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Consumer Demand and the Economy-wide Costs of Regulation: Modeling Households with Empirically Estimated Flexible Functional Forms

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NOTE: This paper was previously circulated under the title: "Consumer Demand Estimation for Heterogeneous U.S. Households". This new version of the paper incorporates textual edits that streamline, but largely leave unchanged, the narrative of the paper. This version of the paper also replaces the AIDS demand system with the QUAIDS demand system in the BEIGE (Basic Economy In General Equilibrium) economy-wide modeling framework and corrects a programming bug in the implementation of alternative demand systems within the model. There are very minor changes to the BEIGE model results due to the replacement of the AIDS demand system with the QUAIDS demand system (these two frameworks have similar estimated price and income elasticities). The corrected programming bug impacted the labor-leisure choice and quantity demanded results. Aggregate welfare results are largely unchanged. All empirical results from the econometric estimation are also unchanged.

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ABSTRACT: This paper estimates flexible demand systems for heterogeneous households in the United States and links the estimated parameters with an economy-wide model to assess their relative contributions to the social cost of regulation. We estimate elasticities for several final demand categories as well as labor-leisure elasticities that are important for calibrating the labor-leisure choice in the economy-wide model and find that estimated elasticities are relatively similar across regions but vary meaningfully by income. Using the estimated elasticities, we explore the implications of both the functional form and its parameterization in a simplified computable general equilibrium model for the social and distributional costs of illustrative policy scenarios. Model variants with less flexible consumer demand systems overestimate social costs when policy shocks are small and underestimate social costs when policy shocks are large relative to models that assume more flexible consumer demand. Furthermore, we find that parameterizing the model with elasticities that vary with household income is important for adequately characterizing the distributional implications of a policy.

KEYWORDS: Preference Structure; Households; Leisure; CGE; Distributional Effects; Environmental Regulation.

JEL CODES: D11, D12, D58, Q52, Q58.

1. Introduction[1]

As agencies and researchers strive to improve their understanding of the costs of large environmental and energy policies, they have turned to computable general equilibrium (CGE) models to capture interactions between regulated sectors and other parts of the economy (Bergman 2005; Nijkamp, et al. 2005). CGE models often specify consumer demand as a variant of the constant elasticity of substitution (CES) utility function, with substitution elasticities based on heuristic arguments or calibrated to estimates from the literature on aggregate consumer responses. The use of CES utility functions in CGE models is of concern given their failure to realistically capture well-known patterns of consumer behavior (Chen 2017; Annabi, et al. 2006). For instance, the imposition of unit budget elasticities violates Engel's Law for food demand, which has been confirmed in the empirical literature (e.g., Clements and Si 2018; Taylor 2019; Holcomb, et al. 1995).[2] In addition, Clements, et al. (2020) show that differentiating demand estimates by household type better captures the non-monotonic relationship between income and consumption, suggesting that CGE models with heterogeneous households can help capture observed behavioral responses when properly parameterized. This paper attempts to fill this gap by first estimating heterogeneous demand elasticities consistent with empirical observations on consumer behavior and then incorporating them into a simplified CGE model to illustrates their importance for evaluating a policy's social costs and distributional implications.

Federal agencies typically assess the economic effects of a regulation as the difference between a baseline, representing the economy without a regulation, and a policy case. In a CGE modeling context, the specification of consumer demand can be important for both sides of this calculation. While preferences are typically assumed to be time invariant, it is important that baseline consumption growth is consistent with projected changes in income and prices over time (Cranfield, et al. 2002; Ho, et al. 2020). In modeled policy outcomes, preferences can play an important role in the tax interaction effect via own-price and cross-price derivatives of demand (West and Williams 2007). Consumer preferences also define final good demand, which helps determine the ability to reduce pollution on the extensive margin. Moreover, how consumer

[1] We thank Bettina Aten for providing price parity data, and Sarah West and Mun Ho for their helpful comments.

[2] Engel's Law states that consumers increase their expenditures for food with as income rises but at a decreasing rate.

preferences are specified can affect the relative share of abatement costs borne by factors of production as well as how different groups of consumers will fare.

Flexible demand systems that allow for non-monotonic income effects and heterogeneous cross-price elasticities have been used to examine the impacts of many types of policies in non-CGE modeling settings (e.g., Härkänen, et al. 2014; Erdil 2006).[3,4] These studies tend to focus on a specific sector and therefore often consolidate the remainder of consumer demand into one or two highly aggregated categories.[5] They also often exclude leisure from the estimation. In the context of environmental and energy policies, Schulte and Heindl (2017) estimate demand for energy and six other aggregate categories (excluding leisure) for Germany disaggregated by household size and expenditure quartiles. Cao, et al. (2020) estimate demand for food, consumer goods, services, and housing (also excluding leisure) in China. West and Williams (2004) include leisure in the consumer demand estimation, but since their focus is on the distributional implications of the U.S. gasoline tax, consumer goods are represented by just two categories: gasoline and all other goods.

Characterizing a consumer demand system in a CGE model is complicated by several factors. CGE models often require demand elasticities at a greater level of disaggregation than are available in many empirical applications and many CGE models require a demand elasticity for leisure to connect consumption decisions with labor supply.[6] The demand system also needs to be regular to ensure that the model is reliably solved (Perroni and Rutherford, 1995).[7,8] In most cases, CGE models simply avoid these issues by calibrating simpler functional forms such as a constant

[3] Flexibility of a demand system is related to the number of constraints imposed on income and price elasticities. Income flexibility allows for the existence of normal and inferior goods, while price flexibility allows for substitutes and complements to be reflected in cross-price elasticities.
[4] Estimation strategies range from differential approaches (i.e., no specific utility function is assumed and the total differential of the Marshallian demand function is estimated) to parametric, semi-nonparametric (e.g. asymptotically globally flexible functional forms) and non-parametric approaches.
[5] One exception to this more focused approach is Taylor (2009), who estimates U.S. national-level income and price elasticities for six aggregate consumption categories using several different flexible demand specifications.
[6] Many CGE models assume leisure is separable and labor supply is an exogenous function of population; some CGE models explicitly model the labor-leisure tradeoff (e.g., ADAGE, EPPA-HE, and IGEM). See Ho, et al (2020).
[7] Regularity for Marshallian demand systems must satisfy properties such as nonnegativity, adding up, homogeneity, and the symmetry and negative semi-definiteness of the Slutsky matrix (Deaton and Muellbauer, 1980). See also Caves and Christensen (1980) and Barnett and Serletis (2008).
[8] West and Williams' (2004) AIDS imposes homogeneity and symmetry conditions. Schulte and Heindl's (2017) QES demand system satisfies homogeneity and symmetry conditions by construction; they test for positivity and negative semi-definiteness. Cao, et al. (2020) impose the curvature constraint locally when concavity does not hold by employing a reparametrized version of the translog model such that the Slutsky matrix is negative semidefinite.

elasticity of substitution (CES) or linear expenditure system (LES).[9] These utility functions have withstood the test of time in large part because they are easy to calibrate, while the needed parameters to calibrate alternative, more empirically grounded functional forms are generally lacking in the literature. It is this gap we hope to address.

Inherent in these simplifying assumptions is a tradeoff between regularity and empirical validity. For instance, while the CES functional form satisfies regularity and has other desirable computational and calibration properties, it does not allow substitution elasticities to differ across pairs of goods and restricts the budget elasticity of demand to one (Ho, et al. 2020).[10] Calibration of simpler functional forms to available estimates in the literature also brings a host of additional complications. For example, behavioral assumptions underlying the estimation framework are often inconsistent with CGE model assumptions. Elasticity estimates in the literature are also often not routinely updated, leading to empirical values that are significantly older than data used to specify CGE baseline and policy scenarios.[11]

In response to these concerns, a few CGE modelers have empirically estimated their own parameters to ensure internal consistency. Several modelers have estimated income elasticities to parameterize the LES demand system (Gharibnavaz and Verikios 2018; Jussila, et al. 2012). Among U.S. CGE models, IGEM is unique in its use of a national level, empirically estimated flexible translog demand system for full consumption of three aggregate goods and leisure (Jorgenson, et al. 2013). Yu, et al. (2004) estimate parameters using AIDADS (An Implicitly Direct Additive Demand System) for use in a global CGE model and show that they are better able to capture empirically-based baseline trends (e.g., decreasing budget elasticities for food with increasing incomes) compared to a demand system with limited flexibility (e.g., LES). De Boer,

[9] A CES utility function is used in the EPPA, ADAGE, and Rutherford CGE models (Paltsev, et al. 2005; Ross 2007; Rutherford 1999). The FARM, AIM CGE, EPPA (v6), GEM-E3, Globe, Imaclim-R, Mirage, and DART CGE models use LES elasticities (Sands, et al. 2017; Fujimori, et al. 2012; Capros, et al. 2013; McDonald, et al. 2007; Ho, et al. 2020). GTAP uses a constant difference in elasticity demand system (Chen 2016).

[10] Variants such as the LES and nested CES functions relax some of these restrictions while maintaining regularity. However, while the budget shares from an LES function can differ with income, budget elasticities of demand approach one as income increases, which is inconsistent with empirical evidence about the non-linearity of the Engle curve (Chen 2016; de Boer and Paap 2009). In addition, LES demand systems do not allow for the existence of inferior goods, elastic demand, or negative cross-price elasticities (Chung 1994; Parks 1969). While the relatively high level of aggregation in CGE models lowers the chance of having elastic demand or an inferior good, Engel curve inflexibility and cross-price elasticity restrictions remain a concern (see Appendix A).

[11] Hertel, et al. (2007) have also been critical of borrowing point estimates from the empirical literature without considering their confidence intervals, potential biases, and differences in aggregation compared to the CGE model.

et al. (2021) consider the CGE modeling implications of the simplifying assumptions needed to estimate LES and IAS (indirect Addilog System) demand system parameters when data are scarce. None of these efforts, however, conduct comparative exercises across consistently estimated parameterizations of alternative demand systems; nor do they consider estimated elasticities for heterogeneous consumer types.

In this study, we estimate several flexible consumer demand systems (i.e., Quadratic Almost Ideal Demand System and Almost Ideal Demand System) for the United States inclusive of leisure and with more goods and services categories than often available in the empirical literature. We also estimate a less flexible consumer demand system (i.e., LES) to compare across different frameworks in a general equilibrium model. We contribute to the empirical literature by both updating available elasticity estimates and exploring the extent to which demand elasticities differ by region and household income. We find that estimated elasticities are relatively similar across regions but vary with income. We also develop a post-processing test for verifying whether estimated parameters satisfy concavity conditions needed for CGE modeling applications. Our estimating framework includes leisure as a demand category so we can derive labor supply elasticities for calibrating the labor-leisure choice in the CGE modeling framework. This allows for consistent interpretation when adapting estimated elasticities to a CGE model across all demand categories.[12] Finally, we run a weak-separability test and find that we fail to reject the null that leisure is weakly separable from other consumption categories suggesting the validity of including leisure as a separate demand category.

We next use our estimated income, price, and labor supply elasticities to investigate the social cost and incidence implications of policy shocks under different consumer demand specifications. Using a simple CGE model called BEIGE (Basic Economy in General Equilibrium), we find that model variants with less flexible consumer demand systems overestimate social costs when policy shocks are small and underestimate social costs when policy shocks are large relative to models that assume more flexible consumer demand. Moreover, we find that parameterizing the model with preferences specific to a given household type (denominated by income) is important for

[12] If leisure is not explicit in the econometric model, estimated elasticities are implicitly inclusive of leisure impacts suggesting that the elasticities cannot consistently be mapped to a CGE model with leisure as a separate category. In general, this issue illustrates the challenges in adapting estimated elasticities from the literature to a CGE model where behavior responses may not perfectly match underlying assumptions implicit in the estimated parameters.

adequately characterizing the distributional outcomes of a policy. To our knowledge, this is the first paper to use a CGE model to compare several consumer demand specifications consistently estimated from the same data set.

The paper is organized as follows. Section 2 describes the empirical framework for estimating demand elasticities. Data and imputation challenges are discussed in Section 3, followed by the demand system estimation strategy in Section 4. Summary statistics are presented in Section 5. Section 6 discusses results from our estimation framework. Section 7 provides an illustrative CGE analysis of how the social costs of regulation and other important outcomes vary across demand specifications and accompanying elasticity estimates. Section 8 concludes.

2. Empirical Framework

The main criteria in choosing a functional form for demand system estimation are flexibility in the budget shares, flexibility in own-price, cross-price, and budget elasticities, regularity[13] and computational tractability.[14] However, as previously mentioned, there is a trade-off between flexibility and regularity of demand functions (McLaren and Yang 2016). Because it is both effectively globally regular and offers a high degree of price and income flexibility, we prefer the QUAIDS specification.[15] For comparison, we also estimate AIDS and LES specifications. The LES specification has some level of Engel flexibility; adding subsistence consumption allows the expenditure share to change as income changes. However, the marginal expenditure shares are constant. QUAIDS relaxes this constraint by including squared income. In addition, own price elasticities in LES demand cannot be elastic unless subsistence consumption is negative. As subsistence demand approaches zero, the budget elasticities approach one (See Appendix B).

Using a static framework, QUAIDS has the following indirect utility function (Banks, et al. 1997):

[13] Even when a demand system satisfies regularity conditions locally, they may not satisfy the regularity conditions for large shocks to the price or income variables (i.e., they are not globally regular).

[14] More flexible demand systems are less computationally tractable because of challenges in precisely estimating parameters. Solving a CGE model calibrated to a flexible functional form is also more computationally challenging.

[15] Some demand systems are “effectively globally regular” (Cooper and McLaren 1996), the regularity region is an unbounded domain that includes all sample price and income/expenditure data points as well as any combination of price and nominal expenditures (McLaren and Yang 2016; Fisher, et al. 2001). The LES and QUAIDS specifications belong to this class (Reimer and Hertel 2004; McLaren and Yang 2016). See Appendix A for other examples.

$$ln\, v(p,m) = [\left(\frac{\ln m - \ln a(p)}{b(p)}\right)^{-1} + \lambda(p)]^{-1}, \qquad (1)$$

where $\lambda(p) = \sum_{i=1}^{N} \lambda_i lnp_i$ and $\sum_{i=1}^{N} \lambda_i = 0$. We define a household's expenditure share for goods category i as $w_i \equiv \frac{p_i q_i}{m}$ where *m* represents total household expenditures such that $\sum_{i=1}^{N} w_i = 1$.

Applying Roy's identity to the indirect utility function, the expenditure share, w_i , for each good category *i* and household *h* with the N-vector *p* has the following form:

$$w_i^h = \alpha_i + \sum_{j=1}^{N} \gamma_{ij} \ln p_j^h + \beta_i \ln \{\frac{m^h}{a(p)^h}\} + \frac{\lambda_i}{b(p)^h} [\ln \left\{\frac{m^h}{a(p)^h}\right\}]^2 \qquad (2)$$

where p_i is the own price of good *i*, p_j is the price of other goods *j*, and $ln\, a(p)$ is a translog price index, where $ln\, a(p) = \alpha_0 + \sum_{i=1}^{N} \alpha_i \ln p_i + \frac{1}{2} \sum_{i=1}^{N} \sum_{j=1}^{N} \gamma_{ij} \ln p_i \ln p_j$ and $b(p) = \prod_{i=1}^{N} p_i^{\beta_i}$.

We employ Pollak and Wales's (1981) translating approach to allow for household heterogeneity. Sociodemographic variables, *s*, enter the model through α, where $\alpha^h = As^h$ and $A = (\alpha_i{}'), \alpha = (\alpha_1, \ldots, \alpha_N)'$. Heterogeneity appears linearly through the intercept and nonlinearly through the translog price index (Lecocq and Robin 2015). Following Jorgenson, et al. (2013) and Cao, et al. (2020), *s* includes age, education level, family size, number of children, and gender. We also include number of income earners and home ownership status as factors impacting the demand for housing and leisure. Note that the share equation reduces to AIDS if all λs are equal to zero.

Regularity requires that the consumer demand system satisfy the adding up, homogeneity in prices, symmetry and curvature/concavity constraints. The first three conditions require that:

$$\sum_{i=1}^{N} \alpha_i = 1 \;\; (adding\ up), \qquad (3a)$$

$$\sum_{i=1}^{N} \beta_i = 0, \sum_{i=1}^{N} \lambda_i = 0, \sum_{j=1}^{N} \gamma_{ij} = 0 \;\; (homogeneity), \qquad (3b)$$

$$\gamma_{ij} = \gamma_{ji}\,, and\ A = w_i[\epsilon_{ij}^c] is\ symmetric \;\; (symmetry), \qquad (3c)$$

where A is an *N x N* matrix and ε_{ij}^c is the compensated elasticity for category *i* with respect to the price of category *j*. Notably, this matrix is symmetric given the definition of the Allen-Uzawa substitution elasticity matrix, $\sigma_{ij}^{au} = \epsilon_{ij}^c / w_j$. The symmetry condition implies that the effect of the logarithm of price i on budget share j is equal to the effect of the logarithm of price j on budget share i. The adding up constraint holds by construction. We test that the homogeneity and symmetry conditions are satisfied and then impose them as needed in the demand system.

The concavity constraint requires that matrix A be symmetric and negative semidefinite (Banks, et al., 1997). If we define A_k as the submatrix of A obtained by taking the upper left-hand corner k × k submatrix of A, concavity is satisfied if (Barnett and Seck 2008):

$$(-1)^k det(A_k) > 0 \text{ for } k = 1, 2, \ldots, N-1. \quad (3d)$$

The share equation (2) is simultaneously estimated for each expenditure category as a function of income, price levels, and other explanatory variables. While coefficient estimates are not directly interpretable as elasticities, they can be calculated. The expenditure elasticity is defined as:

$$\eta_i = \frac{\mu_i}{w_i} + 1, \quad (4)$$

where μ_I is the first differential with respect to $\ln(m)$. The uncompensated price elasticity is:

$$\epsilon_{ij} = \frac{\mu_{ij}}{w_i} - \delta_{ij}, \quad (5)$$

where δ_{ij} is the Kronecker delta (it equals 1 if $i = j$ and 0 otherwise) and μ_{ij} is the first differential of w_i with respect to $\ln(p_j)$. Finally, the compensated price elasticity is defined as:

$$\varepsilon_{ij}^{c} = \epsilon_{ij} + \eta_i w_j , \quad (6)$$

where μ_i and μ_{ij} are calculated as:

$$\mu_i = \frac{\partial w_i}{\partial \ln(m)} = \beta_i + \frac{2\lambda_i}{\prod_{i=1}^{N} p_i^{\beta_i}} [ln(\frac{m}{a(p)})] \text{ , and}$$

$$\mu_{ij} = \frac{\partial w_i}{\partial \ln(p_j)} = \gamma_{ij} - \mu_i\left(\alpha_j + \sum_k \gamma_{jk} ln(p_k)\right) - \frac{\lambda_i \beta_j}{\prod_{i=1}^{N} p_i^{\beta_i}} \{\ln [\frac{m}{a(p)}]\}^2$$

Due to the computational challenges of estimating a highly disaggregated system, it is common to estimate demand for broad consumption categories. We estimate consumer demand for non-durables, consumer services, housing, utilities and public services, transportation, and leisure.

While the empirical literature often excludes leisure, it is important for us to include because it provides information about labor supply elasticities. In addition, consumption and labor supply are related through cross-price elasticities between leisure and other consumption categories. This structure also requires the implicit assumption of weak separability in the associated utility function. Clements, et al. (2020) demonstrate that this is a reasonable assumption when consumption is defined in terms of broad categories. In addition, the level of aggregation makes creating consistent price indices from available data achievable.

