, z_t)}{\partial p_{it}} = -\left[\frac{C_t^{\eta}}{(1-\phi z_t)P_B(\mathbf{p}_t)p_{it}}\right][(1-\varphi)EA_{it} + \beta_i R(C_t, \ \mathbf{p}_t, z_t)], i = 1., N, \tag{33}$$

$$\frac{\partial v(C_t, \ \mathbf{p}_t, z_t)}{\partial z_t} = \frac{C_t^{\eta}}{(1-\phi z_t)P_B(\mathbf{p}_t)}\left[\frac{\varphi}{z_t} + \left(\frac{\phi}{1-\phi z_t}\right)R(C_t, \ \mathbf{p}_t, z_t)\right], \tag{34}$$

and

$$\frac{\partial^2 v(C_t, \ \mathbf{p}_t, z_t)}{\partial C_t^2} = \frac{C_t^{\eta-2}}{P_B(\mathbf{p}_t)}[(\eta-1)[(1-\varphi) + \eta R(C_t, \ \mathbf{p}_t, z_t)] + \eta(1-\varphi)], \tag{35}$$

where $EA_{it} \equiv \frac{\partial \ln[P_A(\mathbf{p}_t)]}{\partial \ln(p_{it})} = \frac{\alpha_i p_{it}^{\tau_A}}{\sum_{j=1}^{N} \alpha_j p_{jt}^{\tau_A}}$.

Eqs. (32) and (33) can be used to derive the demand functions for food via Roy's dentity (4). In a budget or expenditure share form, we have

$$S_{it} = -\left(\frac{\partial v(C_t, \ \mathbf{p}_t, z_t)/\partial p_{it}}{\partial v(C_t, \ \mathbf{p}_t, z_t)/\partial C_t}\right)\frac{p_{it}}{C_t} = \frac{(1-\varphi)EA_{it} + \beta_i R(C_t, \ \mathbf{p}_t, z_t)}{(1-\varphi) + \eta R(C_t, \ \mathbf{p}_t, z_t)}, i = 1, ...N, \tag{36}$$

where $S_{it} \equiv p_{it}q_{it}/C_t$ is the share of the ith (i = 1,…, N) food in total food expenditure, with$\sum_{i=1}^{N} S_{it} = 1$. If food items are weakly separable from nonfood, i.e., $\varphi = 0$, budget shares for food are independent of nonfood. If within-period preferences are homothetic in food items, i.e., $\eta = \beta_i = 0$, i = 1,…, N, then $S_{it} = \alpha_i p_{it}^{\tau_A} / \sum_{j=1}^{N} \alpha_j p_{jt}^{\tau_A}$, i = 1,…, N, that is, budget shares or Engel curves for food are independent of income or expenditure, yielding unitary expenditure elasticities for food.

Using (32) and (34), the inverse demand function for nonfood (15) is given by

$$p_t^z = \frac{\partial v(C_t, \ \mathbf{p}_t, z_t)/\partial z_t}{\partial v(C_t, \ \mathbf{p}_t, z_t)/\partial C_t} = \left(\frac{C_t}{z_t}\right)\frac{\varphi + \left(\frac{\phi z_t}{1-\phi z_t}\right)R(C_t, \ \mathbf{p}_t, z_t)}{(1-\varphi) + \eta R(C_t, \ \mathbf{p}_t, z_t)}, \tag{37a}$$

or, in a share form,

$$S_t^z = \left(\frac{\partial v(C_t, \ \mathbf{p}_t, z_t)/\partial z_t}{\partial v(C_t, \ \mathbf{p}_t, z_t)/\partial C_t}\right)\frac{z_t}{C_t} = \frac{\varphi + \left(\frac{\phi z_t}{1-\phi z_t}\right)R(C_t, \ \mathbf{p}_t, z_t)}{(1-\varphi) + \eta R(C_t, \ \mathbf{p}_t, z_t)}, \tag{37b}$$

where $S_t^z \equiv p_t^z z_t / C_t = (p_t^z z_t / M_t)(C_t / M_t)$ is the ratio of total spending on nonfood to total spending on food items. Eq. (37a) is used to derive the unrestricted demands for nonfood in (16) and (19) and, in turn, the unrestricted demands for food in (17) and (21), conditional on food expenditure and total consumption expenditure, respectively. This allows us to estimate the unrestricted price and expenditure elasticities for food and nonfood (see Readers' Appendix B for a discussion) as well as different measures of RRA (see Sub-Section 2.4). An explicit analytical, closed-form solution is not possible to obtain the unrestricted level of nonfood (16) and hence food consumption (20) from (37a), so we utilize numerical methods and carry out the required calculations.

Using the appropriate derivatives given above, the Euler equation for food consumption (13) with the Box-Cox transformation (7) can be written as

$$\left(\frac{1+r_t}{1+\rho}\right)\frac{\frac{C_{t+1}^{\eta-1}}{P_B(\mathbf{p}_{t+1})}\left[(1-\varphi)+\eta R(C_{t+1},\ \mathbf{p}_{t+1},z_{t+1})\right]}{\frac{C_t^{\eta-1}}{P_B(\mathbf{p}_t)}\left[(1-\varphi)+\eta R(C_t,\ \mathbf{p}_t,z_t)\right]}\left(\frac{\frac{R(C_{t+1},\ \mathbf{p}_{t+1},z_{t+1})}{1-\phi z_{t+1}}\left[\frac{C_{t+1}^{\eta}}{P_B(\mathbf{p}_{t+1})}\right]}{\frac{R(C_t,\ \mathbf{p}_t,z_t)}{1-\phi z_t}\left[\frac{C_t^{\eta}}{P_B(\mathbf{p}_t)}\right]}\right)^{-\varsigma}-1=\varepsilon_{Ct}, \tag{38}$$

and the Euler equation for nonfood (14) becomes

$$\left(\frac{1+r_t}{1+\rho}\right)\left(\frac{p_t^z}{p_{t+1}^z}\right)\frac{\frac{C_{t+1}^{\eta}}{(1-\phi z_{t+1})P_B(\mathbf{p}_{t+1})}\left[\frac{\varphi}{z_{t+1}}+\left(\frac{\phi}{1-\phi z_{t+1}}\right)R(C_{t+1},\ \mathbf{p}_{t+1},z_{t+1})\right]}{\frac{C_t^{\eta}}{(1-\phi z_t)P_B(\mathbf{p}_t)}\left[\frac{\varphi}{z_t}+\left(\frac{\phi}{1-\phi z_t}\right)R(C_t,\ \mathbf{p}_t,z_t)\right]}\left(\frac{\frac{R(C_{t+1},\ \mathbf{p}_{t+1},z_{t+1})}{1-\phi z_{t+1}}\left[\frac{C_{t+1}^{\eta}}{P_B(\mathbf{p}_{t+1})}\right]}{\frac{R(C_t,\ \mathbf{p}_t,z_t)}{1-\phi z_t}\left[\frac{C_t^{\eta}}{P_B(\mathbf{p}_t)}\right]}\right)^{-\varsigma}-1=\varepsilon_{zt}, \tag{39}$$

where ε_{Ct} and ε_{zt} are expectation errors.

