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POPULATION AGING AND STRUCTURAL TRANSFORMATION

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ABSTRACT

We propose and quantify a novel mechanism behind the structural transformation process: older individuals devote a larger share of their expenditures to services, so the relative size of the service sector grows as the population ages. In a large sample of countries, we document that increases in population age are accompanied by the rise in the relative size of the service sector. In household-level data from the U.S. Consumer Expenditure Survey, the fraction of expenditures devoted to services increases with household age. We use a shift-share decomposition and a quantitative model to show that changes in the U.S. population age distribution accounted for about a fifth of the observed increase in the share of services in consumption expenditures between 1982 and 2016. The contribution of population aging to the rise in the service share is about the same size as the contribution of real income growth, and about half as large as that of changes in relative prices.

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1 Introduction

Economic growth is accompanied by large reallocations of economic activity across broad sectors, a phenomenon known as structural transformation (Kuznets, 1957). In advanced economies, the structural transformation process is associated with a decline in the relative size of the Agriculture and Manufacturing sectors and a corresponding rise in the Service sector. Traditional theories that attempt to rationalize this process have relied on non-homothetic preferences with a high income elasticity for services (e.g. Kongsamut et al., 2001), or on a technology-driven increase in the relative price of services coupled with a low elasticity of substitution across sectors (Baumol, 1967; Ngai and Pissarides, 2007).

This paper proposes, documents, and quantifies a novel mechanism behind the structural transformation process: if older individuals devote a larger share of their expenditures to services, then the relative size of the service sector grows as the population ages. We show that, across a large sample of countries, increases in population age are accompanied by a rise in the relative size of the service sector. Using household-level data for the US, we document large differences in sectoral expenditure shares across households of different ages, with older households spending relatively more on services. We then use a shift-share decomposition and a quantitative model of structural change to quantify how much of the rise in the relative size of the service sector in the US over the period 1982-2016 can be accounted for by changes in population age.

To document how structural transformation is related to population aging across countries and time, we use multiple data sources following the Handbook chapter by Herrendorf et al. (2014). Across many countries and years, and several datasets, the service shares of employment, value added, and consumption expenditures are positively related to population aging. Importantly, this empirical regularity persists when controlling for the (possibly nonlinear) relationship between the service shares and income per capita that has been emphasized in the previous literature. After controlling for income, a 1 percentage point increase in the fraction of population that is over 65 is associated with a 1.5 p.p. increase in the service shares of value-added and employment, and a 1 p.p. increase in the service share of consumption expenditures.

We then use household-level data from the US Consumer Expenditure Survey (CES) to document large differences in sectoral expenditure shares across households of different ages. Our data cover the 1982-2016 period and have been widely used to study how service expenditures vary with household income. Older households spend significantly more on services, a pattern monotonic in household age throughout the age distribution. Compared to households in their early 30s, the service expenditure shares of households in their early 60s (resp. over 80) are 8 (resp. 27) percentage points higher. These differences are stable over the sample period, and are equally large when controlling flexibly for household income. The largest differences in expenditure patterns arise in Health, Utilities, and Domestic Care and Childcare, which are intensively consumed by the old, and in Vehicle Purchases, Leasing, and Gasoline and Motor Oil, which are intensively consumed by the young.[1]

We quantify the contribution of population aging to structural change in the US in two complementary ways. First, we perform a simple within-between decomposition of the change in the service expenditure share between 1982 and 2016 (the sample period available in the CES). We write the change in the aggregate service expenditure share as a sum of two terms, one capturing changes in the service share of expenditures within each household-age group, and another capturing changes in the relative aggregate expenditure of the age groups. This decomposition shows that changes in the age-structure of the population accounted for 20% of the observed change in the service expenditure share over this period.

We then use our data along with a structural model to evaluate the relative contributions of changes in relative prices, real income, and the age distribution to the structural change process. We use a two-sector model with heterogenous households whose preferences over goods and services take the Price-Independent Generalized Linear (PIGL) form, augmented with age-specific taste shifters. These preferences were introduced by Muellbauer (1975, 1976), and recently applied to the analysis of structural change by Boppart (2014). In the model, the household-specific expenditure share on goods depends on the relative price of goods vs. services, the household real expenditures, and the household taste shifter. An advantage of the PIGL preferences is that household-level expenditures can be easily aggregated, so that the aggregate expenditure shares are a function of relative prices, aggregate income per capita, and a weighted average of the taste shifters, with weights that correspond to the relative importance of each age group in total expenditures.