4. Data and Imputation Challenges

To estimate U.S. consumer demand, we combine Consumer Expenditure Survey (CEX) data with estimated price levels to generate a pooled cross-section of household-level expenditures and quarterly prices at the state level from 2013 to 2017. We describe each of these data sources below, including how we address several data imputation challenges. We then define the key variables in the demand specification.

4.1. Consumer Expenditure Survey Data

Household expenditure data are from the U.S. Bureau of Labor Statistics CEX public use microdata, which also provide detailed information about household income, demographic, and socioeconomic characteristics. The data are reported for Consumer Units (CUs) where CU members are related by blood, marriage or other legal arrangement, or are financially dependent (i.e., live together and share responsibility for expenditures on housing, food and other living expenses). We assume that a CU is equivalent to a household, though they are not always the same.

The CEX survey is a rotating panel that includes around 7,000 usable interviews for each calendar quarter of the year, of which around one-fourth of the CUs are new to the survey. Interview surveys are designed as a representative sample of the entire U.S. civilian noninstitutional population. The data have been collected since 1980 but income tax data have only been available since 2013. The addition of these income tax data facilitates the calculation of after-tax wages and leisure values. For each of the six expenditure categories in the consumer demand specification, we identify corresponding CEX expenditures. For a few categories, namely leisure and the flow of vehicle services in transportation, we impute expenditure values based on information available in the

CEX. We drop a small number of negative expenditures for health care and housing (470 and 11 observations, respectively).[16] In addition, we remove extreme outliers from the sample.[17]

In determining an appropriate age cut off for the sample, we find that both income and expenditures begin to decline after age 65, with a marked decline after age 70. Older adults also spend far less on transportation and clothing but more on health care. This is true even though most expenditures on nursing home care are excluded from the CEX (Foster 2015). In addition, while adults between 65 and 70 years old are evenly distributed across income groups, a majority of adults over 70 years old are in the low-income group. To facilitate comparison with estimates in the literature and retain some aspect of representativeness for the CGE modeling exercise, we exclude CUs with a reference person aged more than 70 years old (15,548 CUs).[18] See Appendix C for details on the data. We explore the sensitivity of results to the age cut-off in Section 6.1.

In addition, we exclude households with more than two adults (16,182 CUs). We cannot determine how CUs with more than two adults make expenditure decisions – for instance, the degree to which they are made jointly or independently. The number of adults in a household also influences total leisure time and therefore labor supply elasticities. CUs with more than two adults also may not be considered households from a tax perspective (e.g., roommates). Section 7.3 examines the sensitivity of the results to including CUs with more than two adults.[19]

4.1.1. Measuring Leisure

Most CGE models calibrate the labor-leisure choice in one of two ways: by using estimated labor supply elasticities from the literature and calibrating leisure to the level of output and general labor supply characteristics in the economy (Fox, 2002), or by estimating the leisure/labor elasticities

[16] CUs are asked to exclude expenditures they expect will be reimbursed by someone outside the CU (e.g., insurance company or employer). We remove reimbursements and gifts from the health care expenses category.
[17] At the national level, we drop CUs with an hourly wage greater than $2,500 (14 observations) and quarterly housing expenditures greater than $162,562 (35 observations). We also drop outliers within each income group (170 observations). We find little difference in elasticity estimates when we include outliers in the demand estimation.
[18] A reference person is the CU member who is reported by the respondent as the main person in charge of paying and/or making decision for major expenditures such as rent.
[19] While we exclude these CUs from the sample for the final demand system estimation, they are included in the Heckman correction model and vehicle services imputation process to ensure consistency across subsamples.

empirically. To pursue this latter approach, we include leisure explicitly in the consumer demand system. However, leisure price and quantity are not directly reported in the CEX.

To impute these values for each CU, we use the after-tax hourly wage as a proxy for leisure price, multiplied by an estimate of leisure time to obtain leisure expenditures. We use the American Time Survey definition for leisure, which includes activities such as socializing and communicating, watching TV, participating in sport, exercise, and recreation (Bureau of Labor Statistics 2015).

Specifically, after-tax wages for each reference person in a CU, *i,* are calculated as:

$$\textit{After-tax wage}_i = \frac{reference\ \ person\, wage\ i}{hours\, worked\, by\, reference\ \ person\, i} * (1 - \textit{federal tax}_i - \textit{state tax}_i) \qquad (7)$$

Federal and state marginal tax rates, $\textit{fed tax}_i$ and $\textit{state tax}_i$, are reported for each CU member. We calculate average marginal tax rates for each CU using the wages of each CU member as weights.

Quarterly leisure expenditures are calculated by multiplying the after-tax hourly wage by leisure time (i.e., time endowment - CU working hours):

$$\textit{leisure expenditures}_i = \{[(90 * dte) * (\#\ of\ adults_i)] - \textit{total hours worked}_i\} * \textit{after-tax wage} \quad (8)$$

where *dte* is the daily time endowment. *Total hours worked* are for all CU members over the past three months. We rely on an assumption from Fullerton and Rogers (1993) that each working adult has an annual time endowment of 4,000 hours, or 10.96 hours per day, on average. Assuming an eight hour work day, average leisure time for an adult is then 2.96 hours per day. We explore the sensitivity of results to different time endowment values in Section 7.3.

Compensated and uncompensated labor supply elasticities are calculated as follows:

$$(Un)comp. labor\ supply\ elas. = -\left(\frac{leisure\ time}{work\ time}\right) * (Un)comp. leisure\ demand\ elas\text{ticity} \quad (9a)$$

Wage elasticities for labor supply are then calculated using the Slutsky formula:

$$Wage\ labor\ supply\ elasicity = \frac{Comp.labor\ supply\ elasicity - Uncomp.labor\ supply\ elasicity}{expenditure\ share\ of\ leisure} \qquad (9b)$$

Some CUs report zero wages, but this does not necessarily mean that the price of leisure is zero. The decision not to work is due to factors such as a higher reservation wage, number of children, and marriage status (Ballard 2000). We use the Heckman selection model (Heckman 1979) to address selection bias for reported wages. We first estimate a probit model where the dependent variable indicates whether we observe a wage for a CU. Similar to West and Williams (2004), we then estimate the after-tax hourly wage separately by gender for one-adult and two-adult CUs.[20] The wage equation uses the state-level unemployment rate, number of children, and prices for each consumption category as selection variables. Education, age, marriage status, race, the state of CU residence, and whether a CU lives in an urban area are included as controls. For CUs with more than one adult, spouse education level, age, and race are also included.[21] See Appendix D for the Heckman correction results for wages.

The after-tax hourly wage suffers from two potential sources of endogeneity (West and Williams 2007). First, gross wage is calculated by dividing each CU member's salary by hours of work, where both variables may possess measurement error. Thus, total hours of work and wages may be correlated. Second, the marginal income tax rate depends on income. We use the reference person's mean net wage by occupation and state, calculated separately by gender, to instrument for leisure price. In the first stage, we estimate leisure price as a function of the demographic variables in the demand estimation, prices, and the wage instrument. The predicted error term from this stage is then included in the demand estimation. Standard errors are bootstrapped.

4.1.2. Durable Good Purchases

When durable good purchases are reported as one-time expenditures, we replace them with their quarterly service flows. For housing, the CEX reports the rental value of the home in which the CU currently resides. For our demand estimation, we add together the estimated rental value of an owned home and any timeshare or vacation home available for rent. For transportation expenditures, no such equivalent is directly reported in the CEX. Thus, we replace vehicle purchases with their quarterly vehicle service flow based on Slesnick (2001):

[20] While some estimate a higher labor supply elasticity for females than males (Fuchs, et al. 1998; West and Williams 2007), others find that the labor supply elasticity for married women has decreased over time and is closer to that for men (Heim 2007). While we estimate the wage separately by gender, the demand system and associated labor supply elasticities are not estimated separately in the main results.

[21] Spouse education and age variables are missing for around 25% of two-adult CUs. We estimate a separate Heckman correction model for these CUs while we exclude these two variables from the estimation. We use the predicted hourly wage from this regression as the leisure price for CUs with zero wages.

$$S_t = 0.25(r_t + \delta)(1-\delta)^T P_0 \,, \qquad (10)$$

where P_0 is the initial vehicle purchase price T years ago as defined by the CEX. r_t is an assumed value for the after-tax rate of return, and δ is the depreciation rate. We use the U.S. 20-year real Treasury rate as a measure of the after-tax rate of return and the scrappage rates in Bento, et al. (2018) as a measure of the depreciation rate. Depreciation rates are assigned to each vehicle in the CEX data based on reported age and type of vehicle.[22]

Because durable good purchases such as for housing and vehicles are large and infrequent, not all households report expenditures on durable goods during the quarters in which they are surveyed. The vehicle purchase price is missing for around 24% of the vehicles in our sample. To impute a value for these vehicles, we employ an approach similar to Meyer and Sullivan (2017). We first estimate the relationship between household and vehicle characteristics and the vehicle purchase price for CUs with complete information in the CEX survey:

$$\ln(P_t) = v_1 veh\_age_{it} + v_2 fuel\_type_{it} + v_3 own\_use_{it} + v_4 veh\_new_{it} + v_5 family\_size_{it} + v_6 education_{it} + v_7\, age_{it} + v_8\, male_{it} + v_9\, region_{it} + v_{10}\, truck_i + v_{11} veh\_make_i + v_{12}\, veh\_year_i + \epsilon_{it} \,, \qquad (11)$$

where own_veh and veh_new indicate whether the vehicle is for own use and is purchased as new or used, respectively. We also include vehicle age, fuel type, if a vehicle is a truck, its make, and year fixed effects in addition to CU demographic variables. We impute the predicted vehicle purchase price for households when this information is missing by multiplying the relevant vehicle and household characteristics for a CU-vehicle combination by the estimated coefficients. The imputed and reported vehicle purchasing prices are then used to calculate a vehicle services flow. Appendix D reports the results for the imputed vehicle services flow regression. Note that around 15% of the CUs do not own any vehicles (i.e., vehicle services flow has a zero value).

4.1.3. Zero Expenditures

[22] We use the average passenger car scrappage rates for automobiles and motorcycles and the average light truck scrappage rates for all other vehicle types (Bento, et al. 2018). The depreciation rate for vehicles produced after 2014 is assumed to be the same as for 1987-2014, while we use the rates for 14 year old vehicles for older vehicles.

Some households report zero expenditures on one or more consumption categories. These censored observations can occur due to factors such as affordability, non-preferences, or non-frequency. Ignoring these observations can create selection bias. We address this issue by estimating the two-step Heckman correction model and including estimated inverse Mills ratios as right-hand-side variables in the demand system estimation (Heien and Wesseils 1990). The Heckman correction model for each expenditure share includes number of children, home ownership status and log of prices for other expenditure categories as selection variables. Control variables include age, education, race, gender, number of adults in the household, marriage status, state, and month and year of interview. See Appendix D for the Heckman correction results for expenditures. This approach can still be biased if the number of censored observations is large (Shonkwiler and Yen 1999). This is not a major concern for our study; because we use highly aggregated consumption categories, a relatively low fraction of consumption expenditures is zero. The category with the most zero expenditures is consumer services; less than five percent of the observations are zero.

4.2. Consumption Price Data

The CEX reports CU expenditures for the three months before the interview, which means that reported expenditures may span multiple calendar-defined quarters or years. To match price data with irregular interview dates, we construct three-month price indices that vary monthly using the Cost-of-Living Index (COLI) from the Center for Regional Economic Competitiveness.

We use quarterly COLI data for 2013-2017. MSA-level price indices are aggregated to the state-level and are available for the first three quarters of each year. We use the average of the first three quarters as the fourth quarter price index in a given year. We then derive monthly price indices and re-aggregate to three-month periods that match the expenditure data based on the CU month and year of interview and state of residence.[23] We directly assign COLI price indices to the housing, utilities, and health care expenditure categories; we make judgements regarding the closest approximation or aggregate across COLI price indices in other cases (see Appendix E). Since COLI price indices are only available for urban areas, we use "all goods" Regional Price

[23] Due to confidentiality, the state is suppressed for around 11.5% of the observations in the CEX public use micro data, where it is replaced with a comparable state (e.g., Delaware might be replaced by New Jersey).

Parities (RPP) from the Bureau of Economic Analysis for nonmetropolitan versus metropolitan portions of each state to calculate non-urban COLI price indices by consumption category.[24,25]

5. Demand System Estimation

The budget share equation, estimated simultaneously for all categories, is as follows:

$$w_i^h = \alpha_i + \sum_{j=1}^{6} \gamma_{ij} \ln p_j^h + \beta_i \{\ln m^h - (\alpha_0 + \sum_{i=1}^{6} \alpha_i \ln p_i + \frac{1}{2} \sum_{i=1}^{6} \sum_{j=1}^{6} \gamma_{ij} \ln p_i \ln p_j)\} + \lambda_i \frac{[\ln m^h - (\alpha_0 + \sum_{i=1}^{6} \alpha_i \ln p_i + \frac{1}{2} \sum_{i=1}^{6} \sum_{j=1}^{6} \gamma_{ij} \ln p_i \ln p_j)]^2}{\prod_{i=1}^{6} p_i^{\beta_i}} + u_i^h, \quad (12)$$

where, w_i^h is the budget share for good i in household h. The variable p is the price index for each good and m^h represents household total expenditures. The α's are linear combinations of demographic variables, s^h, such that $\boldsymbol{\alpha}^h = \boldsymbol{\alpha}_i' \, \boldsymbol{s}^h$ (Lecocq and Robin 2015). The $\boldsymbol{s}^h$ vector includes reference person age, family size, number of income earners, race, home ownership status, number of children, region fixed effects, and estimated inverse Mills ratios for each expenditure category.

To estimate the demand equations, we employ a methodology from Lecocq and Robin (2015), which uses Blundell and Robin's (1999) iterated linear least-squares (ILLS) estimator. The method is computationally less demanding than nonlinear seemingly unrelated regression (SUR) but shares some common features. Operationally, the ILLS estimator consists of a series of iterations where a SUR of expenditure shares is estimated in each iteration. The initial values for $ln\ a(\boldsymbol{p})$ and $\mathrm{b}(\boldsymbol{p})$ (Equation 2) are the Stone price index and the unit vector, respectively, and the price aggregators are updated in each iteration using the estimated parameters until numerical convergence. Budget and price elasticities for each good category are then calculated using the estimated parameters from the demand system in equations (4) through (6).

One identification concern is potential endogeneity in expenditures and prices. Endogeneity in expenditures might arise when the demand system does not include all goods and services that a household purchases (Dhar, et al. 2003). Endogeneity of expenditures is less of a concern in this

[24] RPPs are available for aggregated categories of expenditures but do not match all the categories that we need for our estimation. In addition, they are only calculated annually. See Appendix E for more details.

[25] The BEA has separate state-level RPPs for metropolitan and non-metropolitan areas for all items, goods, services, and rent. We use (non-metropolitan RPP/metropolitan RPP) for all items as a weight to calculate non-urban price indices for each category.

study since we estimate a full demand system. Price endogeneity may also arise when estimating demand systems. Even if just one price is endogenous, it can be spread to other price coefficients due to the homogeneity, symmetry, and adding up conditions (Huffman 2011). The degree to which this is a concern is related to the specificity of the consumption categories in the demand estimation (Dhar, et al. 2003; Bronsard and Salvas-Bronsard 1984).

The potential for measurement error or unobserved features of goods to act as sources of price endogeneity exists mainly when prices are calculated through unit values or when expenditures are divided by quantities. Measurement error in unit values may exaggerate the importance of endogenous prices (Huffman 2011), while differences in quality and consumer's tastes across goods could influence prices. We use state level prices for each consumption category, which are the same across households who live in the same state and are interviewed in the same month. Section 4.1.1 discusses how we address potential endogeneity in wages.

6. Summary Statistics

The final dataset includes 75,266 CUs with one or two adults and reference persons that are 70 years old or less (Table 1). By far, CUs spend the greatest share of total expenditures on leisure (49% overall, and 38% and 56% for one-adult and two-adult households, respectively). While West and Williams (2004) report a similar average leisure share for two-adult household (55%), they report a markedly higher average leisure share for one-adult households (49%) over 1996-1998.[26] The large variation in leisure expenditures is mainly due to the wide range of the reported after-tax wages used in its derivation. Spending on housing and nondurables constitute about 16% and 15% of the total expenditures, respectively. The share of spending in other expenditure categories ranges from 9 percent (consumer services) to 6 percent (utilities).

[26] Aside from the difference in timeframe, our leisure share may differ due to a slightly lower time endowment and use of reported wage instead of the Heckman-corrected wage for the initial leisure value calculation. We use the Heckman corrected wage as the leisure price for CUs that report zero wages, but not for the leisure expenditures calculation. We instead use another Heckman correction model for leisure expenditures similar to other expenditures. West and Williams (2004) use the Heckman-corrected wage for both leisure price and expenditure value.

Table 1: Summary Statistics (Expenditures in US Dollars, 2013-2017)

Variable	N	Mean	SD	Min	Max	Mean Expenditure Share
Non-durable	73,819	2,545	2,049	0	196,275	0.15
Consumer services	73,819	1,857	3,275	0	153,902	0.09
Utilities	73,819	913	575	0	10,605	0.06
Housing	73,819	2,613	2,447	0	58,163	0.15
Transport	73,819	1,223	1,377	0	38,492	0.06
Leisure	73,819	16,593	27,046	0	811,598	0.49

Table 2 compares the average expenditure share for each category at the national level to those for three income groups (low, medium, and high) and four Census regions.[27] The expenditure share for each category varies with income, with particularly stark differences evident for leisure, non-durables, and housing. Leisure share increases with income, while other consumption categories' shares decrease with income. In contrast, variation in relative shares across regions is small.

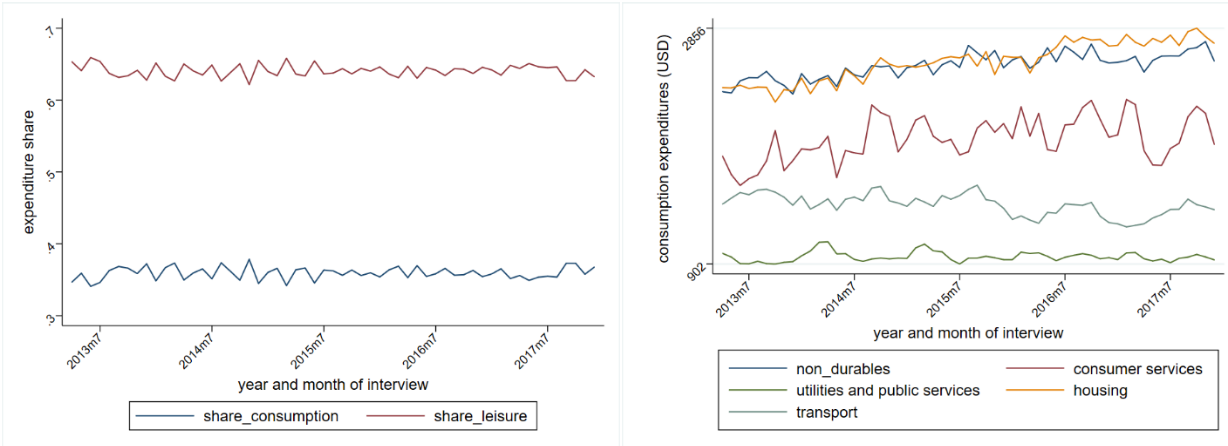
Table 2: Summary Statistics (Mean Expenditure Shares)

	National	Income Groups			Census Regions			
		Low	*Medium*	*High*	*Midwest*	*Northeast*	*South*	*West*
Non-durable	0.15	0.20	0.13	0.11	0.15	0.15	0.15	0.14
Cons. services	0.09	0.09	0.08	0.08	0.09	0.09	0.08	0.08
Utilities	0.06	0.08	0.05	0.04	0.06	0.06	0.07	0.05
Housing	0.15	0.22	0.14	0.11	0.14	0.17	0.15	0.17
Transport	0.06	0.07	0.06	0.06	0.07	0.06	0.07	0.06
Leisure	0.49	0.33	0.53	0.59	0.49	0.48	0.48	0.50
Observations	73,819	23,264	24,056	26,499	14,595	13,559	27,090	18,575

Average full consumption expenditure shares for consumption and leisure stay roughly constant over the 2013 to 2017 timeframe (Figure 1; left panel). However, expenditures for categories such as housing and non-durables have increased, while expenditures on transportation have declined over time (Figure 1; right panel).