Provided that the price indices have desirable properties with the conditions on parameters in (30) and (31) satisfied, the augmented MPIGLOG indirect utility function (29) is regular with respect to the within-period properties over the regions $R(C_t,\ \mathbf{p}_t, z_t) > 0$, $z_t - \gamma > 0$ and $\phi z_t < 1$. The intertemporal regularity condition with respect to C_t requires that the Box-Cox form (7) of the MPIGLOG indirect utility function be concave in C_t; see (22) in Sub-Section 2.4. For $\zeta \geq 0$ with $R(C_t,\ \mathbf{p}_t,z_t) > 0$, $(z_t - \gamma) > 0$, and $\phi z_t < 1$, this condition is satisfied when the augmented MPIGLOG indirect utility function is concave, i.e., $\frac{\partial^2 \nu(C_t,\ \mathbf{p}_t,z_t)}{\partial C_t^2} < 0$ in (35).

3.2. Estimation procedures

To obtain the values of parameters of the augmented MPIGLOG indirect utility function (29) together with the Box-Cox parameter ζ and the time preference rate ρ appearing in the intertemporal optimization problem (8), we jointly estimate the budget share equations for food in (36) and the inverse demand function for nonfood in a share form (37b) along with the Euler equations for food consumption and nonfood in (38) and (39). Although the Euler equations contain all information to identify the parameters, their use only is not efficient because they neglect the information given in the food and nonfood budget share equations. In estimation, it should be noted that food consumption C_t and nonfood z_t are not exogenous but endogenously determined in the consumer's optimization problem, implying that they are correlated with the error terms. Current food prices $\mathbf{p}_t$ and the interest rate r_t may be not strictly exogenous either. Moreover, there are variables dated $t+1$ that need to be treated properly in estimation. The use of the realized values causes them to be correlated with the error terms. These facts suggest an instrumental variables approach, particularly the Generalized Method of Moments (GMM) (Hansen, 1982), to estimate the empirical model because the Euler equations, which state that the expectation at time t of a function of variables at times t and $t+1$ is zero, provide moment conditions. Under rational expectations, an expectation error is orthogonal to any information available to the consumer at time t.

Invoking rational expectations to the budget share equations is, however, only appropriate when these equations hold without error or are non-stochastic. In practice, these equations also contain errors arising from optimization or taste shocks. These errors are likely to be correlated with variables in the budget share equations and the Euler equations as well. Also, serial correlation is a common issue in estimation of the budget share equations. This implies that the Euler equations and the budget share equations hold in expectation under weaker conditions than the rational expectations model suggests. In estimation, we experienced a lack of identification with GMM and thus employ nonlinear three stage least squares (3SLS) to estimate the system of Eqs. (36), (37b), (38), and (39), using as instruments a set of variables that does not include any current variables appearing in the equation system.[12] To accommodate evidence of significant positive serial correlation in the budget share equations revealed in initial estimation, we used Moschini and Moro (1994)'s correction for autoregressive errors.

To estimate food consumption and nonfood growth equations in (25) and (26) as well as in (27)and (28), we assume that all explanatory variables may not be strictly exogenous. Accordingly, we pursue an instrumental variables method, using as instruments one-period lags of all regressors. Conditional variances of food consumption and nonfood are given by $\sigma_{ct+1}^2 \equiv E_t(\Delta\ln C_{t+1})^2$ and $\sigma_{zt+1}^2 \equiv E_t(\Delta\ln z_{t+1})^2$,[15] but are not directly observable. Thus, we take their realized values, $(\Delta\ln C_{t+1})^2$ and $(\Delta\ln z_{t+1})^2$, by instrumenting them with lagged values under rational expectations). We also assume that other explanatory variables such as the interest rate and growth variables may not be strictly exogenous and thus instrument them with lagged values.[16]

[15] They are also obtained by a second-order Taylor series expansion of an Euler equation with CRRA utility for C_t and z_t (see Ludvigson and Paxson, 2001; Dynan, 1993).

[16] We considered the following set of instruments: a time trend, all food and nonfood prices and the interest rate lagged one period, and food consumption and nonfood lagged one period. It is common to use laggard variables as instruments for aggregate time series data in consumption studies. Lagged variables tend to have strong correlations with current endogenous variables, implying that the weak instrument problem caused by the use of their lagged values as instruments appears not to a problem. In addition, our chosen instruments satisfy the regularity conditions and the overidentifying restrictions are not rejected; see Tables 2 and 4.

4. Data and descriptive analysis

In this section, we discuss the data used in our study and present a brief analysis of these data.

4.1. Data

We used aggregate annual time series data for the United States covering the period 1959 –2019.[17] Most of the data were obtained from Personal Consumption Expenditures in the National Income and Product Accounts (NIPA), published by the Bureau of Economic Analysis, U.S. Department of Commerce. We followed Okrent and Alston (2011, p. 62,) and constructed nine aggregate categories for food and beverages and a nonfood composite. Nine food and beverages items include: x_1 = cereals and bakery, x_2 = meat (beef, pork, other red meats, poultry, seafood and fish), x_3 = eggs, x_4 = milk and dairy products (fluid milk and processed dairy products), x_5 = fruits and vegetables (fresh and processed fruits and vegetables), x_6 = other foods at home (fats and oil, sweets and sugars, other food, not elsewhere classified), x_7 = non-alcoholic beverages, x_8 = food away from home – food in purchased meals, and x_9 = alcoholic beverages – alcoholic beverages purchased for off-premises and alcohol in purchased meals. The aggregate price index for each food category is constructed as a weighted average of the component price indexes, with expenditure shares for each component good serving as weights. Nonfood (z) is an aggregate of all goods excluding food and beverages, measured by real nonfood expenditure obtained by current nonfood expenditure divided by its implicit price index (p^z).