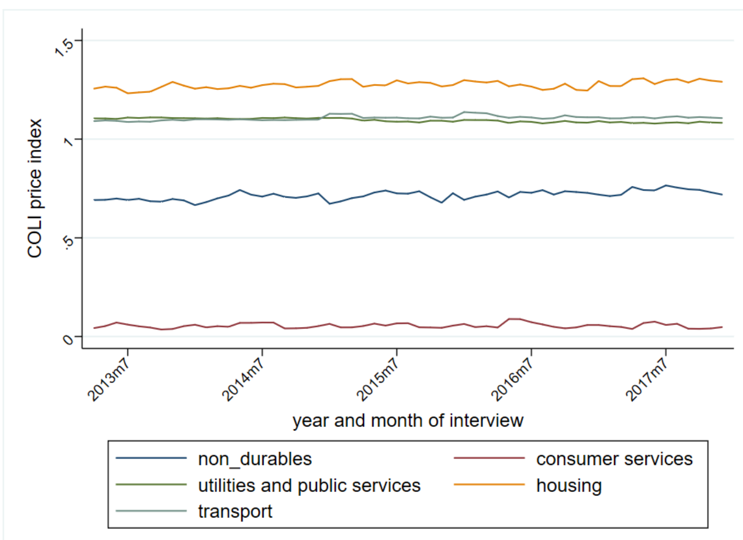
[27] Income groups are defined by dividing the sample into three groups based on the households' equivalence-scale adjusted before-tax income divided by $(adults + children)^{0.5}$ to account for the influence of family size.

Figure 1: Average Consumption Expenditures: Shares (left), by Category (right)



Average three-month COLI price indices indicate that housing is the most expensive consumption category, followed by utilities, while consumer services has the lowest relative prices (Figure 2). Since there is little variation in the price indices over time, this study mainly uses heterogeneity across individuals to derive elasticity estimates.

Figure 2: Aggregated COLI price indices



7. Demand System Estimation Results

Using the expenditure shares and prices for each category, CU demographic information and the predicted inverse Mills ratios from the Heckman correction models, we estimate consumer demand for U.S. households using QUAIDS, state fixed effects, and COLI price data (Table 3).

Table 3: National level demand system estimation results

Variables	(1) Non-durables share	(2) Consumer services share	(3) Utilities share	(4) Housing share	(5) Transport share	(6) Leisure share
γ_ln(p_non_dur)	-0.008**	-0.001	-0.001	-0.003	-0.002	0.015*
	(0.004)	(0.005)	(0.002)	(0.005)	(0.003)	(0.008)
γ_ln(p_cons_serv)	-0.001	0.024***	-0.001	-0.002	-0.006***	-0.014***
	(0.002)	(0.002)	(0.001)	(0.002)	(0.001)	(0.003)
γ_ln(p_utility)	-0.001	-0.001	0.000	-0.012	0.016***	-0.003
	(0.007)	(0.007)	(0.003)	(0.008)	(0.005)	(0.013)
γ_ln(p_housing)	-0.003	-0.002	-0.012***	0.014*	-0.006	0.008
	(0.006)	(0.007)	(0.003)	(0.008)	(0.004)	(0.012)
γ_ln(p_transport)	-0.002	-0.006	0.016***	-0.006	0.007	-0.011
	(0.008)	(0.009)	(0.004)	(0.010)	(0.006)	(0.015)
γ_ln(p_leisure)	0.015***	-0.014***	-0.003***	0.008***	-0.011***	0.005**
	(0.001)	(0.001)	(0.000)	(0.001)	(0.001)	(0.002)
β_ln(income)	-0.110***	-0.017***	-0.040***	-0.061***	-0.018***	0.246***
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.002)
λ_ln(income)^2	0.003***	0.002***	-0.001***	-0.001***	-0.001***	-0.002***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
α_1st_stage_error	0.001***	-0.000***	0.000***	0.000***	0.000***	-0.001***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
α_age	-0.000***	0.001***	0.000***	0.000***	0.000***	-0.001***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
α_family_size	0.025***	0.009***	0.008***	0.005***	0.001*	-0.048***
	(0.001)	(0.001)	(0.000)	(0.001)	(0.001)	(0.001)
α_#of income earner	-0.011***	-0.028***	-0.004***	-0.019***	-0.003***	0.064***
	(0.001)	(0.001)	(0.000)	(0.001)	(0.000)	(0.001)
α_white	0.006***	0.001	-0.006***	0.009***	-0.002***	-0.008***
	(0.001)	(0.001)	(0.000)	(0.001)	(0.001)	(0.001)
α_own_home	0.018***	0.024***	0.013***	-0.068***	0.007***	0.005***
	(0.001)	(0.001)	(0.000)	(0.001)	(0.001)	(0.002)
α_#of child	-0.016***	-0.011***	-0.006***	-0.003***	-0.002***	0.037***
	(0.001)	(0.001)	(0.000)	(0.001)	(0.001)	(0.002)
Observations	73,819	73,819	73,819	73,819	73,819	73,819

Bootstrapped standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1.

The λs are all statistically significant, indicating that AIDS is insufficient for capturing demand responses. However, they are estimated at or near zero, so nonlinearities are quite small. While the demographic controls also are statistically significant, they, too, often have fairly small coefficient estimates. Thus, we expect that budget and price elasticities estimated using QUAIDS or AIDS should be similar (Table 4). See Appendix F for additional results.

The income and price elasticities are calculated using the estimated parameters and equations 4, 5, and 6. At the national level, all six expenditure categories are price inelastic with the un-compensated price elasticity ranging from -0.7 for consumer services to close to unity for leisure. All consumption categories except for leisure are also income inelastic. The utilities category has the lowest budget elasticity with a value of 0.35, while leisure has the highest elasticity at 1.53.

Table 4: Income and own-price elasticity results (national level)

	Budget Elasticity			**Un-compensated Price Elasticity**		
Non-durables	0.433***	0.418***	0.428***	-0.816***	-0.819***	-0.281***
	(0.00)	(0.00)	(0.01)	(0.03)	(0.03)	(0.01)
Consumer services	0.952***	0.924***	1.013***	-0.740***	-0.742***	-0.612***
	(0.01)	(0.01)	(0.01)	(0.02)	(0.02)	(0.01)
Utilities	0.345***	0.352***	0.192***	-0.893***	-0.896***	-0.146***
	(0.01)	(0.00)	(0.00)	(0.05)	(0.05)	(0.00)
Housing	0.587***	0.592***	0.482***	-0.791***	-0.793***	-0.312***
	(0.01)	(0.01)	(0.01)	(0.05)	(0.05)	(0.01)
Transport	0.642***	0.658***	0.482***	-0.857***	-0.859***	-0.276***
	(0.01)	(0.01)	(0.01)	(0.08)	(0.08)	(0.01)
Leisure	1.532***	1.543***	1.233***	-0.928***	-0.932***	-0.956***
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Sample	National	National	National	National	National	National
Model	QUAIDS	AIDS	LES	QUAIDS	AIDS	LES
Fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Observations	73,819	73,819	73,819	73,819	73,819	73,819

Bootstrapped standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1.

The price elasticity for utilities is close to estimates in the literature. Alberini, et al (2011) report an own-price elasticity of demand for electricity between −0.86 and −0.67, and own price elasticity of demand for gas between −0.69 and −0.57.[28] Results for transportation and housing are also consistent with available estimates. Fouquet (2012) estimates income and price elasticities for

[28] Note that utilities in our paper include non-energy utilities, public services, electricity, natural gas, and heating oil.

aggregate land transport services in the UK of 0.8 and -0.6, respectively. Albouy, et al. (2016) estimate income and price elasticities for housing of 0.67 and -0.67, respectively.

Regardless of the specification, all consumption categories are income and price inelastic; leisure is budget elastic. While the AIDS and QUAIDS elasticities are very similar, the LES specification yields smaller elasticities in absolute terms. Differences across specifications are more noticeable for price elasticities mainly due to the subsistence value. When the subsistence value is lower, the LES price elasticities approach the Cobb-Douglas price elasticity of one. The rank-orderings of budget and un-compensated price elasticities for utilities, housing, and transportation are similar to Taylor (2009) where utilities have lower elasticities than housing and transportation using AIDS. The rank-orderings are not always the same when using QUAIDS, particularly for price elasticities. Note that Taylor (2009) does not include leisure in his demand specification.

Budget elasticities by income group and Census region are qualitatively similar to the national level (Table 5):[29] leisure is budget elastic and all other consumption categories are income inelastic. That said, there are some interesting differences in relative magnitude. For instance, the low-income group has substantially lower budget elasticities for nondurables and housing and higher elasticities for consumer services than the middle- and high-income groups. The high-income group has a noticeably lower budget elasticity for leisure compared to other groups. These variations stem in part from different expenditure shares across income groups. The estimated budget elasticities across Census regions demonstrate less variation. Their magnitudes are similar to the national-level results with the exception of lower budget elasticities for utilities, transport, and consumer services in the South and a higher budget elasticity for utilities in the Northwest.

The price elasticity results demonstrate greater heterogeneity (Table 6). As at the national level, uncompensated price elasticities for each income group are inelastic. However, categories such as housing and transportation are price elastic for some Census regions.[30] The absolute value of the elasticity for nondurables, utilities, housing, and transport is lower for low-income households compared to medium- and high-income households, while it is higher for leisure.

[29]We use the total equivalence-scale adjusted before-tax income to define three income groups. Following West and Williams (2004), we divide before-tax income by [(adults+children)]^0.5 to adjust for family size.

[30] National level cross-price elasticities as well as the compensated price elasticities by income group and Census regions are in Appendix F. The elasticity results for other specifications are in Appendix G.

Last, we examine the regularity of the demand system. The adding-up condition is imposed by construction. Homogeneity and symmetry conditions also are imposed after each iteration in the estimation when they are found to have failed.[31] To test the curvature condition, we check the constraints provided in Equation 3(d) where the compensated own-price elasticities need to be negative and the determinant of the matrix, including compensated cross-price elasticities multiplied by expenditure shares, need to be positive for kth order principal minors if k is an even number and negative if k is an odd number. The former condition holds for all estimates. The submatrices determinants have the expected sign at the national level and for all income groups and regions except the South using QUAIDS and AIDS. Thus, in all but one case the Slutsky matrix is negative semi-definite and the concavity condition is satisfied.

[31] Note that satisfying the symmetry condition ($\gamma_{ij} = \gamma_{ji}$ in Equation 2) in a flexible functional form does not necessarily imply that cross-price elasticities are symmetric.

Table 5: Budget elasticity results

		Income Group			Census Region			
	National	**Low**	**Medium**	**High**	**Midwest**	**Northeast**	**South**	**West**
Nondurables	0.433***	0.189***	0.418***	0.380***	0.443***	0.26	0.397***	0.455***
	(0.00)	(0.02)	(0.01)	(0.01)	(0.03)	(0.15)	(0.10)	(0.01)
Consumer services	0.952***	1.068***	0.678***	0.909***	0.980***	1.045***	0.781***	0.929***
	(0.01)	(0.02)	(0.01)	(0.02)	(0.02)	(0.02)	(0.10)	(0.02)
Utilities	0.345***	0.187***	0.288***	0.183***	0.317***	0.520***	0.372***	0.434***
	(0.01)	(0.02)	(0.01)	(0.01)	(0.05)	(0.07)	(0.10)	(0.01)
Housing	0.587***	0.238***	0.544***	0.587***	0.541***	0.613***	0.608***	0.535***
	(0.01)	(0.02)	(0.01)	(0.01)	(0.04)	(0.07)	(0.08)	(0.01)
Transport	0.642***	0.519***	0.499***	0.533***	0.670***	0.666***	0.537***	0.610***
	(0.01)	(0.02)	(0.01)	(0.02)	(0.04)	(0.09)	(0.12)	(0.02)
Leisure	1.532***	1.575***	1.656***	1.376***	1.531***	1.485***	1.534***	1.590***
	(0.00)	(0.01)	(0.01)	(0.01)	(0.03)	(0.06)	(0.06)	(0.01)
Model	QUAIDS	QUAIDS	QUAIDS	QUAIDS	QUAIDS	QUAIDS	QUAIDS	QUAIDS
Price data	COLI	COLI	COLI	COLI	COLI	COLI	COLI	COLI
Fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	73,819	23,264	24,056	26,499	14,595	13,559	27,090	18,575

Bootstrapped standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1.

Table 6: Uncompensated price elasticity results

		Income Group			Census Region			
	National	**Low**	**Medium**	**High**	**Midwest**	**Northeast**	**South**	**West**
Nondurables	-0.816***	-0.670***	-0.736***	-0.850***	-0.820***	-0.713***	-0.873***	-0.805***
	(0.03)	(0.08)	(0.04)	(0.04)	(0.06)	(0.11)	(0.04)	(0.06)
Consumer services	-0.740***	-0.660***	-0.721***	-0.620***	-0.721***	-0.699***	-0.649***	-0.766***
	(0.02)	(0.04)	(0.03)	(0.03)	(0.05)	(0.08)	(0.15)	(0.04)
Utilities	-0.893***	-0.785***	-0.839***	-0.928***	-0.926***	-0.923***	-0.774***	-0.995***
	(0.05)	(0.14)	(0.07)	(0.06)	(0.15)	(0.11)	(0.10)	(0.06)
Housing	-0.791***	-0.573***	-0.834***	-0.753***	-1.587***	-0.694***	-0.690***	-0.710***
	(0.05)	(0.15)	(0.07)	(0.07)	(0.22)	(0.11)	(0.12)	(0.07)
Transport	-0.857***	-0.625**	-0.830***	-0.870***	-1.186***	-1.206***	-0.016	-0.950***
	(0.08)	(0.19)	(0.13)	(0.12)	(0.20)	(0.22)	(0.32)	(0.12)
Leisure	-0.928***	-0.942***	-0.811***	-0.895***	-0.947***	-0.918***	-0.968***	-0.927***
	(0.00)	(0.01)	(0.01)	(0.01)	(0.01)	(0.03)	(0.03)	(0.01)
Model	QUAIDS	QUAIDS	QUAIDS	QUAIDS	QUAIDS	QUAIDS	QUAIDS	QUAIDS
Price data	COLI	COLI	COLI	COLI	COLI	COLI	COLI	COLI
Fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	73,819	23,264	24,056	26,499	14,595	13,559	27,090	18,575

Bootstrapped standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1.

7.1 Labor Supply Elasticities

Labor supply elasticities are calculated using the estimated leisure elasticities as follows:

*(Un)compensated labor supply elasticity = - (leisure time/work time) * (Un)compensated leisure demand elasticity* (18)

Compensated price and budget elasticities for labor supply are expected to be in the range of 0 to 0.3 and -0.1 to 0, respectively (McClelland and Mok 2012). Although the compensated price elasticities for labor supply we estimate are within the expected range, the budget elasticities are high (Table 7). Note that the one other budget elasticity estimated for use in a U.S. CGE model by Jorgenson (2013) is even higher (-2.3 for a reference household). One potential reason for high budget elasticities is the assumed time endowment. A smaller time endowment is expected to result in a smaller budget elasticity.

Table 7: labor supply elasticity (daily time endowment = 10.96 hours)

Sample	**Budget elasticity**	**Un-compensated price elasticity**	**Compensated price elasticity**
National	-0.57	0.34	0.09
Low-income group	-0.58	0.35	0.05
Medium-income group	-0.61	0.30	0.03
High-income group	-0.51	0.33	0.05
Midwest region	-0.57	0.35	0.10
Northeast region	-0.55	0.34	0.10
South region	-0.57	0.36	0.09
West region	-0.59	0.34	0.10

7.2 Sensitivity Analyses

We estimate the demand system using various alternative specifications. These include replacing the COLI price indices with the RPP price indices, converting nominal expenditures to real values, using alternative assumptions for the time endowment, changing the age range and the number of adults that are included in the sample, and estimating consumer demand without leisure. We find that the national-level elasticities are similar across these various specifications except in the case of the budget elasticities when leisure is not included as a consumption category. In this case, as expected, the budget elasticities for the remaining expenditure categories are substantially higher. Importantly, the price elasticities are robust to the exclusion of leisure from the demand system.

Because wealth may play a role in the consumption decisions of some households - and may not correlate well with income (e.g., for retirees or high-income families), we also estimate demand using adjusted consumption expenditures to define the three income groups instead of adjusted before-tax income. Compared to the main income-group results, the budget elasticities for categories such as nondurables, consumer services and transportation are lower for the low-income group. In addition, the budget elasticity for leisure is higher for all income groups. The price elasticities are relatively robust to this alternate specification. Sensitivity analysis results are available in Appendix G.

We also calculate labor supply elasticities based on estimation results that rely on different daily time endowment assumptions (Table 8). The labor supply elasticities are sensitive to the value assumed. The higher the time endowment parameter, the larger the absolute value of the labor supply elasticity. This finding is consistent with Ballard (2000) and is of some importance since the labor supply elasticity can have a significant impact on welfare calculations in policy analyses. Note that the variation derives from the numerator in Equation 18 (leisure time), since the leisure elasticities are similar across different time endowments.

Table 8: Results sensitivity: labor supply elasticity

Daily time endowment	Budget elasticity	Uncompensated price elasticity	Compensated price elasticity
10.96	-0.567	0.343	0.094
13.3	-1.012	0.630	0.144
15	-1.334	0.843	0.173

In addition, we estimate the demand system separately by gender and marital status (Table 9). For labor supply, we find that there is greater variation in budget elasticities differentiated by marital status than for gender. Compensated price elasticities are similar for CUs with a married male reference person and a married or single female reference person but lower for CUs with a single male reference person. These results are broadly consistent with the literature, which has shown that while labor supply elasticities can vary significantly by gender, the gap is shrinking over time (Heim 2007).

Table 9: Labor supply elasticity by gender (daily time endowment = 10.96 hours)

Sample	Budget elasticity	Un-compensated price elasticity	Compensated price elasticity
All	-0.567	0.343	0.094
Married male	-0.624	0.349	0.095
Married female	-0.632	0.348	0.097
Single male	-0.510	0.331	0.078
Single female	-0.546	0.343	0.099

Finally, we calculate labor supply elasticities based on the different functional forms using the national level results and a daily time endowment of 10.96 hours (Table 10). While the labor supply elasticities are similar for the AIDS and QUAIDS functional forms, the budget elasticity for the LES specification is somewhat lower and the price elasticities are slightly higher.

Table 10: Labor supply elasticity by functional form

Functional form	Daily time endowment	Budget elasticity	Un-compensated price elasticity	Compensated price elasticity
QUAIDS	10.96	-0.567	0.343	0.094
AIDS	10.96	-0.571	0.345	0.094
LES	10.96	-0.456	0.354	0.153

8. Illustrative Analysis of Environmental Regulation

In this section, we investigate the implications of alternative flexible functional forms, calibrated to the empirically estimated elasticities in section 7, on the overall costs of an illustrative environmental regulation. We motivate the broader issues and direction of future research using the BEIGE (Basic Economy In General Equilibrium) model, a simplified representation of the EPA's subnational intertemporal dynamic CGE model of the U.S. economy called SAGE (see Marten, et al. 2021).[32]

We compare model results with a QUAIDS specification to those with a LES specification and the default nested CES demand system in BEIGE.[33] For simplicity, we model an illustrative environmental regulation in the manufacturing sector as a mandate requiring more inputs to produce the same level of output. While Marten, et al. (2019) find that the input composition of the compliance requirements can affect social costs, we leave this sensitivity to future research and assume additional inputs are split between capital and labor according to the capital-labor share in the reference equilibrium for the manufacturing sector. We vary the shock size from $100 million to $100 billion.

8.1. BEIGE Model Overview

BEIGE is a static CGE model calibrated to data representative of the U.S. economy in 2016. This version of the model includes six producing sectors (agriculture, energy, construction, manufacturing, transportation, and services), a single representative household, government, and international trade based on a small open economy. The core logic in the model follows the standard microeconomic foundations of most CGE models: (1) consumers maximize welfare subject to a budget constraint, and (2) producers maximize profits subject to technology constraints and are assumed to be perfectly competitive.

Production is described by a nested constant elasticity of substitution function (Figure 3). The top-level nest describes the trade-off between aggregate factors and material inputs governed by the elasticity of substitution, σ^{mva}, set to 0.1 for all sectors. The second level nests describe the substitutability between factor inputs (labor and capital) and material inputs. Materials are aggregated according to the Leontief assumption ($\sigma^{m} = 0$) whereas factor substitution is slightly more flexible ($\sigma^{va} = 0.7$).[34] Firms face ad-valorem taxes on output and capital demands akin to rates in Marten, et al. (2021).

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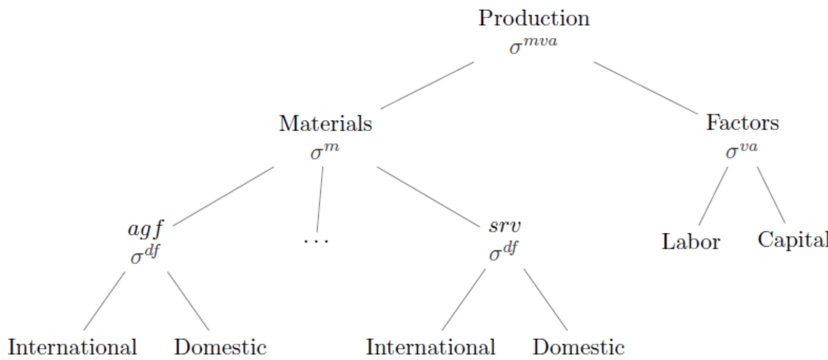
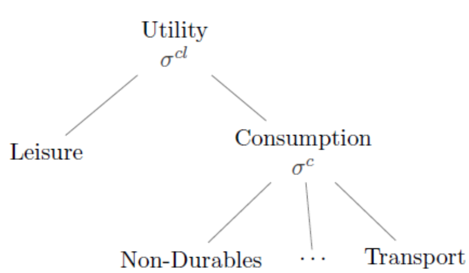
32 How more flexible functional forms interact with features such as dynamics; multiple sectors, regions, and households; and complex trade mechanisms in a CGE model is beyond the scope of this paper.
33 We have also run the model with an AIDS specification and find very similar results as the QUAIDS case.
34 The third-level nests describe demand for domestic versus imported varieties of a commodity. We assume trade follows the Armington assumption where demand for goods depend on location of production.

Figure 3: BEIGE Production Structure



The default representation of consumer preferences (Figure 4) is based on a nested constant elasticity of substitution function. The top-level nest governs substitutability between leisure and aggregate consumption based on the elasticity of substitution, σ^{cl}. Because conventional input-output tables do not include leisure demand as a final demand category, the level of leisure is imputed to target an exogenous budget elasticity of labor supply. Non-leisure consumption is composed of non-durables, consumer services, utilities, housing, and transport to match empirical estimates in Section 7. The CES sub-nest that governs the substitutability between these different categories is based on the elasticity of substitution, $\sigma^{c} = 0.9$. This assumes that uncompensated cross-price elasticities between non-leisure consumer demand categories are negative, or effectively complements.

Figure 4: Default BEIGE Utility Structure



Household income includes labor (net of labor tax payments), capital income, and government transfer payments that is assumed to balance with full consumption. The capital endowment is held fixed, and while the total time endowment is also fixed, it can be redistributed between labor supply and leisure demand. The representative government accrues tax income from output, labor and capital taxes and demands public expenditures based on Leontief preferences.

BEIGE has been augmented to include representations of the QUAIDS and LES demand systems, calibrated to national elasticity estimates from previous sections, to compare with the default CES-based assumption. We use the U.S. Bureau of Economic Analysis (BEA) Personal Consumer Expenditure bridge file to incorporate estimated elasticities directly within the QUAIDS or LES demand systems (Table 11). This is implemented in BEIGE by assuming the mapping is in fixed proportions, which translates the commodity price structure into composite consumer demand category prices that mimic the CEX categories. The model is solved as a mixed complementarity problem following Rutherford (1995) and Marten, et al. (2021).[35]

Table 11: Mapping from BEIGE Commodities to Consumer Demand Categories[36]

	Non-durables	Consumer services	Utilities	Housing	Transport
Agriculture	0.69	0.31			
Manufacturing	0.48	0.27	0.01	0.14	0.11
Transportation	0.00	0.21	0.03	0.05	0.71
Services	0.11	0.52	0.04	0.28	0.06
Energy	0.00	0.51	0.48		

8.2. Calibration Targets

The first step in calibrating a demand system of full consumption is to choose a value of leisure that is consistent with an assumed labor supply elasticity. The value of leisure is chosen based on Equation 18, but in this context the level of "work" is informed by the total value of labor demands in the input output table. We use the estimated labor supply elasticities in Table 10 for the QUAIDS and LES models. For the CES demand system, we calculate the budget elasticity of labor supply directly using the same assumptions on the level of "work" and leisure as in the QUAIDS and LES cases, given that the implicit budget elasticities are unity. Then, to facilitate a fair comparison between functional forms that feature internally consistent representations of preferences between leisure and non-leisure consumption, we estimate the

[35] We set the default numeraire in the model to the price of foreign exchange. Because the model solves for relative prices, this choice affects the denomination of equilibrium price changes but does not impact quantity changes given the homogeneity assumptions embedded in this class of equilibrium models.
[36] Construction is not included here since it is not consumed as a final good in the reference input output data.

value of σ_{cl} using CEX data in a simplified econometric setting with two goods: leisure and aggregate non-leisure consumption. We find that σ_{cl} = 0.33.

Table 12 describes the calibrated labor supply elasticities in BEIGE for the three demand systems. The CES budget elasticity of labor supply is smaller in absolute value than the QUAIDS and LES cases because the leisure budget elasticity is restricted to unity. Notably, the calibration routine must satisfy the Slutsky equation. Because of inconsistencies in the budget shares between the underlying CEX data for the QUAIDS and LES estimates and the consumer demand accounts in the input output data, we target the income and compensated elasticities of labor supply and allow the uncompensated elasticity to adjust.[37]

Table 12: Implicit Calibrated/Simulated Labor Supply Elasticities

	QUAIDS	LES	CES
Uncompensated	0.240	0.276	0.170
Budget Elasticity	-0.629	-0.414	-0.370
Compensated	0.107	0.196	0.098

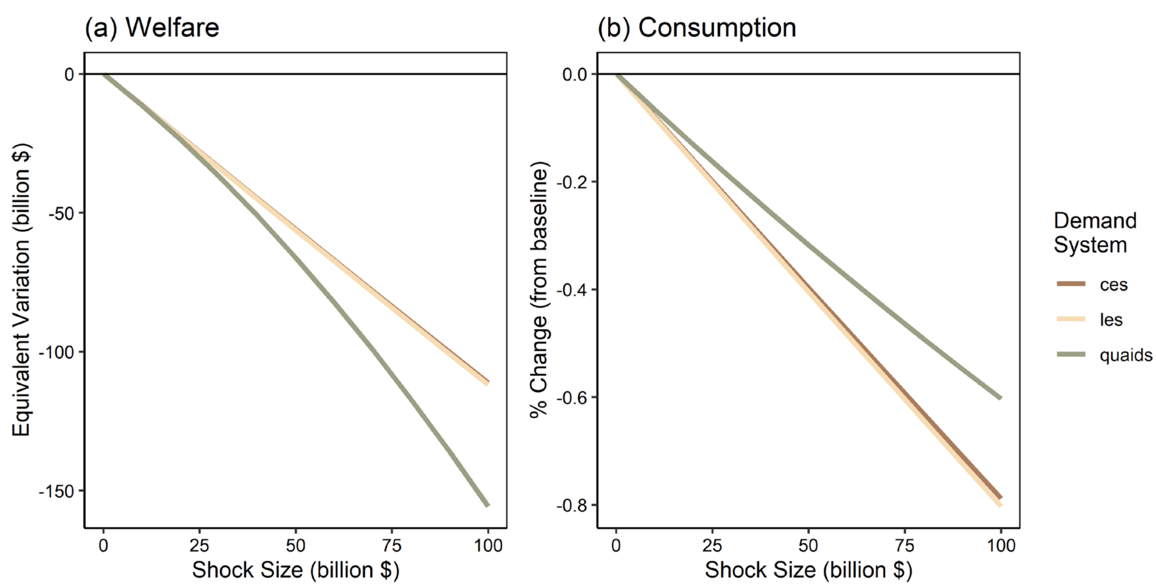
8.3. Simulation Results: Functional Form Comparison

The aggregate impacts on welfare and non-leisure total consumption of a suite of illustrative regulatory shocks on the manufacturing sector are reported in Figures 5a and 5b, respectively. Changes in welfare are reported as equivalent variation, or the change in income needed to achieve the new equilibrium utility level at reference prices. We find that the total welfare cost of the policy shocks exceeds the compliance cost (or imposed shock size) by 11-13%, 12-13%, and 8-55% for the CES, LES, and QUAIDS model versions, respectively. The QUAIDS model produces a wider range than found in Marten, et al. (2019) who estimate that social costs exceed compliance costs by 6-33% (across several sensitivity scenarios) using the SAGE model. Consistent with Marten, et al. (2019), the social cost markup in the CES and LES model variants declines with the size of the shock. The opposite is true for the QUAIDS model. For smaller shocks, the CES and LES models produce nearly identical aggregate welfare costs but

[37] These values can be backed out of BEIGE to verify that the model is calibrated properly. See Appendix H for more on the calibration procedure and comparisons of estimated and calibrated consumer demand elasticities.

underestimate social costs relative to the QUAIDS-based model. For the $100 million dollar shock, the QUAIDS model variant produces welfare costs roughly 35-38% lower than the alternative demand systems. However, as the shock size increases, the welfare costs produced by the QUAIDS-based model diverge in the opposite direction from the other two representations of consumer preferences.[38] The QUAIDS-based model is calibrated to estimated local elasticities that are reflective of variation in prices and quantities in the CEX/COLI data. To the extent that this is appropriate to model relatively larger shocks to the economy as is the case in the outer ranges of simulations illustrated in this paper will be the subject of future research. Figure 5b reports the percent change in aggregate non-leisure consumption relative to the reference equilibrium. While the figure characterizes the changes in aggregate non-leisure consumption in the QUAIDS-based model as less than the other alternatives, it highlights the importance of leisure demand when calculating welfare impacts as the QUAIDS-based model reports the largest welfare costs due to the policy.

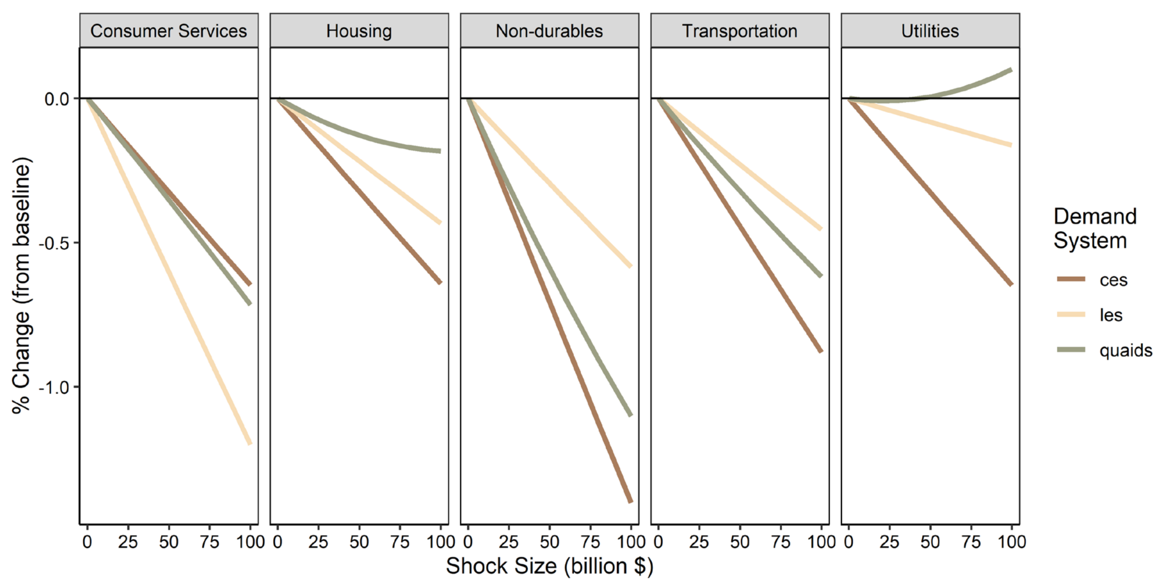
Figure 5: Welfare (a) and Aggregate Non-leisure Consumption (b)



[38] Notably, the annual compliance costs of most EPA regulatory activities tend toward the lower end of the range of shock sizes considered in this paper. We also verify that the post policy equilibrium satisfies all conditions for regularity (homogeneity, adding up, symmetry, and concavity) in the QUAIDS-based simulations. Homogeneity and adding up conditions hold by default because demand system parameters are unchanged due to policy simulations. Using changes in price, quantity, and income levels, we verify that both the symmetry condition and the concavity condition (by checking that A_k is negative semi-definite) also hold.

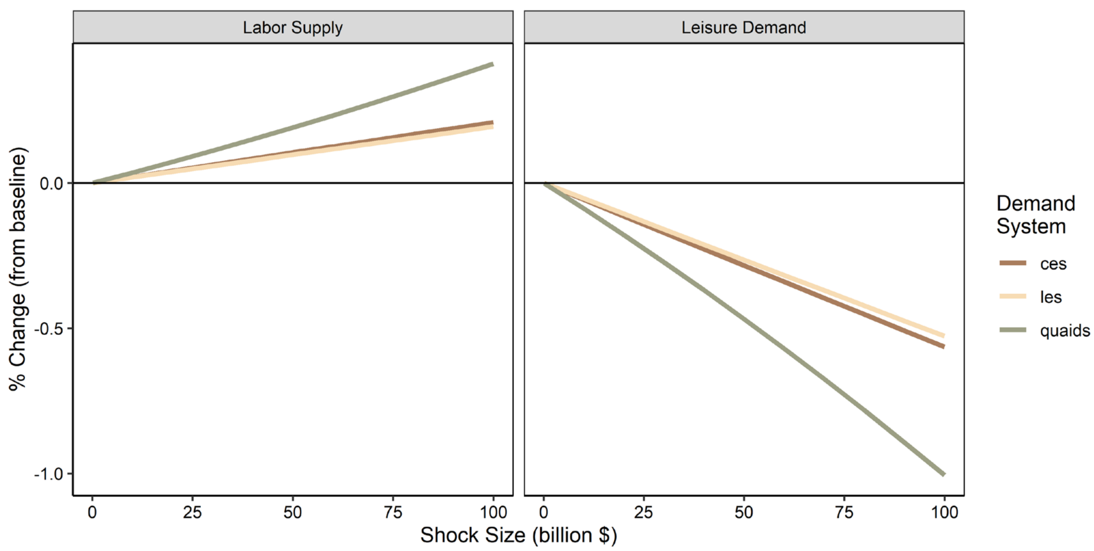
The change in aggregate consumption is driven by both price and income changes induced by the regulatory requirement. The regulatory requirements in the manufacturing sector makes it more costly to produce, leading to increases in the sector's output price. As noted in Table 11, manufacturing output constitutes a significant portion of each consumer demand category (particularly for non-durables). The new policy equilibrium therefore features increased prices (relative to the consumer price index) for some non-leisure consumption categories. Rising prices in some consumer demand categories lead to reductions in quantity demanded. In these simulations, the chosen demand system does not impact the price changes induced by the regulatory requirement for non-leisure consumption categories. However, the functional form impacts the percent change in quantity demanded given differences in cross-price elasticities (Figure 6). For instance, the calibrated price elasticity for consumer services is higher in absolute value in the LES-based model. The opposite is true for the QUAIDS- and CES-based models for non-durables and transportation. Note that differences in quantity impacts may lead to differential distributional outcomes in a CGE model with heterogenous agents.

Figure 6: Percent Change in Consumer Demand Category Quantities



The reduction in consumption is also driven by a reduction in income due to decreases in factor prices. The modeled shock requires additional labor and capital to comply with the regulation. While the regulatory requirements increase demand for factors in the manufacturing sector, putting upward pressure on factor prices, reductions in the quantity produced (output effect) and the reallocation of factor demands across sectors puts downward pressure on the wage rate and capital rental rate.[39] In these simulations the latter effects dominate leading to reductions in the wage rate and capital rental rate (relative to the consumer price index). The reductions in the wage rate and aggregate income induces different labor supply responses across the demand systems in accordance with the labor supply elasticities used to calibrate each framework. Figure 7 illustrates the percent change in labor supply and leisure demand due to the policy shock.[40] In all model variants, the income effect dominates the price effect by shifting time spent away from leisure demand even though the opportunity cost of not working becomes smaller. The magnitude of the impact, however, depends on the functional form and implicit labor supply and leisure demand price and income elasticities.[41] For instance, the QUAIDS leisure demand budget elasticity is relatively larger (see Appendix H) leading to a greater reallocation of time to labor supply.[42]

Figure 7: Labor-Leisure Choice



[39] As a simplifying assumption, we model the price of leisure as the wage rate, implicitly assuming that it is equivalent to the opportunity cost of not working.
[40] Caution is warranted in comparing leisure demand impacts across demand systems because each demand system has a different reference value. While based on the same underlying data, differences in estimated leisure demand elasticities lead to slight differences in leisure values (see budget shares in Table H.1 of Appendix H). That said, imputed leisure values across the three demand system representations are within 2% of one another.
[41] The labor supply response in the modeled outcomes is dependent on assumed labor supply elasticities. We caution modelers to carefully assess how exogenous assumptions can impact endogenous outcomes.
[42] Feedback effects from labor supply decisions also impact the equilibrium wage rate. For instance, the wage rate declines relatively more in the QUAIDS-based model given the larger labor supply responses.