Total food expenditure (C) is the sum of nominal expenditures on the nine food categories. Total expenditure (M) is the sum of total consumption expenditures on food and nonfood goods.

In general, food spending accounts for about 17 percent, and nonfood spending about 83 percent of total consumption spending. We considered disposable income $\left(Y^d\right)$obtained from NIPA in our analysis because it is treated as an important variable influencing consumption. Food expenditure, total expenditure, and disposable income are expressed in per capita by dividing them by population, and all data are seasonally adjusted, measured in 2012 dollars. In intertemporal analysis, the interest rate plays an essential role. For the (nominal) interest rate (r), we used the three-month Treasury bill rate taken from Federal Reserve Board's H.15 Statistical Release.

4.2. Brief descriptive analysis

Fig. 1 presents the time series plots of growth rates or annual percentage changes in nominal food and total spending as well as in real food spending and nonfood. In general, the growth rates of these variables show wide fluctuations, falling during recessionary periods. Nominal food spending has an average growth rate of 5.44 percent per year and a standard deviation of 2.44 percent during the sample period. A similar pattern is observed for total spending, with an average growth rate of 6.46 percent per year and a standard deviation of 2.53 percent. Nonfood has an average growth rate of 2.93 percent per year and a standard deviation of 1.78 percent during the sample period. Food spending growth in real terms appears to fluctuate more than the growth rate of nonfood.

The time series plots of the aggregate prices of food and nonfood as well as the interest rate are shown in Fig. 2. As can be seen, the price indexes of food and nonfood move almost together with a stable upward trend over time. On the other hand, the interest rate shows a fluctuating pattern over time with the business cycle, and tends to move with the inflation rate.

Table 1 contains descriptive statistics for the relevant variables to be considered in the empirical analysis. Looking at standard deviations and minimum and maximum values of the variables, there are variations over time. Nevertheless, there appears to be weak evidence for the prevalence of intertemporal variations or year-to-to fluctuations in the relevant variables.

5. Estimation and results

Empirical investigation of the empirical model in Section 3 was carried out using aggregate annual time series data discussed in Section 4 for the United States for the period 1959 - 2019. In this section, we present results of estimating the model.

5.1. Parameter estimates

Table 2 reports the estimation results for the empirical model based on joint estimation of the ten food and nonfood budget share equations along with the two Euler equations for food consumption and nonfood. To ensure that the estimated model is properly behaved, the regularity conditions for within-period and intertemporal preferences are checked, and all of them are satisfied at every sample period. The χ^2 based J-test shows that the overidentifying restrictions are not decisively rejected at the conventional significance levels. This indicates that the conditions upon which our parameter estimates are premised hold, thus providing evidence for the validity of the chosen instruments in our estimation. We also note that the general fit of the budget share system as indicated by the R^2 values is quite good, given the parsimonious parametric form of the augmented MPIGLOG indirect utility function (29). Furthermore,

[17] Ideally, we would need household panel data with demographic information to examine consumer behavior. This is particularly so, because the use of aggregate time series data to estimate the representative agent model, adopted in almost all food consumption studies, creates a well-known aggregation problem. The use of household panel survey data might alleviate this problem. Unfortunately, household panel data lack sufficient information about disaggregate goods and have short time series, which is not conducive to a dynamic or intertemporal analysis requiring long time series like our study.

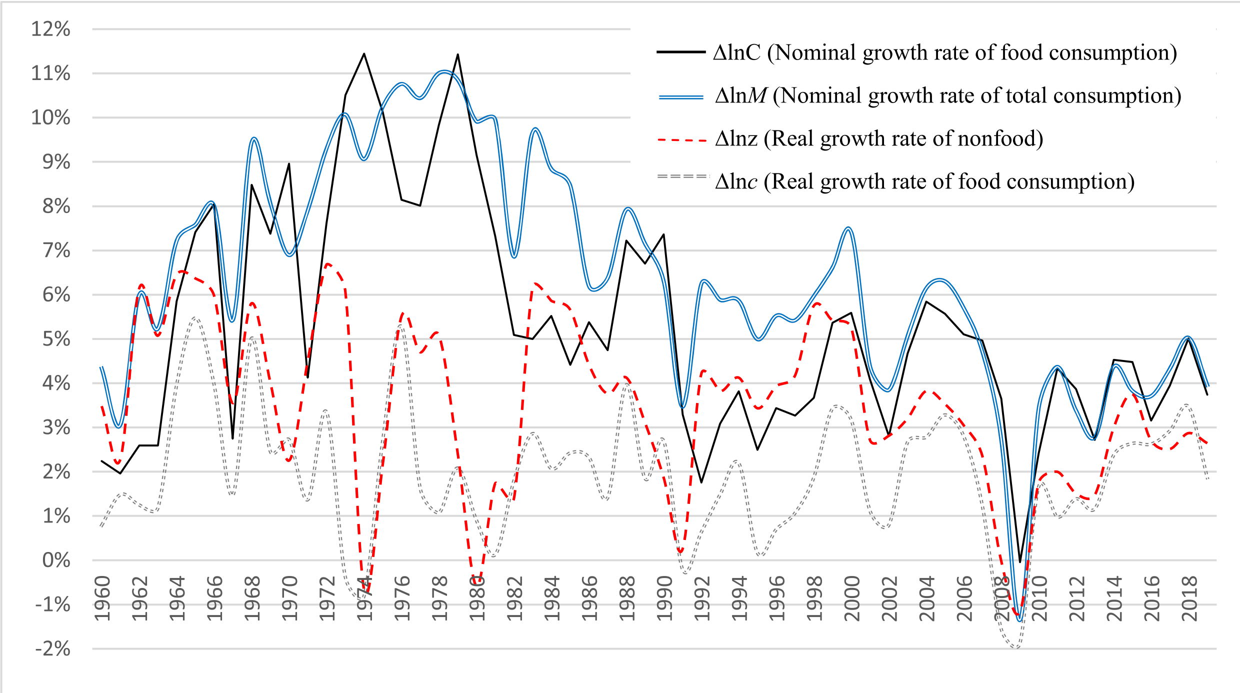

Fig. 1. Annual growth rates of food and nonfood consumption, 1960 - 2019.
Notes: The variables are constructed using NIPA data, published by the Bureau of Economic Analysis, U.S. Department of Commerce.

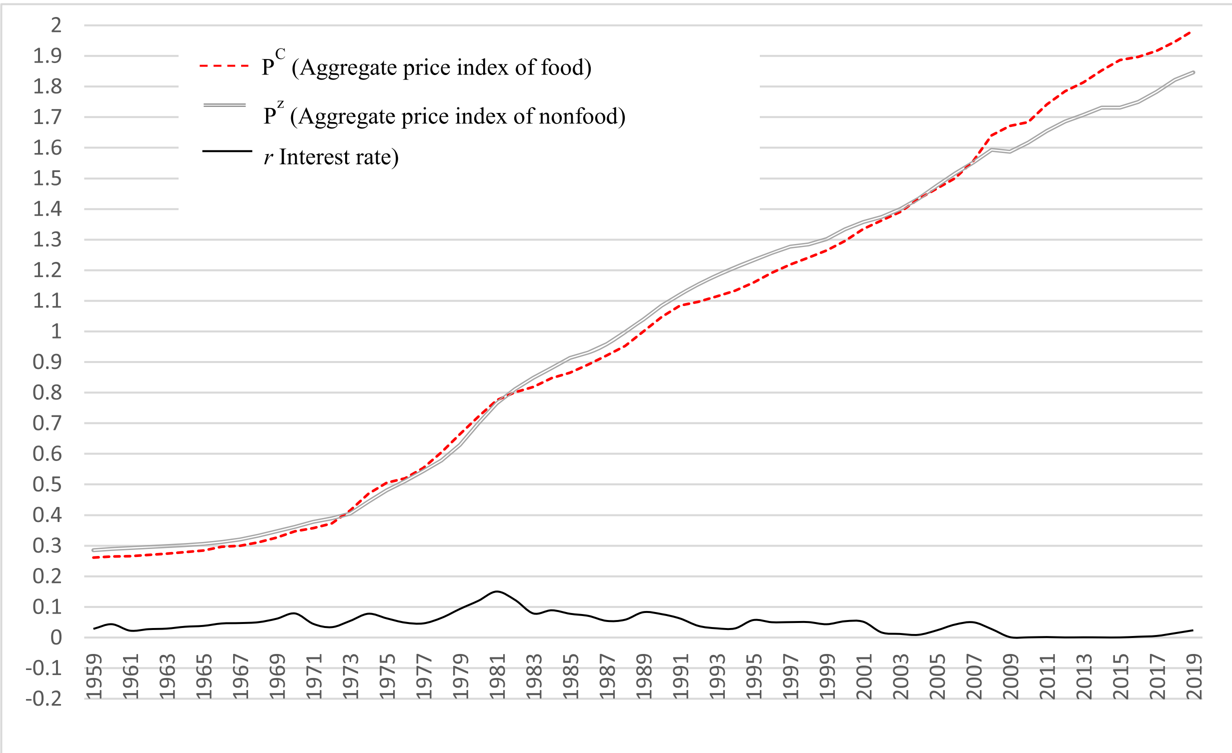

Fig. 2. Movements of price indices and interest rate over time, 1959 - 2019.
Notes: The price indexes P^C and P^z are obtained from NIPA data, published by the Bureau of Economic Analysis, U.S. Department of Commerce. The interest rate r is the three-month Treasury bill rate taken from Federal Reserve Board's H.15 Statistical Release.

Table 1
Summary statistics, 1960 - 2019.

Variable	Mean (%)	Std Dev	Minimum	Maximum
Δ In C	5.44	2.44	0.50	12.82
Δ In z	2.93	1.78	−4.93	5.95
Δ In p_1	3.20	5.22	−9.16	26.19
Δ In p_2	3.03	5.58	−6.07	23.97
Δ In p_3	2.96	4.18	−7.78	18.18
Δ In p_4	3.25	4.00	−8.24	15.34
Δ In p_5	3.35	6.67	−11.47	41.15
Δ In p_6	1.92	7.06	−11.65	25.21
Δ In p_7	3.89	2.54	−1.37	12.33
Δ In p_8	3.17	7.72	−7.22	45.51
Δ In p_9	2.29	2.70	−3.20	14.06
Δ In p_z	3.14	2.33	−0.38	10.69
In $(1+r)$	4.44	3.08	0.03	13.99
Δ In Y^d	5.42	2.49	−1.14	10.33
Δ In M	6.46	2.53	−1.35	11.01
σ_c^2	0.35	0.32	0.00	1.64
σ_z^2	0.12	0.09	0.01	0.35

Notes: C = food consumption, z = quantity index of nonfood, p_1 = price of cereals and bakery, p_2 = price of meat, p_3 = price of egg, p_4 = price of milk and dairy products, p_5 = price of fruit and vegetables, p_6 = price of other foods, p_7 = price of non-alcoholic beverage, p_8 = price of take-away food, p_9 = price of alcoholic beverage, p^z = nonfood price, r = interest rate, Y^d = disposable income, M = total consumption, σ_c^2 = conditional variance of food consumption measured by its realized value $(\Delta \text{In} C)^2$, and σ_z^2 = conditional variance of nonfood quantity measured by its realized value $(\Delta \text{ In } z)^2$. Most of the variables are constructed using NIPA data, published by the Bureau of Economic Analysis, U.S. Department of Commerce. The interest rate r is the three-month Treasury bill rate taken from Federal Reserve Board's H.15 Statistical Release.

autocorrelation diagnostics revealed in the Durbin-Watson and Box-Pierce χ^2 statistics suggest that serial correlation in the error terms is no longer severely pathological.

While these results lend credence to our proposed methodology, there are some estimated parameters that are of particular interest. For example, the estimated ζ (0.846) is significantly different from zero, substantiating the relevance of the Box-Cox transformation of the indirect utility function (7). The value of φ (0.334) is significantly positive to provide evidence against weak separability of food items from nonfood. The estimated value of η (0.275) is also significantly positive, and not all of β_i, $i = 1,\ldots,$ N, are insignificantly different from zero, implying that within-period preferences are not homothetic in food items. Finally, the estimated time preference rate $\rho$of 0.067 means that consumers discount the utility of future consumption at an annual rate of 6.7 %. The intertemporal stability condition for consumers facing a given interest (Kim, 2017). With the average annual interest rate of 4.6 % in the sample period, this condition is violated, implying that U.S. consumers are, to a large extent, deemed impatient, in the sense that they have a high time preference for present consumption relative to the risk-free interest rate. Interestingly, when the equity rate of return is used, the stability condition is satisfied.