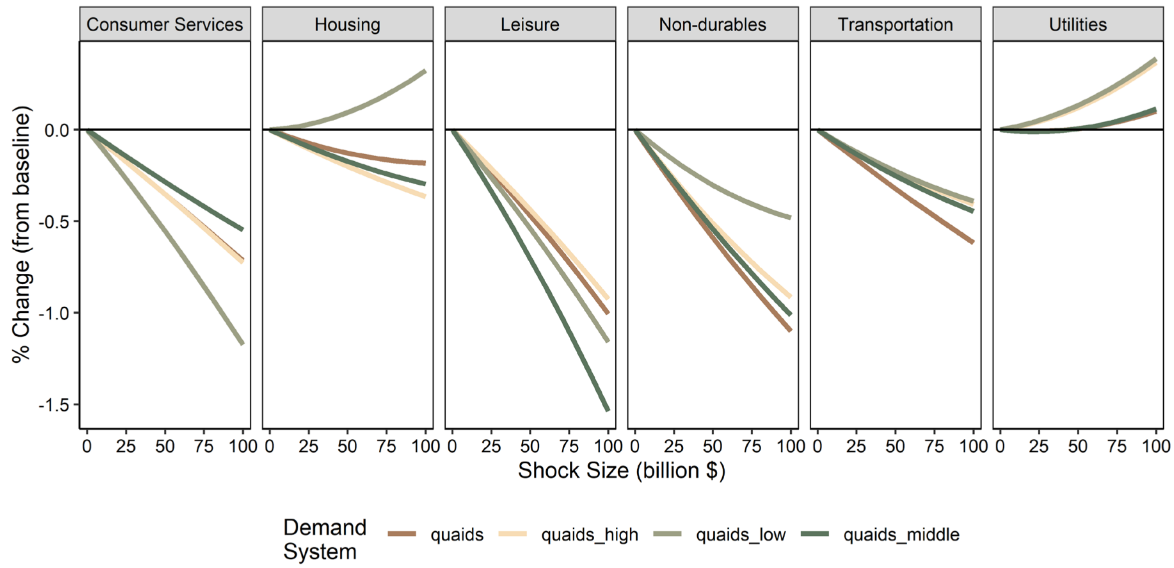
On the production side, the policy shock induces labor demand changes both in the manufacturing sector and other sectors in the economy. Outside of manufacturing where changes in labor demands are largely driven by the regulatory requirement, reductions in the wage rate induce increases in labor demands by all sectors except agriculture and services. Reductions in labor demand elsewhere in the economy are due to both indirect impacts (increases in material demands by producers) and the assumption of full employment. The model produces similar patterns for overall changes in sectoral production (See Appendix I).

8.4. Result Sensitivity: Heterogeneous Elasticities in the QUAIDS-based Model

We evaluate the policy scenarios for the QUAIDS-based model calibrated to values estimated for low-, middle- and high-income household types. These model simulations still feature a single representative household, but now assume *all* households exhibit the preferences of either the national composite ("quaids"), low-income ("quaids_low"), middle income ("quaids_middle"), or high-income ("quaids_high") group. See Appendix H on the calibration. Figure 8 reports the percent change in quantity demanded across preference assumptions. The estimated and calibrated leisure budget elasticity in the low-income and upper-income cases are smaller than the middle-income case. Therefore, the labor demand impacts are relatively muted compared to the middle-income group, implying that the low- and upper-income-based representative agent is less responsive to changes in income. Accordingly, labor supply increases are largest for the middle-income group case. As in Section 8.3, the quantity demanded for non-leisure goods is dependent on the behavioral assumptions embedded in the chosen demand system.[43]

Figure 8: Percent Change in Quantity Demanded Across Heterogeneous QUAIDS Models

[43] Notably, we find that the welfare estimates are not sensitive to the assumed QUAIDS-based calibration in the simplified modeling framework of BEIGE.



This set of simulations represents a relatively crude way to tease out potential impacts of heterogeneous elasticity estimates given that we assume away interactions between heterogenous agents. More complex CGE models such as SAGE have several features that will likely interact with these heterogeneous demand systems. For instance, households receive income from varying sources in models with multiple agent types. In SAGE, higher income households receive a relatively larger share of their disposable income from capital investments whereas lower income households receive a large majority of their income through transfer payments. While BEIGE does not capture these distinctions, the income and price elasticities used to calibrate the QUAIDS models already account for some of these features implicitly from the CEX data. While not modeled explicitly, low- and upper-income groups are less responsive to wage rate increases in BEIGE, which may be due to less reliance on labor income for some individuals in these groups.

9. Conclusion and Next Steps

Our aim in this paper is to generate price and income elasticities consistent with observed consumer behavior for use in economy-wide models of the United States. In doing so, we contribute to the literature by updating available estimates and providing new evidence for heterogeneous elasticities across income type. We also fill a gap in the literature by comparing the economy-wide consequences of several different empirically-based consumer demand systems in the context of hypothetical environmental regulation. While our focus in this paper is on the use of estimated elasticities in a CGE modeling context, we recognize that by estimating elasticities for a broad set of consumer demand categories, these estimates may also be useful in a wider variety of empirical settings.

We produce a set of income and price elasticities by estimating alternative specifications of consumer demand for several demand categories including leisure, across household types and regions in the United States. We compare estimated models from the more restricted frameworks typically considered by CGE modelers to more flexible functions found to better represent observed behavior in consumer demand. Our preferred approach uses a QUAIDS functional form to allow both income and price flexibility. Across all model specifications, we find that income and price elasticities are generally heterogeneous across income groups, but not across regions within the United States.

By including leisure demand in the estimation, we can calculate consistent labor supply elasticities to characterize the labor-leisure choice in a CGE model. We also verify via a separability test that the model is better specified with leisure as its own demand category. While the estimated budget elasticity for leisure is robust to the value chosen for the daily time endowment, the labor supply elasticity is strongly influenced by this choice. This finding confirms the importance of the time endowment choice when estimating labor supply elasticities, particularly for use to conduct welfare analyses of various policies.

We then conduct a simple CGE modeling exercise to compare impacts across the QUAIDS demand system to more conventional demand systems (LES and CES) for an illustrative environmental policy. The QUAIDS and LES demand systems are calibrated to the empirical estimates in this paper; the CES-based demand system is calibrated to a substitution elasticity consistent with the CEX data to facilitate a fair comparison. We show that the chosen function and elasticity targets can have significant implications for the labor-leisure choice and therefore on the returns to labor and overall welfare costs. For smaller shock sizes, the flexible functional form model estimates social costs more than 30% lower than the less flexible alternatives. By comparing modeling outcomes across preference structures for low-, middle-, and high-income households, we find differential impacts in response to the policy shock suggesting that heterogeneous elasticities are important for characterizing distributional impacts across households.

Future work could seek to explore the distributional implications of heterogeneous elasticity estimates in the context of more complex CGE modeling frameworks with multiple heterogeneous agents. A model with multiple households could pick up on additional effects via both heterogeneous preferences and sources of income. Future work could also further explore the relationship between large policy changes and calibrating the model to empirically estimated local elasticities as well as expand the set of modeled consumer demand categories to link with larger-scale CGE models of the United States.

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Appendix A: Selecting a Consumer Demand Functional Form

The main criteria in choosing a functional form for our demand system estimation – with the ultimate goal of using it in a CGE model - are flexibility in the budget shares, flexibility in the own-price, cross-price, and income elasticities, regularity, and computational tractability. However, as was previously mentioned, there is a trade-off between flexibility and regularity of demand functions; no functional form satisfies both global regularity and flexibility (McLaren and Yang 2016). We discuss each criterion briefly below.

Regularity: Even when a demand system provides sensible results for the prices and quantities used in the estimation (i.e., the regularity properties for a rational consumer choice hold locally), they may not satisfy the regularity conditions for large shocks to the price or income variables (i.e., global regularity). Regularity is an important feature that is required when a demand system is used in welfare analyses and simulations that consider the effects of a wide range of different policies. For instance, the utility functions may be locally consistent with the income and price elasticities that are used for the initial year's equilibrium in a CGE model. However, this information is used to specify the full range of consumer responses and therefore needs to be consistent with the consumer behavior beyond this local domain (Perroni and Rutherford 1995). Regularity in terms of Marshallian demand systems means satisfying properties such as nonnegativity, adding up, homogeneity, and the symmetry and negative semi-definiteness of the Slutsky matrix (Deaton and Muellbauer 1980).

Flexibility: The flexibility of a demand system is related to the number of constraints imposed on the income and price elasticities; demand systems with fewer constraints allow more income and price flexibility. Income flexibility allows for the existence of normal and inferior goods, while price flexibility allows for substitutes and complements to be reflected in cross-price elasticities. The rank of a demand system provides information about the degree of income flexibility of a demand system, and describes "the maximum dimension of the function space spanned by the Engel curves of the demand system" (Lewbel 1991). In rank one demand systems, the budget share is constant (i.e., does not change with income level). A higher rank for a demand system denotes greater flexibility in the budget share of goods as income changes.

A rank one demand system is compatible with a homothetic preference function such as CES where the Engle curve is linear and passes through the origin. Rank two demand systems also have linear Engle curves, but they do not necessarily pass through the origin. The most common rank two demand system is LES (Geary 1950, Stone 1954). Non-linear Engle curves correspond to a rank three demand system. Lewbel (1991) uses kernel regressions to show that while rank two demand systems are sufficient for samples of consumer expenditure data that exclude very low and very high expenditures, rank three demand systems are required when the sample includes them (i.e., non-linearity of the Engel curve becomes more important). Higher rank order demand systems, on average, are associated with more price flexibility. Rank three demand systems allow for non-constrained income and own price elasticities, but the degree of cross price flexibility varies across rank three demand systems.

Following from these differences, income flexibility allows for flexibility in the budget share. Specifically, the budget share of consumption can change as income changes. This more accurately reflects the empirical data showing that low-income households spend a different share of their budget on some consumption categories than high-income groups. Rank one demand systems do not allow budget share flexibility, while higher ranking demand system do.

Tractable computation: Computational tractability can be associated with either estimating the demand system itself or with solving a CGE model calibrated to a particular functional form. The former refers to issues such as failing to have precise parameter estimates in a flexible demand system because there are more parameters that need to be estimated. The latter refers to the computational challenges when solving a CGE model that is calibrated to a flexible functional form.

We do not review all possible functional forms, since previous studies give comprehensive reviews (e.g., Phlips 2014; Huang, et al. 2013). Table A.1 summarizes some common rank two and rank three demand systems estimated in the empirical literature with regards to regularity and flexibility, including LES (Linear Expenditure System), Rotterdam, Translog, AIDS (Almost Ideal Demand System), QES (Quadratic Expenditure System) AIDADS (An Implicitly Direct Additive Demand System), IAS (Indirect Addilog System), and QUAIDS (Quadratic Almost Ideal Demand System).

In general, rank two demand systems impose linearity of the Engel curve, while this constraint is relaxed in rank three functional forms. Price flexibility varies across different functional forms with QUAIDS providing flexibility in both own- and cross- price elasticities.

An important constraint for all these flexible functional forms is that they are not globally regular, mainly due to failure to maintain the curvature constraint globally (i.e., the violation of negative semi-definiteness of the Slutsky matrix). However, the range of prices and incomes/expenditures for which these functional forms are regular varies. While all of these functional forms satisfy regularity locally, the literature demonstrates that some demand systems are "effectively globally regular" (Cooper and McLaren, 1996).[44] This implies that the regularity region for these functional forms is an unbounded domain that includes all sample price and income/expenditure data points as well as any combination of price and nominal expenditures, which then allows higher levels of real expenditures than the minimum value in the sample (McLaren and Yang, 2016; Fisher, et al., 2001). Although not all of the functional forms summarized in Table A.1 have been evaluated for effective global regularity, demand systems such as LES, QES, AIDADS, and QUAIDS belong to this class (Reimer and Hertel, 2004; McLaren and Yang, 2016).

Because it is both effectively globally regular and offers a high degree of price and income flexibility, the QUAIDS functional form is our preferred specification. Functional forms such as LES, QES, and AIDADS also have appealing regularity properties but are less flexible. In addition, Cranfield, et al., (2002) evaluate the performance of LES, AIDS, AIDADS, QUAIDS, and QES functional forms using a cross sectional sample of different income level countries and find that AIDADS, QUAIDS, and QES functional forms perform better than LES and AIDS based on both in-sample and out-sample criteria.

[44] The regular region is the set of income/expenditure and prices in which the indirect utility function satisfies regularity conditions.

Table A.1: Common rank two and rank three consumer demand systems

Demand System	Rank Order	Benefits with regard to Regulatory and/or Flexibility	Restrictions/Limitations
LES	Two	- Adding-up, homogeneity, and Slutsky symmetry conditions satisfied. - Flexible budget share	- Linear Engel curve (constant marginal budget share) - No inferior goods, no complementary goods, and no elastic demand
Rotterdam	Two	- Adding-up condition satisfied. - Flexible budget share - Allows for cross-price elasticities.	- Linear Engel curve - Concern regarding integrability of the functional forms
Translog	Two/Three	- Allows different household types to have different demands. - Flexible budget share - Allows for cross-price elasticities. - Allows exact aggregation over households	- Linear Engel curve in rank two Translog case - Number of goods is limited to <=5 - Failure in providing satisfactory cross-price elasticities consistent with the data
AIDS	Two	- Flexible budget share - Better suited than AIDADS when price variation is large and aggregation or cross-price effects are important. - Allows for exact (non-linear) aggregation over households. - Allows for cross-price elasticities.	- Linear Engel curve - Budget shares not constrained to unit interval
QES	Three	- Flexible budget share - Non-linear Engel curve - Flexible price elasticities	- Limited Engel-flexibility due to linear marginal expenditure
AIDADS	Three	- Flexible budget share and restricted to unit interval - Non-linear Engel curve (a generalized LES) - Better suited than AIDS when large variation in income - Flexible range of income and price elasticities	- Narrow range of cross-price elasticities - Maximum 10 commodities/sectors - Difficulty in demands aggregation across income levels - Constant subsistence levels (relaxed in Modified AIDADS)
IAS	Three	- Flexible budget share - Non-linear Engel curve - Adding-up, homogeneity, and Slutsky symmetry conditions satisfied. - Allows for inferior goods, elastic demand and negative cross-price elasticities.	- No independent cross-price elasticities
QUAIDS	Three	- Flexible budget share - Non-linear Engel curve - Flexible range of income and price elasticities	- Curvature condition can be rejected for very high expenditures.

Sources: Parks (1969), Chung (1994), Banks, et al. (1997) , Cranfield, et al. (2000), Yu, et al. (2000), Cranfield, et al. (2003), Yu, et al. (2004), Reimer and Hertel (2004), Lejour, et al. (2006), Erdil (2006), Barnett and Seck (2008), De Boer and Paap (2009), Preckel, et al. (2010), Chen (2016), McLaren and Yang (2016), Sommer and Kratena (2017), Ho, et al. (2020).

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Appendix B: LES Demand Framework

The LES demand functions stem from the following Stone-Geary utility maximization.

$$Max\ U = \prod (q_i - a_i)^{b_i}$$
$$s.t. \sum p_i q_i = M \ \ and \ \sum b_i = 1 \ , \qquad (7)$$

where b_i is the marginal expenditure share of category *i*. a_i represents the minimum subsistence level for category *i*. The utility function reduces to a Cobb-Douglas form when the subsistence level is zero for all categories. The resulting Marshallian demand functions then have the form below:

$$q_i = a_i + \frac{b_i}{p_i}(M - \sum_{k=1}^{n} \bar{q}_k p_k) \qquad \text{(B1)}$$

Multiplying the demand equation by the price level, we have a linear expenditure equation that is usually used to estimate the model's parameters.

$$p_i q_i = p_i a_i + b_i (M - \sum_{k=1}^{n} a_k p_k) \qquad \text{(B2)}$$

The budget and price elasticities are then calculated as shown.[45]

Budget elasticity: $\eta_i = \ b_i \frac{M}{p_i q_i}$

Own price elasticity: $\varepsilon_{ii} = \frac{(1-b_i)p_i a_i}{p_i x_i} - 1$

Cross price elasticity: $\varepsilon_{ij} = \frac{-b_i p_j a_j}{p_i x_i}$

We observe zero values for some consumption categories that can be due to factors such as infrequency, non-preferences, etc. To address the censoring issue, we estimate a probit model for each expenditure category where the dependent variable is a binary variable for observing

[45] The price elasticities can also be calculated indirectly using the Frisch parameter, which is defined as the negative ratio of total expenditures to discretionary expenditures. Using the Frisch parameter definition, the price elasticities can be rearranged as a function of the Frisch parameter (determined exogenously), income elasticity and expenditures. This indirect approach to calculate price elasticities is useful when the price data are not sufficient (Annabi, et al. 2006; Gharibnavaz and Verikios 2018).

that specific expenditure category. The explanatory variables include various household characteristics such as income, age, race, gender, marriage status, number of children, number of adults, and price levels. Region and month fixed effects are also included in the estimation. After each estimation, the inverse mills ratios are calculated by dividing the predicted probability density function by the predicted cumulative distribution function. In addition, the consumption pattern is expected to differ with household demographics. To consider the impact of demographic characteristics and the censoring problem, we employ a translating approach where the subsistence level is a linear function of demographics and the inverse mills ratios estimated from the selection model.

Appendix B References

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Appendix C: CEX Data Appendix

Table C.1 shows the correspondence between the aggregate consumption categories for our demand system estimation and reported CEX expenditure categories.

Table C.1: Demand System Expenditures

Category	CEX Expenditures Included
Non-Durables	Food (Food, Alcoholic Beverages, Tobacco Products and Smoking Supplies), Consumer Goods (Apparel, Personal Care, Reading)
Consumer Services	Education, Healthcare, Entertainment (including Cable)
Utilities and public services	Electricity, Natural Gas, Heating Oil, Non-Energy Utilities and Public Services (excluding Cable)
Housing	Shelter, Rental Value of Property (Owned Home, Time Share, Owned Vacation Home), Household Operations, Household Furnishings and Equipment
Transportation	Vehicle Services Flow (imputed), Gasoline and Motor Oil, Other Vehicle Expenses, Public Transportation
Leisure	Imputed

Table C.2 reports summary statistics for the household demographic characteristics included in the consumer demand system estimation as controls. Note that the working status of the reference person is a binary variable that is equal to one if the person is working and zero otherwise. Variables such as female, white, married, and home ownership are also binary variables.

When possible, we compared these summary statistics to the 2013-2017 American Community Survey (ACS) Data Profile to check the broad representativeness of our data set. The CEX-derived data set that underlies our estimation has a similar percent who are married (48%) and female (52%) relative to the population as a whole (48% and 51%, respectively), while percent White is somewhat overrepresented in the dataset (79 percent) compared to the ACS (73%).

About 80% of CUs had at least one adult working at the time the CEX data were collected. The average annual before-tax income for a CU was $72,531 with a median of $51,126. Education level is defined as a categorial variable where zero signifies no school attendance and 16 means holding a graduate level degree. The median value of 13 implies that half of the reference persons have completed some college level studies with no degree (less than an Associate degree). On average, 57% of CUs owned a home. The average family size was 2.27 persons with a maximum number of 13 persons (recall that more than two-adult CUs and CUs with reference person above 70 years old are excluded from the main sample). While only 4% of one-adult CUs are married, 76% of two-adult CUs are married.

Table C.2: Summary Statistics (Household demographics)

Variable	N	Mean	SD	Median	Min	Max
CU working status	75,266	0.80	0.40	1	0	1
CU annual income before taxes	75,266	72,531	73,888	51,126	-378,000[46]	965,000
Age of reference person	75,266	45.79	14.32	46	18	70
Age of spouse	34,402	46.72	13.53	46	14	87
Education of reference person	75,266	13.58	1.75	13	0	16
Female (reference person)	75,266	0.52	0.50	1	0	1
White (reference person)	75,266	0.79	0.41	1	0	1
Married (reference person)	75,266	0.48	0.50	0	0	1
Number of children	75,266	0.65	1.08	0	0	11
Number of adults in CU	75,266	1.61	0.49	2	1	2
Number of members in CU	75,266	2.27	1.29	2	1	13
Home ownership	75,266	0.57	0.50	1	0	1

[46] The negative values are for households who lost money during the last 12 months. This variable is used as a RHS variable in the selection models but not for the leisure price. The gross salary/wage variable is instead used for leisure imputation and it is positive.

Appendix D: Vehicle services flow imputation and Heckman correction model results

To include vehicle services flow as part of the transportation expenditure category we first need to estimate the vehicle price for CUs that reported their vehicle information but omitted the vehicle purchasing price. Table D.1 shows the estimation results based on CUs that reported the vehicle purchasing price using the Meyer and Sullivan (2017) approach described in Section 4.1.2. We present a naïve and fixed effect (FE) specifications.

Table D.1: Vehicle purchasing price estimation for missing observations

Variables	Naive Ln(purchase price)	FE Ln(purchase price)
Vehicle age	-0.115***	-0.056***
	(0.001)	(0.002)
Fuel type	0.066***	0.097***
	(0.010)	(0.009)
Own use	0.211***	0.100***
	(0.029)	(0.025)
New vehicle	0.201***	0.262***
	(0.008)	(0.008)
Family size	0.004*	0.004*
	(0.002)	(0.002)
Age	0.001***	0.000
	(0.000)	(0.000)
Education	0.037***	0.012***
	(0.002)	(0.002)
Male	0.059***	0.026***
	(0.006)	(0.006)
Observations	47,313	47,155
R-squared	0.496	0.665
Census Region	Yes	Yes
Fixed effects	No	Yes

Standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1. Fixed effect variables are truck dummy, vehicle make, and vehicle year.

As expected, vehicle age has a negative impact on the purchasing price while, on average, vehicles that are purchased for own use, are new, or use gasoline as the fuel have a higher purchasing price. Household characteristics also affect the vehicle purchasing price. CUs that are larger, have higher income, are more educated and have a male listed as the reference person tend to spend more on their vehicles. The average age of persons in the CU is also positively correlated with purchase price, but it is not a statistically significant determinant in the fixed effects specification. The average vehicle purchasing price predicted using the fixed effects estimation is $12,560, while the average reported price is $19,588. Vehicles with a missing purchasing price are around two years older, on average. Other vehicle attributes and household demographics are similar to the overall sample.

Using the predicted and reported vehicle purchasing prices in addition to other vehicle and household characteristics in Equation 11, the quarterly vehicle services flow for each vehicle is calculated and added up for each CU (some CUs have multiple vehicles). A zero value is used for non-owners, which represent about 15% of the sample. Table D.2 shows that the average quarterly vehicle services flow per CU is about $207 with a standard deviation of $177. Note the existence of a long tail, which is driven by variation across observations in terms of number of vehicles owned or leased and vehicle purchasing price.

Table D.2: Total quarterly vehicle services

Variable	Observations	Mean	Std. Dev.	Min	Max
Quarterly vehicle services flow	78,567	207.17	177.12	0	4,683.49
Number of vehicles	78,567	1.67	1.34	0	21

Another variable needed for estimating the consumer demand system is leisure price. While we use the reported hourly wage to calculate a measure for leisure price for working CUs, we need to impute a value for non-working CUs. To accomplish this, we employ a Heckman correction model. We perform separate estimations based on the number of adults in the CU and the gender of the reference person. In general, we find intuitive results for most of the significant variables in the first-stage selection equation (Table D.3).

Level of education and living in an urban area positively affect the likelihood that the reference person works, except in the case of two adult male-headed CUs where it is negative but insignificant. The more children in a CU, the higher the likelihood that the reference person works, except in the case of one adult female-headed CUs where it is negative and significant. While age is positively related to the likelihood that a reference person works, the square term is negative and significant. A spouse's wage also has a positive impact on the likelihood that the reference person works. Other household and community characteristics are not consistent in terms of sign or significance across specifications. Low p-values from the Wald test of independent equations imply that the error terms of the selection equation and the wage equation are not independent; that is, selection exists.

Table D.3: Heckman correction model results for wage (selection equations)

Variables	(1) Work	(2) Work	(3) Work	(4) Work
Age of reference person	0.064***	0.079***	0.121***	0.117***
	(0.005)	(0.004)	(0.013)	(0.014)
Squared age of reference person	-0.001***	-0.001***	-0.001***	-0.001***
	(0.000)	(0.000)	(0.000)	(0.000)
Education of reference person	0.121***	0.127***	0.005	0.054***
	(0.008)	(0.007)	(0.017)	(0.017)
Married	0.434***	-0.235***		
	(0.060)	(0.055)		
White	0.200***	0.168***	0.195*	0.157
	(0.029)	(0.024)	(0.107)	(0.106)
Urban area	0.359***	0.638***	0.271	0.480*
	(0.114)	(0.103)	(0.282)	(0.277)
State unemployment rate	-0.138***	-0.138***	-0.674***	-0.608***
	(0.012)	(0.010)	(0.033)	(0.032)
Number of children	0.140***	-0.035***	-0.014	-0.050**
	(0.036)	(0.012)	(0.023)	(0.022)
Price of non-durables	0.015***	0.007***	0.059***	0.045***
	(0.002)	(0.002)	(0.005)	(0.005)
Price of consumer services	0.006*	0.004	0.016**	0.017**
	(0.003)	(0.003)	(0.008)	(0.007)
Price of utilities	-0.004	-0.003	-0.009*	-0.006
	(0.003)	(0.002)	(0.005)	(0.005)
Price of housing	-0.005***	-0.005***	-0.005	-0.012***
	(0.001)	(0.001)	(0.005)	(0.004)
Education of spouse			-0.038**	-0.039***
			(0.018)	(0.015)
Age of spouse			-0.002	-0.010*
			(0.005)	(0.005)
Gender of spouse (female)			1.638***	-1.116***
			(0.241)	(0.175)
Race of spouse (white)			-0.006	-0.188*
			(0.104)	(0.108)
Log of spouse wage			0.341***	0.398***
			(0.028)	(0.034)
Observations	15,902	21,792	11,292	9,494

Number of adults	one	one	two	two
Gender	male	female	male	female
State fixed effects	yes	yes	yes	yes
P_c	0.318	0.000	0.000	0.000

Robust standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1. Selection variables are state level unemployment rate, number of children and price of consumption categories. P_c represents the P-value from a Wald test of independent equations.

Table D.4 shows the results for the wage equation when accounting for selection. Conditional on working, we find that older, more educated individuals earn higher wages. As is the case in the selection equation, the square term for age is negative and significant, indicating that the wage begins to decline for those who are either very young or old. We also find that the older and more educated the spouse, the higher the reference person's wage. Those living in urban areas and who are white also earn higher wages, except in the case of two adult male-headed CUs where living in urban areas has a negative but insignificant impact on wage.

Table D.4: Heckman correction model results for wage (wage equation)

Variables	(1) Ln(wage)	(2) Ln(wage)	(3) Ln(wage)	(4) Ln(wage)
Age of reference person	0.073***	0.062***	0.068***	0.031***
	(0.004)	(0.004)	(0.006)	(0.007)
Squared age of reference person	-0.001***	-0.001***	-0.001***	-0.000***
	(0.000)	(0.000)	(0.000)	(0.000)
Education of reference person	0.156***	0.188***	0.119***	0.140***
	(0.006)	(0.006)	(0.006)	(0.009)
Married	0.076*	0.059		
	(0.040)	(0.051)		
White	0.121***	0.068***	0.081*	0.015
	(0.022)	(0.020)	(0.042)	(0.037)
Urban area	0.334***	0.144*	-0.046	0.246***
	(0.089)	(0.083)	(0.076)	(0.090)
Education of spouse			0.072***	0.039***
			(0.006)	(0.007)
Age of spouse			0.003**	0.005**
			(0.002)	(0.002)
Gender of spouse (female)			0.080	0.205***
			(0.075)	(0.063)
Race of spouse (white)			0.058	0.035
			(0.042)	(0.037)
Observations	15,902	21,792	11,292	9,494
Number of adults	one	one	two	two
Gender	male	female	male	female
State fixed effects	yes	yes	yes	yes
P_c	0.318	0.000	0.000	0.000

Robust standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1. Selection variables are state level unemployment rate and number of children and price of consumption categories. P_c represents the P-value from a Wald test of independent equations.

The predicted hourly wages for all reference persons in the data set, both working and non-working, from the Heckman correction models are summarized in Table D.5. On average, the hourly wage for a reference person in a two-adult CU is higher than it is in a one-adult CU, and the average hourly wage for a female reference person is lower than it is for a male reference person regardless of the number of adults in the CU. The predicted wage from the Heckman correction model differs by working status, where the average for working and non-working reference persons are \$21.16 and \$15.43 per hour, respectively.[47]

Table D.5: Predicted hourly wage from Heckman correction model

Variable	N	Mean	SD	Median	Min	Max
Hourly wage (one adult and male)	13,857	19.95	7.24	18.73	1.89	45.66
Hourly wage (one adult and female)	16,352	15.75	6.15	14.54	0.57	47.75
Hourly wage (two adult and male)	24,091	26.29	9.17	25.16	1.46	67.81
Hourly wage (two adult and female)	23,874	19.99	6.70	18.83	1.30	56.03

The final step before estimating the demand system is to estimate the Heckman correction model for each expenditure category to account for potential selection bias from zero expenditures. The results for the first and second stages are shown in Tables D.6 and D.7, respectively. The low p-values in the last row reject the null of no selection for all categories.

Conditional on having positive expenditures within a specific expenditure category, CUs with higher income, that are older, white, have more adults who are married, or with more children tend to have higher expenditures, on average, for most categories (Table D.7). One notable exception is that spending on leisure is inversely related to income and age. Housing expenditures also decline with age. Higher prices for one commodity category sometimes positively affect and other times negatively affect spending in another category. That said, we find that as leisure becomes more expensive, spending in other commodity categories also always increases, on average.

[47] As expected, the imputed wages are substantially higher in more expensive states such as New York and California.

Appendix D References

Meyer, B., and J. Sullivan. 2017. Consumption and Income Inequality in the US Since the 1960s. National Bureau of Economic Research Working Paper #w23655.

Table D.6: Heckman correction model results for expenditures (selection equations)

Variables	(1) Non-durables	(2) Consumer services	(3) Utilities	(4) Housing	(5) Transport	(6) Leisure
Ln(income)	0.494***	0.272***	0.123***	0.242***	0.297***	0.879***
	(0.027)	(0.007)	(0.014)	(0.012)	(0.008)	(0.010)
Age of reference person	0.070***	-0.017***	0.057***	0.051***	0.015***	0.077***
	(0.009)	(0.003)	(0.003)	(0.005)	(0.002)	(0.002)
Squared age of reference person	-0.001***	0.000***	-0.001***	-0.000***	-0.000***	-0.001***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
White	-0.066	0.214***	-0.122***	0.048	0.381***	0.018
	(0.075)	(0.016)	(0.024)	(0.036)	(0.015)	(0.011)
Female	-0.036	0.101***	0.040**	0.099***	-0.067***	-0.098***
	(0.064)	(0.015)	(0.020)	(0.033)	(0.014)	(0.009)
Married	0.029	0.127***	-0.013	0.000	0.356***	-0.367***
	(0.124)	(0.019)	(0.029)	(0.051)	(0.020)	(0.011)
Number of children	-0.087*	-0.013*	0.233***	0.062***	0.023***	-0.104***
	(0.050)	(0.008)	(0.018)	(0.022)	(0.009)	(0.005)
Number of adults in CU	0.250**	0.013	0.204***	0.035	0.104***	0.110***
	(0.109)	(0.012)	(0.022)	(0.033)	(0.012)	(0.011)
Ln(price of non-durables)	-0.835**	-0.690***	-0.025	-0.301	-0.025	0.768***
	(0.422)	(0.112)	(0.138)	(0.251)	(0.102)	(0.063)
Ln(price of consumer services)	-0.301*	-0.022	0.069	-0.014	0.076**	0.226***
	(0.154)	(0.040)	(0.050)	(0.083)	(0.037)	(0.024)
Ln(price of utilities)	0.292	0.415**	-0.286	-0.556	-0.155	-0.643***
	(0.658)	(0.200)	(0.249)	(0.410)	(0.177)	(0.118)
Ln(price of housing)	-0.366	0.115	-0.090	-0.197	0.259*	0.174*
	(0.621)	(0.169)	(0.196)	(0.328)	(0.145)	(0.094)
Ln(price of transport)	-0.915	0.410*	0.303	1.229**	0.736***	0.770***
	(0.890)	(0.217)	(0.282)	(0.507)	(0.202)	(0.131)
Ln(price of leisure)	-0.097***	0.131***	-0.021	-0.019	0.078***	-0.790***
	(0.037)	(0.011)	(0.016)	(0.023)	(0.011)	(0.013)
Home ownership	0.330***	0.342***	0.944***	5.942***	0.946***	-0.009
	(0.080)	(0.019)	(0.030)	(0.141)	(0.018)	(0.008)
Food stamp value	-0.000***					
	(0.000)					
Observations	103,766	107,644	107,644	107,644	107,644	107,644
State fixed effects	yes	yes	yes	yes	yes	yes
Month fixed effects	yes	yes	yes	yes	yes	yes
P_c	0.000	0.000	0.000	0.000	0.000	0.000

Standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1. Selection variable is home ownership (in addition to food stamp value for non-durables category). Dependent variables are binary variables for observance of each expenditure category. The estimates include the whole sample. P_c represents the P-value from a Wald test of independent equations.

Table D.7: Heckman correction model results for expenditure categories[48]

Variables	(1) Non-durables	(2) Consumer services	(3) Utilities	(4) Housing	(5) Transport	(6) Leisure
Ln(income)	0.223***	0.387***	0.169***	0.201***	0.233***	-0.364***
	(0.003)	(0.006)	(0.003)	(0.003)	(0.004)	(0.004)
Age of reference person	0.011***	0.003***	0.031***	-0.021***	0.027***	-0.029***
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Squared age of reference person	-0.000***	0.000***	-0.000***	0.000***	-0.000***	0.000***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
White	0.114***	0.205***	0.033***	-0.034***	0.061***	0.005*
	(0.005)	(0.009)	(0.005)	(0.006)	(0.006)	(0.003)
Female	-0.033***	0.089***	0.051***	0.018***	-0.061***	0.033***
	(0.004)	(0.007)	(0.004)	(0.004)	(0.005)	(0.002)
Married	0.146***	0.337***	0.135***	0.064***	0.192***	0.178***
	(0.004)	(0.008)	(0.004)	(0.005)	(0.006)	(0.003)
Number of children	0.087***	-0.006*	0.098***	0.043***	0.032***	0.041***
	(0.002)	(0.004)	(0.002)	(0.002)	(0.002)	(0.001)
Number of adults in CU	0.127***	0.049***	0.186***	-0.033***	0.115***	0.630***
	(0.003)	(0.005)	(0.003)	(0.003)	(0.004)	(0.002)
Ln(price of non-durables)	-0.054**	-0.309***	-0.009	-0.102***	-0.511***	-0.128***
	(0.025)	(0.046)	(0.026)	(0.032)	(0.034)	(0.017)
Ln(price of consumer services)	-0.010	0.190***	0.009	0.008	-0.127***	-0.040***
	(0.009)	(0.018)	(0.010)	(0.012)	(0.013)	(0.007)
Ln(price of utilities)	-0.048	-0.255***	-0.053	0.107*	0.199***	0.115***
	(0.048)	(0.085)	(0.051)	(0.058)	(0.063)	(0.033)
Ln(price of housing)	0.148***	0.117*	0.039	0.332***	0.121**	-0.039
	(0.039)	(0.071)	(0.042)	(0.047)	(0.052)	(0.026)
Ln(price of transport)	0.244***	0.282***	0.290***	0.575***	-0.161**	-0.087**
	(0.053)	(0.099)	(0.058)	(0.066)	(0.070)	(0.036)
Ln(price of leisure)	0.094***	0.211***	0.049***	0.101***	0.070***	1.319***
	(0.004)	(0.008)	(0.004)	(0.005)	(0.005)	(0.005)
Observations	103,766	107,644	107,644	107,644	107,644	107,644
State fixed effects	yes	yes	yes	yes	yes	yes
Month fixed effects	yes	yes	yes	yes	yes	yes
P_c	0.000	0.000	0.000	0.000	0.000	0.000

48 Recall that for the purpose of comparison, we use the whole sample for Heckman correction models and vehicle services imputation. The final sample of excluding CUs with more than two adults and above 70 years old is used for the demand estimation.

Standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1. Selection variable is home ownership (in addition to food stamp value for non-durables category). The dependent variables are in the log form and conditional on having positive expenditures for the category. P_c represents the P-value from a Wald test of independent equations.

Appendix E: Price Indices

Table E.1: Cost of Living Index Assignment to Expenditure Categories

Expenditure Category	Assigned COLI Price Indices
Housing	Housing
Utilities	Utilities
Food	Grocery items
Transportation	Transportation
Health care	Health care
Beverages	Beer, Wine
Apparel	Men Dress Shirt, Man Denim Jeans, Boy Jeans, Men Slacks, Women Slacks
Personal Care	Haircut, Beauty Salon, Toothpaste, Shampoo, Dry Cleaning
Reading	Newspaper
Recreation	Movie, Tennis balls, Bowling

In addition to the COLI data, we use state-level regional price parities (RPPs) from 2013-2017 in some specifications to examine the sensitivity of results to the price data used. These RPPs are annual and thus inherently they impose the same regional price parities across all months within a specific year. The RPP data includes the following consumption categories: rent, food, apparel, transport, housing, education, recreation, medical, and others. We use a multilateral aggregation method to calculate aggregated RPPs for non-durables and consumer services. For utilities prices (e.g., electricity, water), we use Bureau of Labor Statistics (BLS) monthly prices and State Energy Data System (SEDS) energy consumption data to calculate a weighted average aggregate utility price. Since we don't have state-level water and telephone prices, we assume their price variation is similar to the utilities' price variation for purposes of aggregation.

There is no direct RPP index for some of our aggregate consumption categories, such as consumers services and non-durables. We employ the Geary (also known as the Geary-Khamis) method (Geary 1958, Khamis 1972) to calculate aggregated price indices that maintain the multilateral properties of the original price indices (Aten, et al. 2011). We follow Aten, et al. (2011) and use the following Geary formula to calculate aggregated price levels:

$$P_{ia}^{Geary} = \frac{e_{ia}(P_a)}{e_{ia}(P_n)}, \qquad \text{(E1)}$$

where a and i represent geographic area and expenditure category, respectively. In general, the Geary price for area a and sub-category i can be calculated by dividing expenditures at area prices (P_a) by expenditures at national prices (P_n). The quantity in the nominator and the denominator is the same, so what remains is relative prices. Then, we can calculate price indices for our aggregated categories by adding expenditures at area prices divided by added expenditures at national prices (replaced with the above formula). For example, we calculate consumer services' RPP in area a as:

$$RPP_{cs,a} = \frac{e_{educ,a(P_a)}+e_{med,a(P_a)}+e_{rec,a(P_a)}}{\frac{e_{educ,a(P_a)}}{RPP_{educ,a}}+\frac{e_{med,a(P_a)}}{RPP_{med,a}}+\frac{e_{rec,a(P_a)}}{RPP_{rec,a}}}, \qquad \text{(E2)}$$

where the expenditures for the education, medical, and recreation sub-categories for each area and year (at area prices) are from the CEX.

Given differences in terms of which sub-categories are included in the COLI versus RPP price indices, the aggregate values are not that close for some categories (e.g., COLI prices for categories such as non-durables and consumer services are lower than RPP prices). However, in general the ranking of expenditure categories is relatively consistent across the two price indices.