5.2. *Estimated food and nonfood demand elasticities and relative risk aversion*

Table 3 displays several sets of estimated expenditure and price elasticities for food and nonfood along with different estimates of relative risk aversion (RRA). These estimates are based on the theoretical framework presented in Appendices B and C and, and are evaluated at the sample means of the variables with the parameter estimates from Table 2. In the interest of space, the detailed derivations of the elasticities and RRA using the MPIGLOG derivatives in Sub-Section 3.1 are not presented here but are available upon request.

The columns denoted with "TR" present the traditional elasticities estimated with the food budget share Eqs. (36) excluding nonfood (by setting $\varphi = 0$); estimation does not include the Euler equations for food and nonfood. The traditional model is based on weak separability of food items from nonfood, which is rejected. The columns with "UC" and "UM" are the unrestricted elasticities when nonfood is allowed to vary; UC elasticities are conditional on food consumption C_t, while UM elasticities are conditional on total expenditure on food and nonfood M_t.

Several important results emerge from Table 3. To begin, the expenditure and price elasticities based on TR indicate that traditional studies are biased in comparison with those estimated by the models including nonfood and Euler equations. Of interesting is that when nonfood and Euler equations are included, a comparison of UC and UM elasticities for food reveals a considerable difference in expenditure elasticities but no significant difference in price elasticities. A possible explanation for low UM expenditure elasticities is that non-food (or food) item is fairly sensitive (or insensitive) to income change. Consequently, a rise in income from C_t to M_t results in a sharp increase in non-food but, to a lesser degree, in the demand for food. On average, the UM expenditure elasticities are relatively high for eggs (x_3) and food away from home (x_8) but these elasticities are considerably below 0.5 for cereals (x_1), milk (x_4) and non-alcoholic beverages (x_7). Remarkably, eggs and non-food are own-price responsive having own-price elasticities of −1.06 and −1.03 respectively whereas food away from home has the lowest own-price elasticity at −0.73.

Table 2
Joint estimation results: budget share system and euler equations (t ratios in parentheses).

Parameter	Estimate	Parameter	Estimate	Parameter	Estimate
α_1	0.112 (6.017)	τ_A	0.077 (3.230)	β_9	0.020 (3.090)
α_2	0.071 (1.577)	β_1	0.011 (1.546)	η	0.275 (6.325)
α_3	−0.006 (−0.860)	β_2	0.026 (1.910)	φ	0.334 (3.987)
α_4	0.005 (0.253)	β_3	0.003 (1.372)	γ	−0.284 (−3.291)
α_5	0.045 (2.635)	β_4	0.006 (1.015)	ϕ	0.339 (4.186)
α_6	0.187 (6.187)	β_5	0.013 (2.243)	ξ	0.846 (40.375)
α_7	0.079 (3.899)	β_6	0.031 (2.474)	ρ	0.067 (3.403)
α_8	0.413 (10.411)	β_7	0.010 (1.490)		
α_9	0.093 (5.033)	β_8	0.155 (7.027)		

J test of the overidentifying restrictions: χ^2statistic = 91.198, p value = 0.881

Log-likelihood value: 2393.91

Commodity	R^2	DW statistic	Box-Pierce χ^2statistic $\left(\chi^2_{2.5\%,6} = 14.45\right)$
x_1	0.757	1.884	9.540
x_2	0.980	2.178	20.300
x_3	0.999	2.376	18.300
x_4	0.991	1.649	8.000
x_5	0.975	2.184	7.260
x_6	0.896	2.205	19.400
x_7	0.923	1.635	9.170
x_8	0.996	1.303	11.700
x_9	0.819	1.293	10.800
z	0.996	1.875	4.020

Notes: x_1 = cereals and bakery, x_2 = meat, x_3 = eggs, x_4 = milk and dairy products, x_5 = fruits and vegetables, x_6 = other foods at home, x_7 = non-alcoholic beverages, x_8 = food away from home, x_9 = alcoholic beverages, and z = nonfood. Estimation is based on the nine food budget share equations in (36), the inverse share equation for nonfood in (37b), and the Euler equations for food consumption and nonfood in (38) and (39), using nonlinear 3SLS. The calculated R^2 is the generalized R^2 for instrumental variables regressions (see Pesaran and Smith, 1994), and DW = Durbin-Watson statistic.

Okrent and Alston (2011) used the same food groupings as ours and estimated a nonseparable food demand system by including an aggregate nonfood. Particularly, our estimates show a stable value of around 0.50 for all food items, but in Okrent and Alston, these estimates range from −0.69 for eggs (inferior) to 1.07 for non-food. The overall dissimilarity between our results and those of Okrent and Alston is expected, as this study covers more updated data and, more importantly, employs modeling and estimation methods that are different and more general than any earlier studies.

The estimated RRA coefficient shows a marked difference in different specifications of the model.[18] Specifically, the UC RRA is 0.738 while the UM RRA rises to 2.204. Notably, all RRA coefficients for different specifications fall within the range of the usual a priori values considered reasonable for relative risk aversion (1<RRA<5) (Cochrane, 2005; see also Kocherlakota, 1996). Thus U.S. consumers, in general, have low risk aversion with respect to food as well as total consumption. Note also that the RRA coefficients changed significantly over time, and reveal that consumers have becomes more risk averse in recent years.

The above results indicate that existing studies ignoring nonfood, based on the separability assumption or treating nonfood as exogenous, produce biased results, especially with respect to expenditure elasticities, leading to inaccurate policy implications. Further, they demonstrate the importance of properly allowing for nonfood. In allowing for nonfood, the relevant elasticities and RRA measure should be conditional on total expenditure rather than food expenditure. In a partial awareness of these problems, there are some studies estimating a nonseparable food demand system by including nonfood (Okrent and Alston, 2011; see also Zhen et al., 2017). These studies bypass endogeneity of food expenditure, but they utilize different methodologies and fail to account for the interplay between the consumer's intratemporal and intertemporal decisions.

[18] It should be noted that the *t* values for RRA are calculated with less precision because they are based on the complex RRA formulas; see Readers' Appendix C.

Table 3
Estimation results: nondurable and durable demand elasticities and relative risk aversion (t ratios in parentheses).

Conditioning Variables: TR:$(C_t, \mathbf{p}_t)$, UC:$(C_t, \mathbf{p}_t, p_t^z)$, and UM: $(M_t, \mathbf{p}_t, p_t^z)$								
Commodity	Expenditure Elasticities			Own Food Price Elasticities			Nonfood Price Elasticities	
	TR	UC	UM	TR	UC	UM	UC	UM
x_1	0.854	0.805	0.460	−0.918	−0.925	−0.853	0.053	0.256
	(14.618)	(18.472)	(6.417)	(−42.049)	(−69.777)	(−35.894)	(0.709)	(7.015)
x_2	0.996	1.060	0.505	−0.935	−0.938	−0.925	0.113	0.247
	(344.761)	(16.039)	(5.076)	(−77.112)	(−34.379)	(−105.649)	(0.499)	(5.730)
x_3	0.993	0.697	0.687	−0.849	−0.850	−1.059	0.706	0.213
	(−0.141)	(2.534)	(4.118)	(−2.007)	(−10.996)	(−70.017)	(3.153)	(3.574)
x_4	0.719	1.541	0.439	−0.978	−0.953	−0.991	0.447	0.259
	(0.065)	(5.699)	(4.802)	(−3.228)	(−44.356)	(−216.370)	(0.687)	(6.791)
x_5	1.018	0.995	0.494	−0.935	−0.935	−0.935	0.070	0.250
	(117.823)	(17.534)	(5.542)	(−82.861)	(−53.769)	(−155.704)	(0.380)	(6.122)
x_6	0.915	0.871	0.554	−0.925	−0.926	−0.803	0.012	0.241
	(23.833)	(19.817)	(9.746)	(−47.447)	(−31.438)	(−17.151)	(0.115)	(6.020)
x_7	0.796	0.833	0.477	−0.912	−0.927	−0.878	0.035	0.254
	(9.578)	(18.702)	(6.652)	(−36.069)	(−74.603)	(−42.297)	(0.385)	(6.701)
x_8	1.074	1.071	0.732	−0.998	−0.934	−0.732	0.122	0.213
	(42.048)	(15.532)	(29.718)	(−160.331)	(−7.774)	(−11.436)	(0.509)	(4.840)
x_9	0.943	0.805	0.547	−0.929	−0.931	−0.864	0.021	0.241
	(36.543)	18.472)	(7.384)	(−58.725)	(−43.445)	(−27.005)	(0.153)	(5.740)
z	—	0.842	1.090	—	—	—	−2.046	−1.029
		(2.803)	(27.864)				(−1.322)	(−79.436)

Coefficient of Relative Risk Aversion (RRA)		
TR	UC	UM
2.770	0.738	2.204
(0.290)	(7.518)	(1.288)

Notes: TR = traditional model, UC = unrestricted model conditional on C, UM = unrestricted model conditional on M, C_t = nondurable consumption, $\mathbf{p}_t$ = vector of nine food prices, z_t = nonfood, p_t^z= nonfood prices, and M_t = total expenditure on food and nonfood. x_1 = cereals and bakery, x_2 = meat, x_3 = eggs, x_4 = milk and dairy products, x_5 = fruits and vegetables, x_6 = other foods at home, x_7 = non-alcoholic beverages, x_8 = food away from home, and x_9 = alcoholic beverages, and z = nonfood. Computation of these elasticities and RRA is based on the expressions derived in Appendices B and C evaluated at the sample means of the variables.

5.3. *Estimated food and nonfood consumption growth equations*

In this subsection, we seek to find out whether the observed fluctuations in food consumption and nonfood growth as plotted in Fig. 1 can be explained by the intertemporal food consumption and nonfood equations derived in Eqs. (25) and (26). These equations are estimated by different methods and the main findings are reported in Table 4. We note that results reported in Columns 1 and 2 are based on the nonjoint estimation method which does not allow for the interaction between food consumption and nonfood growth. On the contrary, the findings reported in Columns 3 and 4 are based on joint estimation method that allows for the simultaneity between food consumption and nonfood growth. The last two columns of Table 4 summarize the results of the reduced form of the intertemporal food consumption and nonfood equations (see Eqs. (27) and (28)), which are estimated jointly.

While we assumed perfect capital markets in the theoretical discussion in Section 2, we relax this assumption and include disposable income growth as a measure of liquidity or borrowing constraints. Zeldes (1989) also found the evidence of liquidity constraints, using food consumption as a measure of total consumption. The consumer with liquidity constraints is limited in borrowing or incurring debt, but he can save and earn interest from his assets. An increase in disposable income allows him to borrow, thereby increasing current and future consumption. Liquidity constraints have no direct effect on the intratemporal allocations of food and nonfood, but theyaffect the intertemporal allocation of food consumption and hence nonfood consumption (see Kim, et al., 2021, in a different context). By including disposable income growth, we then estimate the food and nonfood consumption growth equations with an instrumental variables method as discussed in Sub-Section 3.2, using as instruments the first-order lags of all explanatory variables.

As expected, different specifications produce different results. Looking at nonjoint estimation results for food consumption growth, most of the coefficients of prices are small and insignificant. The interest rate also has a very small effect but is significant at a 10 percent level. Disposable income, on the other hand, has a large and significant effect. However, conditional variance for food consumption has the largest and significant effect on food and significant effect on nonfood growth.

The nonjoint estimation results change radically when we allow for the interaction between food consumption and nonfood with joint estimation. This impression is confirmed if we compare the parameter estimates shown in Columns 1 and 2 with those in Columns 3 and 4. The *p* value for the J-statistic shows that the overidentifying restrictions are not rejected at conventional significance levels, supporting the relevance of the chosen instruments. Interestingly, there is an asymmetric simultaneity between food consumption and

Table 4
Estimation results: food consumption and nonfood growth equations (t ratios in parentheses).