Appendix E References

Aten, B., E. Figueroa, and T. Martin. 2011. *Notes on Estimating the Multi-Year Regional Price Parities by 16 Expenditure Categories: 2005-2009.* Bureau of Economic Analysis.

Geary, R. 1958. A note on the comparison of exchange rates and purchasing power between countries. *Journal of the Royal Statistical Society. Series A (General)* 121(1): 97-99.

Khamis, S. 1972. A new system of index numbers for national and international purposes. *Journal of the Royal Statistical Society: Series A (General)* 135(1): 96--121.

Appendix F: Additional Results

Table F.1: Compensated price elasticity results

		Income Group			Census Region			
	National	Low	Medium	High	Midwest	Northeast	South	West
Nondurables	-0.746***	-0.645***	-0.669***	-0.802***	-0.745***	-0.681***	-0.810***	-0.734***
	(0.03)	(0.08)	(0.04)	(0.04)	(0.06)	(0.10)	(0.05)	(0.06)
Consumer services	-0.648***	-0.565***	-0.649***	-0.549***	-0.628***	-0.585***	-0.603***	-0.674***
	(0.02)	(0.04)	(0.03)	(0.03)	(0.05)	(0.06)	(0.13)	(0.04)
Utilities	-0.870***	-0.772***	-0.820***	-0.919***	-0.904***	-0.878***	-0.743***	-0.965***
	(0.05)	(0.14)	(0.07)	(0.06)	(0.14)	(0.11)	(0.10)	(0.06)
Housing	-0.695***	-0.541***	-0.747***	-0.678***	-1.509***	-0.585***	-0.594***	-0.610***
	(0.05)	(0.15)	(0.07)	(0.07)	(0.23)	(0.10)	(0.12)	(0.07)
Transport	-0.811***	-0.589**	-0.794***	-0.839***	-1.135***	-1.166***	0.02	-0.907***
	(0.08)	(0.19)	(0.13)	(0.12)	(0.20)	(0.22)	(0.31)	(0.12)
Leisure	-0.255***	-0.142***	-0.093***	-0.131***	-0.266***	-0.258***	-0.240***	-0.263***
	(0.00)	(0.01)	(0.01)	(0.01)	(0.02)	(0.03)	(0.03)	(0.01)
Model	QUAIDS	QUAIDS	QUAIDS	QUAIDS	QUAIDS	QUAIDS	QUAIDS	QUAIDS
Price data	COLI	COLI	COLI	COLI	COLI	COLI	COLI	COLI
Fixed effect	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	78,134	24,813	25,384	27,937	15,411	14,430	28,611	19,682

Bootstrapped standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1.

Table F.2: Uncompensated cross price elasticity results

	Non-durables	Consumer services	Utilities	Housing	Transport	Leisure
Non-durables	-0.816***	0.064***	0.094*	0.163***	0.06	0.002
	(0.03)	(0.01)	(0.04)	(0.04)	(0.05)	(0.01)
Consumer services	0.024	-0.740***	0.001	0.004	-0.052	-0.189***
	(0.05)	(0.02)	(0.08)	(0.07)	(0.09)	(0.01)
Utilities	0.233***	0.060***	-0.893***	0.028	0.313***	-0.086***
	(0.03)	(0.01)	(0.05)	(0.05)	(0.06)	(0.01)
Housing	0.136***	0.038**	-0.005	-0.791***	0.014	0.021***
	(0.03)	(0.01)	(0.05)	(0.05)	(0.06)	(0.01)
Transport	0.104*	-0.041**	0.286***	0.023	-0.857***	-0.158***
	(0.04)	(0.02)	(0.07)	(0.06)	(0.08)	(0.01)
Leisure	-0.176***	-0.098***	-0.095**	-0.147***	-0.088*	-0.928***
	(0.02)	(0.01)	(0.03)	(0.03)	(0.04)	(0.00)

Bootstrapped standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1.

Table F.3: Compensated cross price elasticity results

	Non-durables	Consumer services	Utilities	Housing	Transport	Leisure
Non-durables	-0.746***	0.106***	0.124**	0.234***	0.091	0.192***
	(0.03)	(0.01)	(0.04)	(0.04)	(0.05)	(0.01)
Consumer services	0.177***	-0.648***	0.067	0.160*	0.015	0.229***
	(0.05)	(0.02)	(0.08)	(0.07)	(0.09)	(0.01)
Utilities	0.289***	0.094***	-0.870***	0.084	0.337***	0.066***
	(0.03)	(0.01)	(0.05)	(0.05)	(0.06)	(0.01)
Housing	0.231***	0.095***	0.036	-0.695***	0.055	0.279***
	(0.03)	(0.01)	(0.05)	(0.05)	(0.06)	(0.01)
Transport	0.207***	0.021	0.330***	0.128*	-0.811***	0.124***
	(0.04)	(0.02)	(0.07)	(0.06)	(0.08)	(0.01)
Leisure	0.071***	0.050***	0.01	0.104**	0.02	-0.255***
	(0.02)	(0.01)	(0.03)	(0.03)	(0.04)	(0.00)

Bootstrapped standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1.

Appendix G: Sensitivity Results

Table G.1: Results sensitivity: budget elasticity (national level)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Non-durables	0.433***	0.407***	0.433***	0.373***	0.336***	0.425***	0.413***	0.444***	0.418***	0.817***
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.003)	(0.00)
Consumer services	0.952***	0.969***	0.950***	0.833***	0.766***	0.836***	1.003***	0.919***	0.885***	1.545***
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.006)	(0.01)
Utilities	0.345***	0.315***	0.347***	0.304***	0.281***	0.300***	0.370***	0.330***	0.339***	0.577***
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.00)	(0.01)	(0.01)	(0.004)	(0.00)
Housing	0.587***	0.573***	0.587***	0.518***	0.479***	0.625***	0.575***	0.587***	0.578***	1.045***
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.00)	(0.01)	(0.01)	(0.004)	(0.00)
Transport	0.642***	0.628***	0.646***	0.572***	0.535***	0.606***	0.650***	0.637***	0.627***	0.994***
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.005)	(0.01)
Leisure	1.532***	1.517***	1.534***	1.528***	1.525***	1.550***	1.505***	1.549***	1.543***	
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.003)	
Model	QUAIDS	QUAIDS	QUAIDS	QUAIDS	QUAIDS	QUAIDS	QUAIDS	QUAIDS	QUAIDS	QUAIDS
Max no. of adults	2	2	2	2	2	n/a	2	2	n/a	2
Max age	70	70	70	70	70	n/a	65	75	70	70
Time endowment	10.96	10.96	10.96	13.3	15	10.96	10.96	10.96	10.96	10.96
Expenditures	Nominal	Nominal	Real	Nominal	Nominal	Nominal	Nominal	Nominal	Nominal	Nominal
Price data	COLI	RPP	COLI	COLI	COLI	COLI	COLI	COLI	COLI	COLI
Leisure	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No
Fixed effect	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	78,134	78,134	78,134	78,134	78,134	109,780	70,488	83,573	93,669	78,134

Bootstrapped standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1.

Table G.2: Results sensitivity: un-compensated price elasticity (national level)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Non-durables	-0.816***	-0.890*	-0.823***	-0.800***	-0.796***	-0.853***	-0.812***	-0.837***	-0.807***	-0.868***
	(0.03)	(0.36)	(0.03)	(0.03)	(0.03)	(0.02)	(0.03)	(0.03)	(0.024)	(0.02)
Consumer services	-0.740***	-0.557*	-0.739***	-0.729***	-0.721***	-0.701***	-0.751***	-0.730***	-0.723***	-0.833***
	(0.02)	(0.28)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.016)	(0.01)
Utilities	-0.893***	-0.938***	-0.858***	-0.893***	-0.891***	-0.885***	-0.885***	-0.864***	-0.904***	-0.892***
	(0.05)	(0.07)	(0.05)	(0.05)	(0.05)	(0.05)	(0.05)	(0.05)	(0.044)	(0.04)
Housing	-0.791***	-0.572	-0.783***	-0.759***	-0.747***	-0.848***	-0.789***	-0.803***	-0.807***	-0.932***
	(0.05)	(0.38)	(0.05)	(0.05)	(0.05)	(0.04)	(0.05)	(0.05)	(0.043)	(0.04)
Transport	-0.857***	-1.145*	-0.846***	-0.829***	-0.821***	-0.945***	-0.804***	-0.878***	-0.894***	-0.966***
	(0.08)	(0.53)	(0.08)	(0.08)	(0.09)	(0.07)	(0.08)	(0.08)	(0.073)	(0.07)
Leisure	-0.928***	-0.958***	-0.927***	-0.951***	-0.963***	-0.971***	-0.937***	-0.935***	-0.936***	
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.01)	(0.00)	(0.004)	
Model	QUAIDS	QUAIDS	QUAIDS	QUAIDS	QUAIDS	QUAIDS	QUAIDS	QUAIDS	QUAIDS	QUAIDS
Max no. of adults	2	2	2	2	2	n/a	2	2	n/a	2
Max age	70	70	70	70	70	n/a	65	75	70	70
Time endowment	10.96	10.96	10.96	13.3	15	10.96	10.96	10.96	10.96	10.96
Expenditures	Nominal	Nominal	Real	Nominal	Nominal	Nominal	Nominal	Nominal	Nominal	Nominal
Price data	COLI	RPP	COLI	COLI	COLI	COLI	COLI	COLI	COLI	COLI
Leisure	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No
Fixed effect	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	78,134	78,134	78,134	78,134	78,134	109,780	70,488	83,573	93,669	78,134

Bootstrapped standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1.

Table G.3: Results sensitivity: compensated price elasticity

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Non-durables	-0.746***	-0.826*	-0.753***	-0.744***	-0.748***	-0.786***	-0.746***	-0.766***	-0.740***	-0.632***
	(0.03)	(0.36)	(0.03)	(0.03)	(0.03)	(0.02)	(0.03)	(0.03)	(0.024)	(0.02)
Consumer services	-0.648***	-0.464	-0.647***	-0.653***	-0.653***	-0.618***	-0.660***	-0.637***	-0.639***	-0.572***
	(0.02)	(0.28)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.016)	(0.01)
Utilities	-0.870***	-0.917***	-0.834***	-0.874***	-0.874***	-0.865***	-0.859***	-0.841***	-0.881***	-0.822***
	(0.05)	(0.07)	(0.05)	(0.05)	(0.05)	(0.05)	(0.05)	(0.05)	(0.044)	(0.04)
Housing	-0.695***	-0.48	-0.687***	-0.681***	-0.678***	-0.744***	-0.698***	-0.707***	-0.714***	-0.630***
	(0.05)	(0.38)	(0.05)	(0.05)	(0.05)	(0.04)	(0.05)	(0.05)	(0.043)	(0.04)
Transport	-0.811***	-1.102*	-0.801***	-0.792***	-0.788***	-0.904***	-0.759***	-0.833***	-0.851***	-0.835***
	(0.08)	(0.53)	(0.08)	(0.08)	(0.09)	(0.07)	(0.08)	(0.08)	(0.073)	(0.07)
Leisure	-0.255***	-0.270***	-0.255***	-0.218***	-0.198***	-0.286***	-0.256***	-0.264***	-0.247***	
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.004)	
Model	QUAIDS	QUAIDS	QUAIDS	QUAIDS	QUAIDS	QUAIDS	QUAIDS	QUAIDS	QUAIDS	QUAIDS
Sample	National	National	National	National	National	National	National	National	National	National
Max no. of adults	2	2	2	2	2	n/a	2	2	n/a	2
Max age	70	70	70	70	70	n/a	65	75	70	70
Time endowment	10.96	10.96	10.96	13.3	15	10.96	10.96	10.96	10.96	10.96
Expenditures	Nominal	Nominal	Real	Nominal	Nominal	Nominal	Nominal	Nominal	Nominal	Nominal
Price data	COLI	RPP	COLI	COLI	COLI	COLI	COLI	COLI	COLI	COLI
Leisure	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No
Fixed effect	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	78,134	78,134	78,134	78,134	78,134	109,780	70,488	83,573	93,669	78,134

Bootstrapped standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1.

Table G.4: Income-group results: using adjusted expenditures to define income groups

	Budget Elasticity			Un-compensated Price Elasticity			Compensated Price Elasticity		
Nondurables	0.075***	0.438***	0.478***	-0.646***	-0.728***	-0.792***	-0.636***	-0.647***	-0.698***
	(0.01)	(0.01)	(0.01)	(0.06)	(0.03)	(0.03)	(0.06)	(0.03)	(0.03)
Consumer services	0.425***	0.421***	0.799***	-0.794***	-0.758***	-0.679***	-0.767***	-0.707***	-0.549***
	(0.01)	(0.01)	(0.01)	(0.04)	(0.02)	(0.02)	(0.04)	(0.02)	(0.02)
Utilities	0.248***	0.385***	0.400***	-0.790***	-1.008***	-0.878***	-0.773***	-0.977***	-0.850***
	(0.01)	(0.01)	(0.01)	(0.13)	(0.06)	(0.05)	(0.13)	(0.06)	(0.05)
Housing	0.312***	0.424***	0.584***	-0.510***	-0.788***	-0.809***	-0.466***	-0.706***	-0.687***
	(0.01)	(0.01)	(0.01)	(0.13)	(0.05)	(0.06)	(0.13)	(0.05)	(0.06)
Transport	0.338***	0.440***	0.587***	-0.664***	-0.769***	-0.826***	-0.645**	-0.732***	-0.770***
	(0.01)	(0.01)	(0.01)	(0.20)	(0.10)	(0.10)	(0.20)	(0.10)	(0.10)
Leisure	1.680***	2.144***	2.135***	-0.918***	-0.550***	-0.679***	-0.036***	0.167***	-0.109***
	(0.01)	(0.01)	(0.02)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
Income group	Low	Medium	High	Low	Medium	High	Low	Medium	High
Model	QUAIDS	QUAIDS	QUAIDS	QUAIDS	QUAIDS	QUAIDS	QUAIDS	QUAIDS	QUAIDS
Max no. of adults	2	2	2	2	2	2	2	2	2
Max age	70	70	70	70	70	70	70	70	70
Time endowment	10.96	10.96	10.96	10.96	10.96	10.96	10.96	10.96	10.96
Expenditures	Nominal	Nominal	Nominal	Nominal	Nominal	Nominal	Nominal	Nominal	Nominal
Price data	COLI	COLI	COLI	COLI	COLI	COLI	COLI	COLI	COLI
Fixed effect	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	24,813	25,384	27,937	24,813	25,384	27,937	24,813	25,384	27,937

Bootstrapped standard errors in parentheses; *** $p<0.01$, ** $p<0.05$, * $p<0.1$.

Table G.5: Results sensitivity: budget elasticity (low income)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Nondurables	0.189***	0.113***	0.162***	0.142***	0.092***	0.287***	0.276***	0.252***	0.250***	0.749***
	(0.02)	(0.02)	(0.016)	(0.01)	(0.02)	(0.01)	(0.01)	(0.01)	(0.010)	(0.01)
Consumer services	1.068***	1.133***	1.084***	0.890***	0.805***	0.885***	1.085***	1.026***	0.930***	1.709***
	(0.02)	(0.02)	(0.019)	(0.02)	(0.02)	(0.01)	(0.02)	(0.02)	(0.014)	(0.01)
Utilities	0.187***	0.151***	0.146***	0.185***	0.152***	0.238***	0.378***	0.223***	0.277***	0.587***
	(0.02)	(0.02)	(0.018)	(0.02)	(0.02)	(0.01)	(0.01)	(0.01)	(0.011)	(0.01)
Housing	0.238***	0.210***	0.213***	0.177***	0.112***	0.475***	0.420***	0.301***	0.384***	0.972***
	(0.02)	(0.03)	(0.020)	(0.02)	(0.02)	(0.01)	(0.01)	(0.02)	(0.012)	(0.01)
Transport	0.519***	0.550***	0.522***	0.444***	0.396***	0.581***	0.603***	0.545***	0.543***	1.046***
	(0.02)	(0.02)	(0.018)	(0.02)	(0.02)	(0.01)	(0.01)	(0.02)	(0.012)	(0.01)
Leisure	1.575***	1.462***	1.538***	1.623***	1.629***	1.599***	1.626***	1.601***	1.628***	
	(0.01)	(0.01)	(0.007)	(0.01)	(0.01)	(0.00)	(0.01)	(0.01)	(0.005)	
Model	QUAIDS	QUAIDS	QUAIDS	QUAIDS	QUAIDS	QUAIDS	QUAIDS	QUAIDS	QUAIDS	QUAIDS
Max no. of adults	2	2	2	2	2	n/a	2	2	n/a	2
Max age	70	70	70	70	70	n/a	65	75	70	70
Time endowment	10.96	10.96	10.96	13.3	15	10.96	10.96	10.96	10.96	10.96
Expenditures	Nominal	Nominal	Real	Nominal	Nominal	Nominal	Nominal	Nominal	Nominal	Nominal
Price data	COLI	RPP	COLI	COLI	COLI	COLI	COLI	COLI	COLI	COLI
Leisure	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No
Fixed effect	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	24,813	24,813	24,813	24,813	24,813	36,640	21,954	27,326	28,401	24,813

Bootstrapped standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1.

Table G.6: Results sensitivity: budget elasticity (medium income)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Nondurables	0.418***	0.373***	0.417***	0.354***	0.316***	0.390***	0.457***	0.427***	0.417***	0.837***
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.006)	(0.01)
Consumer services	0.678***	0.676***	0.677***	0.568***	0.507***	0.573***	0.757***	0.656***	0.632***	1.584***
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.010)	(0.01)
Utilities	0.288***	0.230***	0.290***	0.247***	0.220***	0.226***	0.382***	0.268***	0.293***	0.551***
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.006)	(0.01)
Housing	0.544***	0.532***	0.543***	0.473***	0.431***	0.590***	0.558***	0.548***	0.542***	0.987***
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.006)	(0.01)
Transport	0.499***	0.464***	0.503***	0.423***	0.380***	0.485***	0.524***	0.522***	0.489***	1.035***
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.010)	(0.01)
Leisure	1.656***	1.625***	1.658***	1.639***	1.626***	1.624***	1.660***	1.647***	1.661***	
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.006)	
Model	QUAIDS	QUAIDS	QUAIDS	QUAIDS	QUAIDS	QUAIDS	QUAIDS	QUAIDS	QUAIDS	QUAIDS
Max no. of adults	2	2	2	2	2	n/a	2	2	n/a	2
Max age	70	70	70	70	70	n/a	65	75	70	70
Time endowment	10.96	10.96	10.96	13.3	15	10.96	10.96	10.96	10.96	10.96
Expenditures	Nominal	Nominal	Real	Nominal	Nominal	Nominal	Nominal	Nominal	Nominal	Nominal
Price data	COLI	RPP	COLI	COLI	COLI	COLI	COLI	COLI	COLI	COLI
Leisure	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No
Fixed effect	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	25,384	25,384	25,384	25,384	25,384	36,890	22,636	27,274	31,401	25,384

Bootstrapped standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1.