Estimation Method						
Regressor	Nonjoint		Joint		Reduced Form	
	$\Delta \ln C$	$\Delta \ln z$	$\Delta \ln C$	$\Delta \ln z$	$\Delta \ln C$	$\Delta \ln z$
Constant	0.027	0.014	0.022	0.016	0.018	0.018
	(9.969)	(5.900)	(10.022)	(9.309)	(8.594)	(7.497)
$\Delta \ln p_1$	−0.028	—-	−0.036	−0.006	−0.019	−0.006
	(−1.003)		(−1.806)	(−0.355)	(−1.032)	(−0.282)
$\Delta \ln p_2$	−0.001	—-	−0.015	−0.015	−0.013	−0.027
	(−0.041)		(−0.829)	(−0.912)	(−0.772)	(−1.448)
$\Delta \ln p_3$	0.003	—-	0.013	−0.015	−0.002	−0.005
	(0.556)		(0.444)	(−0.561)	(−0.095)	(−0.158)
$\Delta \ln p_4$	0.054	—-	0.014	0.019	0.021	−0.001
	(2.709)		(0.581)	(0.824)	(0.990)	(−0.044)
$\Delta \ln p_5$	0.010	—-	−0.003	−0.034	0.003	−0.016
	(0.562)		(−0.168)	(−2.210)	(0.184)	(−1.010)
$\Delta \ln p_6$	0.000	—-	−0.003	−0.016	−0.007	−0.012
	(−0.007)		(−0.209)	(−1.230)	(−0.578)	(−0.883)
$\Delta \ln p_7$	0.020	—-	−0.074	−0.038	−0.071	−0.085
	(1.330)		(−1.201)	(−0.649)	(−1.207)	(−1.300)
$\Delta \ln p_8$	−0.340	—-	−0.016	0.000	−0.016	−0.002
	(−3.505)		(−1.213)	(0.041)	(−1.343)	(−0.140)
$\Delta \ln p_9$	0.066	—-	−0.016	−0.012	−0.028	0.017
	(1.388)		(−0.452)	(−0.368)	(−0.921)	(0.504)
$\ln(1+r)$	0.076	−0.005	0.059	−0.015	0.006	0.019
	(1.619)	(−0.106)	(1.603)	(−0.442)	(0.173)	(0.487)
$\Delta \ln p_z$	—-	−0.222	—-	−0.165	0.490	−0.337
		(−2.937)		(−2.348)	(4.046)	(−2.504)
$\Delta \ln C$	—-	—-	—-	−0.197	—-	—-
				(−3.215)		
$\Delta \ln z$	—-	—-	0.025	—-	—-	—-
			(0.518)			
$\Delta \ln Y^d$	0.113	0.181	0.358	0.397	0.237	0.179
	(2.660)	(3.025)	(5.403)	(5.610)	(3.989)	(2.713)
σ_C^2	7.854	—-	5.093	—-	2.659	8.838
	(17.354)		(10.895)		(3.187)	(5.858)
σ_z^2	—-	12.040	—-	11.115	5.823	1.762
		(14.057)		(14.346)	(4.293)	(1.899)
R^2	0.956	0.905	0.953	0.915	0.965	0.924
DW	1.919	1.977	1.757	1.726	1.408	1.454
J test (p value)	0.300	0.037	0.194		0.195	
Wald test (p value)	0.001	—-	0.015		0.001	

Notes: C = food consumption, z = quantity index of nonfood, p_1 = price of cereals and bakery, p_2 = price of meat, p_3 = price of egg, p_4 = price of milk and dairy products, p_5 = price of fruit and vegetables, p_6 = price of other foods, p_7 = price of non-alcoholic beverage, p_8 = price of take-away food, p_9 = price of alcoholic beverage, r = interest rate, p^z = nonfood price, Y^d = disposable income, σ_c^2 = conditional variance of food consumption, σ_z^2 = conditional variance of nonfood. The calculated R^2 is the generalized R^2 for instrumental variables regressions (see Pesaran and Smith, 1994), DW = Durbin-Watson statistic, J test is a test the overidentifying restrictions, and Wald test is a test for the null hypothesis that all the coefficients for food prices are zero. Estimation is based on the growth equations for food consumption and nonfood in (25) and (26) as well as in (27) and (28), using an instrumental variables method.

nonfood growth. Nonfood growth has a positively small but insignificant effect on food consumption growth, as evidenced by the coefficient of 0.025 for joint estimation result. Nevertheless, food consumption growth has a large negative and significant effect on nonfood growth with the coefficient of −0.197 for the joint estimation result. The interest rate has a small and positive effect on food consumption growth, but, surprisingly, it has a negative effect on nonfood growth; it is insignificant in both cases. In addition, the effects of disposable income on food consumption and nonfood growth is strong and significant whilst conditional variance has the largest effect on food consumption, and particularly on nonfood growth.

Moving to the results based on reduced-form estimation method (see Columns 5 and 6 in Table 4), we figure out that the variables, in general, have the same signs and similar magnitudes as those of the joint estimation result. We read that the price of nonfood has a significant positive effect on food consumption growth but a negative effect on nonfood growth. Unpredictably, the interest rate has a negligible effect on both food and nonfood consumption. Additionally, there are significant positive effects of disposable income on food consumption and nonfood, particularly on food consumption. The evidence of uncertainty in food consumption and nonfood growth is also noticeable. In particular, uncertainty about nonfood has a substantial effect on food consumption growth. For instances, an increase in one unit of conditional variance of food consumption leads to a 2.659 % increase in expected food consumption growth, but an increase in one unit of conditional variance of nonfood leads to a 5.823 % increase in expected food consumption growth.

The present analysis is predicated on the premise that relative prices of food items play an important role in food and nonfood demands as well as in food and nonfood consumption. Table 4 reveals that growth of food prices, in general, has no significant effect on food consumption and nonfood growth. To examine this, we conducted a Wald test, which has a χ^2distribution, for the null hypothesis that all the coefficients for food prices are zero. The p values show that the null hypothesis is decisively rejected at conventional significance levels, suggesting strong evidence for the relative price effects of food items in food and nonfood consumption.

We draw some conclusions from the foregoing results. Although the estimated intertemporal functions for food consumption and nonfood have high R^2s, the observed fluctuations in food and nonfood spending growth depicted in Fig. 1 cannot be sufficiently explained by the variables identified in those equations. This is, to a large extent, due to a lack of sufficient intertemporal or temporary variations in major variables. Growth of food prices, generally, has significant effect on food consumption and nonfood growth. Nonfood price growth also has a significant effect on them. There is a strong effect of disposable income on food consumption and nonfood growth, with the effect being higher for food consumption growth. More importantly. there is considerable evidence of uncertainty for these goods, which is reflected in precautionary saving behavior Estimation of the elasticity of intertemporal substitution (EIS) is a key issue in macroeconomic and dynamic analyses. This elasticity is an important determinant of consumption and saving, and is essential to understanding many issues in the economy ranging from the effects of monetary and fiscal policies to the fluctuations in the business cycle (Hall, 1988). Our findings indicate that the EIS for food is very close to zero. Given that food is a necessity, the absence of intertemporal substitution in food consumption is, to a certain extent, plausible because necessities are not easily substitutable across time in response to a change in the interest rate. Notably, the low EIS is not unexpected and is consistent with Hall's (1988) assertion that consumption growth is completely insensitive to changes in interest rates, and hence, the intertemporal elasticity is very close to zero.