Table G.7: Results sensitivity: budget elasticity (high income)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Nondurables	0.380***	0.316***	0.433***	0.515***	0.390***	0.211***	0.478***	0.186***	0.362***	0.922***
	(0.01)	(0.02)	(0.01)	(0.01)	(0.01)	(0.02)	(0.01)	(0.02)	(0.012)	(0.01)
Consumer services	0.909***	0.940***	0.902***	0.724***	0.562***	0.746***	1.221***	0.768***	0.932***	1.481***
	(0.02)	(0.02)	(0.02)	(0.01)	(0.01)	(0.02)	(0.03)	(0.02)	(0.016)	(0.02)
Utilities	0.183***	0.120***	0.282***	0.446***	0.316***	-0.265***	0.342***	-0.251***	0.138***	0.503***
	(0.01)	(0.02)	(0.01)	(0.01)	(0.01)	(0.03)	(0.01)	(0.03)	(0.013)	(0.01)
Housing	0.587***	0.564***	0.605***	0.602***	0.492***	0.540***	0.627***	0.501***	0.567***	1.001***
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.02)	(0.012)	(0.01)
Transport	0.533***	0.508***	0.570***	0.576***	0.461***	0.398***	0.600***	0.424***	0.503***	1.002***
	(0.02)	(0.02)	(0.02)	(0.01)	(0.01)	(0.02)	(0.02)	(0.03)	(0.017)	(0.01)
Leisure	1.376***	1.367***	1.410***	1.585***	1.572***	1.361***	1.308***	1.342***	1.359***	
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.00)	(0.01)	(0.00)	(0.005)	
Model	QUAIDS	QUAIDS	QUAIDS	QUAIDS	QUAIDS	QUAIDS	QUAIDS	QUAIDS	QUAIDS	QUAIDS
Max no. of adults	2	2	2	2	2	n/a	2	2	n/a	2
Max age	70	70	70	70	70	n/a	65	75	70	70
Time endowment	10.96	10.96	10.96	13.3	15	10.96	10.96	10.96	10.96	10.96
Expenditures	Nominal	Nominal	Real	Nominal	Nominal	Nominal	Nominal	Nominal	Nominal	Nominal
Price data	COLI	RPP	COLI	COLI	COLI	COLI	COLI	COLI	COLI	COLI
Leisure	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No
Fixed effect	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	27,937	27,937	27,937	27,937	27,937	36,250	25,898	28,973	33,867	27,937

Bootstrapped standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1.

Table G.8: Results sensitivity: un-compensated price elasticity (low income)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Nondurables	-0.670***	-1.001	-0.677***	-0.639***	-0.628***	-0.768***	-0.682***	-0.711***	-0.671***	-0.793***
	(0.08)	(1.16)	(0.08)	(0.08)	(0.08)	(0.06)	(0.07)	(0.07)	(0.065)	(0.04)
Consumer services	-0.660***	-0.85	-0.661***	-0.649***	-0.643***	-0.663***	-0.638***	-0.670***	-0.662***	-0.865***
	(0.04)	(0.65)	(0.04)	(0.04)	(0.04)	(0.03)	(0.05)	(0.04)	(0.038)	(0.02)
Utilities	-0.785***	-0.855***	-0.714***	-0.808***	-0.803***	-0.824***	-0.809***	-0.766***	-0.834***	-0.862***
	(0.14)	(0.21)	(0.15)	(0.14)	(0.15)	(0.11)	(0.12)	(0.13)	(0.117)	(0.09)
Housing	-0.573***	0.277	-0.544***	-0.533***	-0.511***	-0.713***	-0.646***	-0.623***	-0.634***	-0.889***
	(0.15)	(1.36)	(0.16)	(0.15)	(0.15)	(0.11)	(0.13)	(0.14)	(0.120)	(0.08)
Transport	-0.625**	-1.233	-0.593**	-0.591**	-0.578**	-0.849***	-0.484**	-0.662***	-0.691***	-0.863***
	(0.19)	(1.36)	(0.20)	(0.19)	(0.20)	(0.15)	(0.18)	(0.18)	(0.169)	(0.12)
Leisure	-0.942***	-0.964***	-0.950***	-0.949***	-0.965***	-1.004***	-0.879***	-0.944***	-0.904***	
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.00)	(0.01)	(0.01)	(0.007)	
Model	QUAIDS	QUAIDS	QUAIDS	QUAIDS	QUAIDS	QUAIDS	QUAIDS	QUAIDS	QUAIDS	QUAIDS
Max no. of adults	2	2	2	2	2	n/a	2	2	n/a	2
Max age	70	70	70	70	70	n/a	65	75	70	70
Time endowment	10.96	10.96	10.96	13.3	15	10.96	10.96	10.96	10.96	10.96
Expenditures	Nominal	Nominal	Real	Nominal	Nominal	Nominal	Nominal	Nominal	Nominal	Nominal
Price data	COLI	RPP	COLI	COLI	COLI	COLI	COLI	COLI	COLI	COLI
Leisure	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No
Fixed effect	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	24,813	24,813	24,813	24,813	24,813	36,640	21,954	27,326	28,401	24,813

Bootstrapped standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1.

Table G.9: Results sensitivity: un-compensated price elasticity (medium income)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Nondurables	-0.736***	-1.185*	-0.739***	-0.727***	-0.722***	-0.790***	-0.707***	-0.766***	-0.726***	-0.866***
	(0.04)	(0.54)	(0.04)	(0.04)	(0.04)	(0.04)	(0.04)	(0.04)	(0.034)	(0.03)
Consumer services	-0.721***	-1.195**	-0.720***	-0.719***	-0.713***	-0.670***	-0.756***	-0.706***	-0.703***	-0.862***
	(0.03)	(0.42)	(0.03)	(0.03)	(0.03)	(0.02)	(0.03)	(0.03)	(0.023)	(0.02)
Utilities	-0.839***	-0.844***	-0.809***	-0.830***	-0.821***	-0.798***	-0.878***	-0.820***	-0.840***	-0.906***
	(0.07)	(0.09)	(0.07)	(0.07)	(0.07)	(0.07)	(0.06)	(0.07)	(0.059)	(0.06)
Housing	-0.834***	-1.386*	-0.824***	-0.805***	-0.795***	-0.933***	-0.833***	-0.871***	-0.848***	-0.993***
	(0.07)	(0.55)	(0.07)	(0.07)	(0.07)	(0.06)	(0.07)	(0.07)	(0.059)	(0.06)
Transport	-0.830***	-3.431***	-0.822***	-0.817***	-0.812***	-0.997***	-0.851***	-0.909***	-0.852***	-0.985***
	(0.13)	(0.88)	(0.13)	(0.13)	(0.13)	(0.12)	(0.12)	(0.13)	(0.112)	(0.11)
Leisure	-0.811***	-0.840***	-0.810***	-0.864***	-0.890***	-0.894***	-0.719***	-0.814***	-0.814***	
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.007)	
Model	QUAIDS	QUAIDS	QUAIDS	QUAIDS	QUAIDS	QUAIDS	QUAIDS	QUAIDS	QUAIDS	QUAIDS
Max no. of adults	2	2	2	2	2	n/a	2	2	n/a	2
Max age	70	70	70	70	70	n/a	65	75	70	70
Time endowment	10.96	10.96	10.96	13.3	15	10.96	10.96	10.96	10.96	10.96
Expenditures	Nominal	Nominal	Real	Nominal	Nominal	Nominal	Nominal	Nominal	Nominal	Nominal
Price data	COLI	RPP	COLI	COLI	COLI	COLI	COLI	COLI	COLI	COLI
Leisure	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No
Fixed effect	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	25,384	25,384	25,384	25,384	25,384	36,890	22,636	27,274	31,401	25,384

Bootstrapped standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1.

Table G.10: Results sensitivity: un-compensated price elasticity (high income)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Nondurables	-0.850***	-0.603	-0.849***	-0.785***	-0.808***	-0.898***	-0.852***	-0.904***	-0.856***	-0.972***
	(0.04)	(0.57)	(0.04)	(0.03)	(0.03)	(0.05)	(0.04)	(0.06)	(0.040)	(0.03)
Consumer services	-0.620***	0.832	-0.650***	-0.720***	-0.708***	-0.545***	-0.569***	-0.562***	-0.589***	-0.828***
	(0.03)	(0.55)	(0.03)	(0.03)	(0.02)	(0.03)	(0.05)	(0.04)	(0.029)	(0.02)
Utilities	-0.928***	-1.104***	-0.886***	-0.910***	-0.923***	-0.980***	-0.950***	-0.947***	-0.958***	-0.893***
	(0.06)	(0.08)	(0.05)	(0.03)	(0.04)	(0.08)	(0.04)	(0.09)	(0.053)	(0.05)
Housing	-0.753***	-0.006	-0.755***	-0.751***	-0.761***	-0.801***	-0.733***	-0.749***	-0.795***	-0.885***
	(0.07)	(0.55)	(0.07)	(0.05)	(0.05)	(0.07)	(0.07)	(0.09)	(0.062)	(0.05)
Transport	-0.870***	-0.525	-0.866***	-0.868***	-0.881***	-0.878***	-0.808***	-0.856***	-0.944***	-0.991***
	(0.12)	(0.80)	(0.12)	(0.08)	(0.09)	(0.14)	(0.13)	(0.16)	(0.113)	(0.10)
Leisure	-0.895***	-0.897***	-0.847***	-0.584***	-0.852***	-1.073***	-0.827***	-1.066***	-0.948***	
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.006)	
Model	QUAIDS	QUAIDS	QUAIDS	QUAIDS	QUAIDS	QUAIDS	QUAIDS	QUAIDS	QUAIDS	QUAIDS
Max no. of adults	2	2	2	2	2	n/a	2	2	n/a	2
Max age	70	70	70	70	70	n/a	65	75	70	70
Time endowment	10.96	10.96	10.96	13.3	15	10.96	10.96	10.96	10.96	10.96
Expenditures	Nominal	Nominal	Real	Nominal	Nominal	Nominal	Nominal	Nominal	Nominal	Nominal
Price data	COLI	RPP	COLI	COLI	COLI	COLI	COLI	COLI	COLI	COLI
Leisure	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No
Fixed effect	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	27,937	27,937	27,937	27,937	27,937	36,250	25,898	28,973	33,867	27,937

Bootstrapped standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1.

Table G.11: AIDS demand system estimation results (national level)

Variables	(1) Non-durables share	(2) Consumer services share	(3) Utilities share	(4) Housing share	(5) Transport share	(6) Leisure share
γ_ln(p_non_dur)	-0.008**	0.000	-0.006***	-0.002	-0.003	0.019**
	(0.004)	(0.004)	(0.002)	(0.005)	(0.003)	(0.008)
γ_ln(p_cons_serv)	0.000	0.027***	-0.002***	-0.001	-0.005***	-0.018***
	(0.002)	(0.002)	(0.001)	(0.002)	(0.001)	(0.003)
γ_ln(p_utility)	-0.006	-0.002	0.003	-0.012	0.013***	0.003
	(0.007)	(0.007)	(0.003)	(0.008)	(0.005)	(0.013)
γ_ln(p_housing)	-0.002	-0.001	-0.012***	0.011	-0.005	0.010
	(0.006)	(0.007)	(0.003)	(0.008)	(0.004)	(0.012)
γ_ln(p_transport)	-0.003	-0.005	0.013***	-0.005	0.009	-0.008
	(0.008)	(0.009)	(0.004)	(0.010)	(0.006)	(0.015)
γ_ln(p_leisure)	0.019***	-0.018***	0.003***	0.010***	-0.008***	-0.005***
	(0.001)	(0.001)	(0.000)	(0.001)	(0.001)	(0.002)
β_ln(income)	-0.089***	-0.010***	-0.040***	-0.063***	-0.021***	0.223***
	(0.001)	(0.001)	(0.000)	(0.001)	(0.000)	(0.001)
α_age	-0.000	0.001***	0.000***	0.000***	0.000***	-0.001***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
α_family_size	0.028***	0.010***	0.008***	0.006***	-0.001**	-0.051***
	(0.001)	(0.001)	(0.000)	(0.001)	(0.001)	(0.001)
α_#of income earner	-0.014***	-0.026***	-0.006***	-0.020***	-0.003***	0.069***
	(0.001)	(0.001)	(0.000)	(0.001)	(0.000)	(0.001)
α_white	0.009***	0.001	-0.005***	0.010***	-0.001**	-0.014***
	(0.001)	(0.001)	(0.000)	(0.001)	(0.001)	(0.001)
α_own_home	0.021***	0.027***	0.014***	-0.069***	0.008***	-0.002
	(0.001)	(0.001)	(0.000)	(0.001)	(0.001)	(0.002)
α_#of child	-0.019***	-0.011***	-0.005***	-0.005***	0.001	0.040***
	(0.001)	(0.001)	(0.000)	(0.001)	(0.001)	(0.002)
Sample	National	National	National	National	National	National
Model	AIDS	AIDS	AIDS	AIDS	AIDS	AIDS
Price data	COLI	COLI	COLI	COLI	COLI	COLI
State fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Inverse mills ratios	Yes	Yes	Yes	Yes	Yes	Yes
Observations	75,070	75,070	75,070	75,070	75,070	75,070

Bootstrapped standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1.

Appendix H: Labor Supply and Consumer Demand Elasticity Calibration for BEIGE

Expenditure shares differ slightly by demand system because the imputed value of leisure differs (given we use alternative budget elasticities for calibration). We report estimated CEX-based expenditure shares for comparison (Table H.1). In all cases, the calibrated value of leisure is smaller than the estimated value. The other noticeable difference is that the consumer services category represents a much larger share of expenditures in the input output data relative to the CEX. This impacts our ability to target estimated cross-price elasticities precisely for this category.

Table H.1: Expenditure Shares

	CEX	QUAIDS	LES	CES
Non-durables	0.165	0.127	0.130	0.129
Consumer services	0.099	0.365	0.373	0.372
Utilities	0.068	0.033	0.034	0.033
Housing	0.162	0.195	0.199	0.199
Transportation	0.069	0.069	0.071	0.070
Leisure	0.437	0.211	0.195	0.195

We calibrate consumer demand by defining unknown parameters in terms of known parameters consistent with the reference equilibrium. The calibration procedure for incorporating the QUAIDS and LES demand systems into BEIGE is loosely based on Roland-Holst and Mensbrugghe (2009). For QUAIDS, we solve for $\alpha_i, \beta_i, \gamma_{ij}$, and λ_i in terms of reference quantities and prices (from the input output matrix) and estimated income and own/cross price elasticities (from Table 4). Because the CEX-based expenditure shares are inconsistent with those from the input output table, changes to the elasticity values are needed to fully balance the system of equations.[49] In the LES case, we calibrate the system to estimate subsistence demands matched as closely as possible with the budget elasticities in Table 4. The routine also relies on the Frisch parameter calculated from the CEX to determine total subsistence

[49] We define a matrix balancing routine to impose the consistency requirements of the QUAIDS demand system on the calibrated values. This routine minimizes the needed changes in the behavioral parameters subject to the homogeneity, symmetry and adding up constraints. The additional constraint in the CGE application, relative to the estimating framework, is that budget shares must match those derived from the input output data. Discrepancies in the calibrated vs. estimated elasticities reported in Table H.2 are minimized to accommodate those differences.

demand for the U.S. economy (accommodating an imbalance in the number of needed equations relative to unknown parameters in the calibration framework).[50]

We compare the budget and own-price elasticities of the econometrically estimated values with the calibrated values in BEIGE (Table H.2). Like the calibrated labor supply elasticities, all calibrated values can be backed out of the model to verify the efficacy of the calibration routine.

Table H.2: Results of the Calibration Procedure

		QUAIDS		LES		CES
		Estimated	Calibrated	Estimated	Calibrated	Calibrated
Income Elasticities	Non-durables	0.42	0.58	0.43	0.45	1
	Consumer services	0.92	1.31	1.01	1.53	1
	Utilities	0.35	0.45	0.19	0.21	1
	Housing	0.59	0.57	0.48	0.56	1
	Transportation	0.66	0.90	0.48	0.48	1
	Leisure	1.54	1.54	1.23	1.12	1
Own Price Uncompensated Elasticities	Non-durables	-0.82	-1.00	-0.28	-0.32	-0.89
	Consumer services	-0.74	-0.85	-0.61	-0.97	-0.88
	Utilities	-0.90	-1.15	-0.15	-0.13	-0.90
	Housing	-0.79	-0.87	-0.31	-0.41	-0.89
	Transportation	-0.86	-0.69	-0.28	-0.32	-0.90
	Leisure	-0.93	-0.59	-0.96	-0.75	-0.46

The calibrated income and uncompensated own-price elasticities by income group are reported in Table H.3. These values differ slightly from the estimated values due to the issues discussed above.

Table H.3: Calibrated Income and Own-price Uncompensated Elasticities from QUAIDS-Income Disaggregation

	Budget Elasticities				Uncompensated Price Elasticities			
	National	Low	Middle	High	National	Low	Middle	High
Non-durables	0.58	0.26	0.58	0.40	-1.00	-0.66	-0.93	-1.00
Consumer services	1.13	1.50	0.95	1.18	-0.85	-0.70	-0.76	-0.82
Utilities	0.45	0.26	0.40	0.20	-1.15	-0.84	-1.04	-0.97
Housing	0.57	0.18	0.76	0.82	-0.87	-0.48	-0.90	-0.88

[50] The Frisch parameter is defined as the negative ratio of total expenditures to discretionary expenditures. Using the estimated parameters from the LES demand system estimation, this value is -1.64 at the national level.

Transportation	0.90	0.65	0.70	0.71	-0.69	-0.53	-0.74	-0.73
Leisure	1.54	1.58	1.95	1.38	-0.59	-0.47	-0.52	-0.45

Appendix H References

Roland-Holst, D., and D. van der Mensbrugghe. 2009. General equilibrium techniques for policy modeling. Working paper.

Appendix I: Additional BEIGE Simulation Results

Figure I.1: Percent Change in Labor Demand by Sector

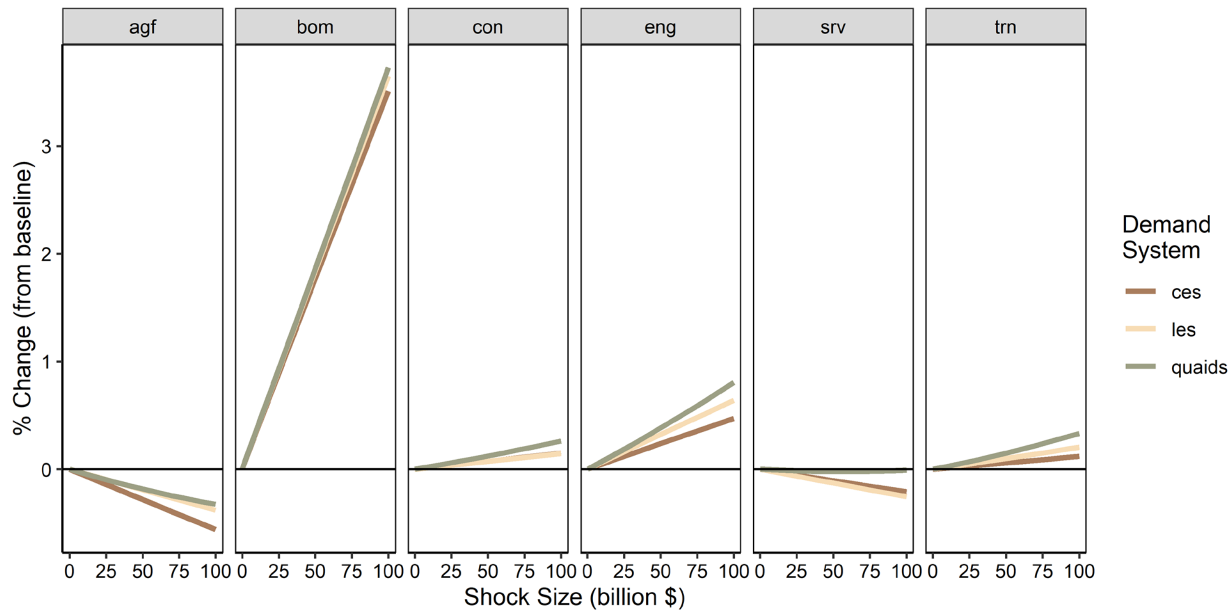

Figure I.2: Percent Change in Output by Sector