Based on the assumption that food and other consumption goods are additively separable, Zeldes (1989), Runkle (1991), Naik and Moore (1996) found that EIS is positive. These findings are questioned by Attanasio and Weber (1995), and they contended that the aforesaid assumption may seriously bias the EIS estimates solely based on food consumption. Evidently, our analysis is much more comprehensive in analyzing intertemporal substitution in food consumption as we incorporate nonfood and allow for relative prices of food as well as conditional variances by including disposable income. Incidentally, there are studies on farm households estimating the EIS that found high intertemporal substitution in consumption (Abdulkadri and Langemeier, 2000; Lense, 2000).

From the above discussions, we find that the key factors driving expected food consumption and nonfood growth are nonfood price growth, disposable income growth, and uncertainty about the future. Pope (2009) posed a question whether falling growth rates of food consumption during recessions are due to a fall in disposable income or they reflect uncertainty about the future. We believe that both are responsible for falling consumption growth. A fall in disposable income from the previous period during a recession causes consumption growth to fall. By the same token, economic weakness creates uncertainty to consumers, inducing them to delay consumption to the future with falling consumption growth accompanied by an increase in precautionary savings – a situation we observe during the coronavirus pandemic that began at the end of 2019 (Smith, 2020).

6. Summary and conclusion

Estimation of food demand has been an abiding interest in economic analysis to understand consumers' food consumption behavior. The tenor of this study is that a proper understanding of food consumption behavior entails an integration of the studies on food demand and intertemporal food expenditure with allowance for nonfood. To this end, we have presented a novel theoretical and empirical framework utilizing an intertemporal two-stage budgeting procedure, and performed an empirical analysis using U.S. data for 1959–2019. We find that separability of food items from nonfood adopted in most food demand studies is untenable. Moreover, excluding nonfood and failing to account for endogeneity of food expenditure and nonfood would lead to significant bias in estimated expenditure elasticities for food as well as in relative risk aversion. We further find that US consumers have a high time preference for present consumption relative to the risk-free interest rate. The estimated coefficient of relative risk aversion reveals that US consumers, in general, have low risk aversion with regard to food as well as total consumption. Unsurprisingly, no strong evidence is found for intertemporal substitution in food and in nonfood as well in response to a change in the interest rate. Most notably, we find that disposable income growth and, in particular, uncertainty are the key factors driving food and nonfood consumption growth.

Overall, these findings are illuminating and cannot be accounted for by a food demand study alone. To draw firm conclusions about food consumption behavior, more empirical work may be in order with a possibly refined empirical model and the better use of data. In particular, as pointed out in Footnote #18, household panel data, though ideal to examine consumer behavior with demographic information, lack sufficient information about disaggregate goods and have short time series, which is not conducive to a dynamic or intertemporal analysis requiring long time series. For this reason, annual time series data is employed in our analysis. Also, to provide detailed information about food items and for analytical tractability and manageability, nonfood items are aggregated and treated like a single good. We realize that not all nonfood goods share the same property, and relative prices of these durable goods have changed dramatically. Thus, it might be desirable to disaggregate them into several categories.[19] These limitations, especially of data, allow future research to expand and validate our findings in different contexts and with larger samples. Yet, our analysis underscores the importance of an integrated analysis for a proper understanding of consumers' food consumption behavior. An additional benefit of

[19] Given that our focus in this paper is to provide detailed information about food, we are not sure that disaggregation of nonfood affects our conclusions about food. Nonetheless, there are studies that disaggregate nonfood into several categories Deaton and Muellbauer, 1980; Blundell et al., 1994; Kim et al, 2020; Kim et al, 2020), but they treat food as an aggregate quantity.

such an analysis is to use the estimated food consumption growth equation as a forecasting tool. This equation identifies the relevant variables influencing food consumption growth and has a good predictive power as revealed by high R^2.

To conclude, while we utilized intertemporal two-stage budgeting to analyze food consumption behavior, this framework can also be employed to analyse nonmarket goods, such as public goods and environmental quality or amenities, which have been a long-standing interest in many areas of economics including agricultural and environmental economics (see Bockstael and McConnell, 1993). The key issue raised here is whether we can recover underlying consumer preferences, defined over market and nonmarket goods, from a demand system for market goods that is observable and depends on nonmarket goods. This, in turn, allows us to make welfare measurement for changes in nonmarket goods. Although it is widely believed that this is possible under certain special conditions such as weak complementarity or weak neutrality, Ebert (1998) showed that if the marginal willingness-to- pay functions for nonmarket goods can be estimated from surveys and questionaires, this information together with the estimated demands for market goods can be used to recover underlying consumer preferences and hence to derive welfare measures for nonmarket goods. However, the intertemporal framework can be utilized to analyze nonmarket goods when there is no available information about the marginal willingness-to-pay for these goods, without making any assumption about preferences, by treating food items as market goods and nonfood as nonmarket goods. This is based on the idea that the intertemporal first-order condition captured by the Euler equation for consumption (9), contains all information about consumer preferences as represented by the restricted indirect utility function (3). Hence, it provides essential information that is missing from the estimation of the demands for market goods to identify the parameters of the marginal willingness to pay for nonmarket goods.[20]

CRediT authorship contribution statement

H . Youn Kim: Writing – original draft, Methodology, Investigation, Formal analysis, Conceptualization. **K . K . Gary Wong:** Writing – review & editing, Software, Methodology, Formal analysis, Data curation.

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.eap.2024.12.015.

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[20] In this analysis, nonfood is endogenously determined, but nonmarket goods are typically determined exogenously. Hence, there is no need to include the Euler equation for nonmarket goods given in (39) for nonfood. Kim, et al. (2020) applied this procedure to public goods to measure the shadow price or marginal willingness to pay for them using national defense as an example.

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