The relative strengths of the mechanisms that determine structural change in the model depend on the elasticity of substitution across sectors, the income elasticity of each sector, and the relative size of the age-specific taste shifters. Following Boppart (2014), we use

[1]It is well-known that the CES only contains health expenditures paid directly by households (i.e., it excludes payments made by Medicare, Medicaid, or private insurance). According to the National Health Expenditure Survey (NHES), out-of-pocket health expenses represent a similar fraction of total health expenses across the age distribution, so the differences in health expenditures persist after adding non-out-of-pocket expenditures. Appendix B.2 repeats our analysis after rescaling household-specific expenditure shares in the CES to match the aggregate expenditures reported in National Accounts data.

the model's structural equations for the household-specific expenditure shares and cross-sectional household data to estimate the sectoral income elasticities, and use the same methodology to estimate age-specific taste shifters. We then use the structural equation for the aggregate expenditure shares and aggregate data on expenditures and prices to estimate the parameter governing the elasticity of substitution between goods and services.

Having estimated the preference parameters allows us to decompose the log change in the services share additively into the components driven by aging, technology, real income growth, and a residual which can be interpreted as arising from age- and income-neutral changes in preferences over time. We find that population aging played a significant role in the increase in the expenditure share of services during this period, accounting for about 20 percent of the total. The increase in the relative price of services accounted for about 40% of the overall change, the rise in the real incomes another 20%, and residual taste changes the remaining 20%. Finally, we combine our estimates of age-specific taste shifters for services with population estimates to project that the US service expenditure share will increase by a further 10 log points between today and 2050. The impact of aging on structural transformation is set to become stronger in the future compared to its past role.

Our paper contributes to a large literature that attempts to rationalize the structural transformation process (see the recent survey by Herrendorf et al., 2014). Most theories focus on the non-homotheticity of the relative demand for services with respect to income (e.g. Kongsamut et al., 2001), or on changes in relative prices driven by differential long-growth rates of productivity (e.g. Ngai and Pissarides, 2007) or capital deepening and factor intensity differences across sectors (Acemoglu and Guerrieri, 2008). Alternative recent theories for the structural transformation process have also emphasized the roles of international trade (Matsuyama, 2009; Uy et al., 2013; Cravino and Sotelo, 2019), home production (Buera and Kaboski, 2012), and changes in the labor supply driven by changes in schooling (Porzio and Santangelo, 2019). We contribute to this literature by proposing a novel and complementary demand-side mechanism for the structural transformation process.

Our analysis is also related to the quantitative literature that combines the mechanisms listed above to evaluate their relative importance. Herrendorf et al. (2013) show that the relative strength of the income and substitution forces depend on whether expenditures and prices are measured using expenditure or value-added data. Boppart (2014) and Comin et al. (2015) introduce the PIGL and Generalized CES preferences, respectively, and re-evaluate these mechanisms allowing for non-vanishing long-run income effects. Swiecki (2017) uses a framework that allows for international trade across countries and shows that substitution effects are most important in developed countries, while income effects are more important in accounting for the shift out of agriculture during the early stages of the development process. We contribute to this body of work by showing that expenditure patterns differ across the age distribution, and thus an important portion of the structural change process may be driven by the population composition changes.

Finally, our paper builds on the literature documenting the differences in consumption patterns across the age distribution. Hobijn and Lagakos (2005) show that differences in spending patterns by age lead to differences in CPI inflation across age groups. Like us, they find that the largest disparities are in health care expenditures (disproportionally consumed by the elderly) and gasoline prices (disproportionally consumed by the young). Aguiar and Hurst (2013) analyze consumption expenditures on non-durable goods, and find large differences in consumption patterns of young vs. old households in food, nondurable transportation, and clothing and personal care. We contribute to this literature by showing how these differences in consumption patterns affect the structural transformation process.

The rest of the paper is organized as follows. Section 2 describes the relationship between population age and the share of services in the economy across countries, US households, and time. Section 3 quantifies the contribution of the observed population aging to structural change, and Section 4 concludes. The Appendix collects the robustness results.

2 Population aging and structural transformation: Facts

This section presents new empirical evidence documenting that population aging is systematically related to a shift in economic activity from Agriculture and Manufacturing sectors towards Service sectors. We organize our evidence in two sections, one showing how structural transformation relates to population aging across countries and time using aggregate data, and another showing how sectoral expenditure shares vary with household age using micro-data for the US.

2.1 Cross-country evidence

We start by describing how population aging is related to structural transformation across space and time. The empirical analysis follows the structure in the Handbook chapter by Herrendorf et al. (2014), who document how economic activity reallocates across Agriculture, Manufacturing, and Services as income per capita rises. We use the same data sources and empirical strategy to document how this reallocation is related to population aging. In particular, we start by studying changes in sectoral value-added and employment shares for a broad set of developed countries using data from EU KLEMS. We then study changes in sectoral consumption shares using data from the OECD. Appendix A.2 shows that our findings extend to a broader set of countries using data from the World Development Indicators (WDI) for employment or the United Nations (UN) for value added.

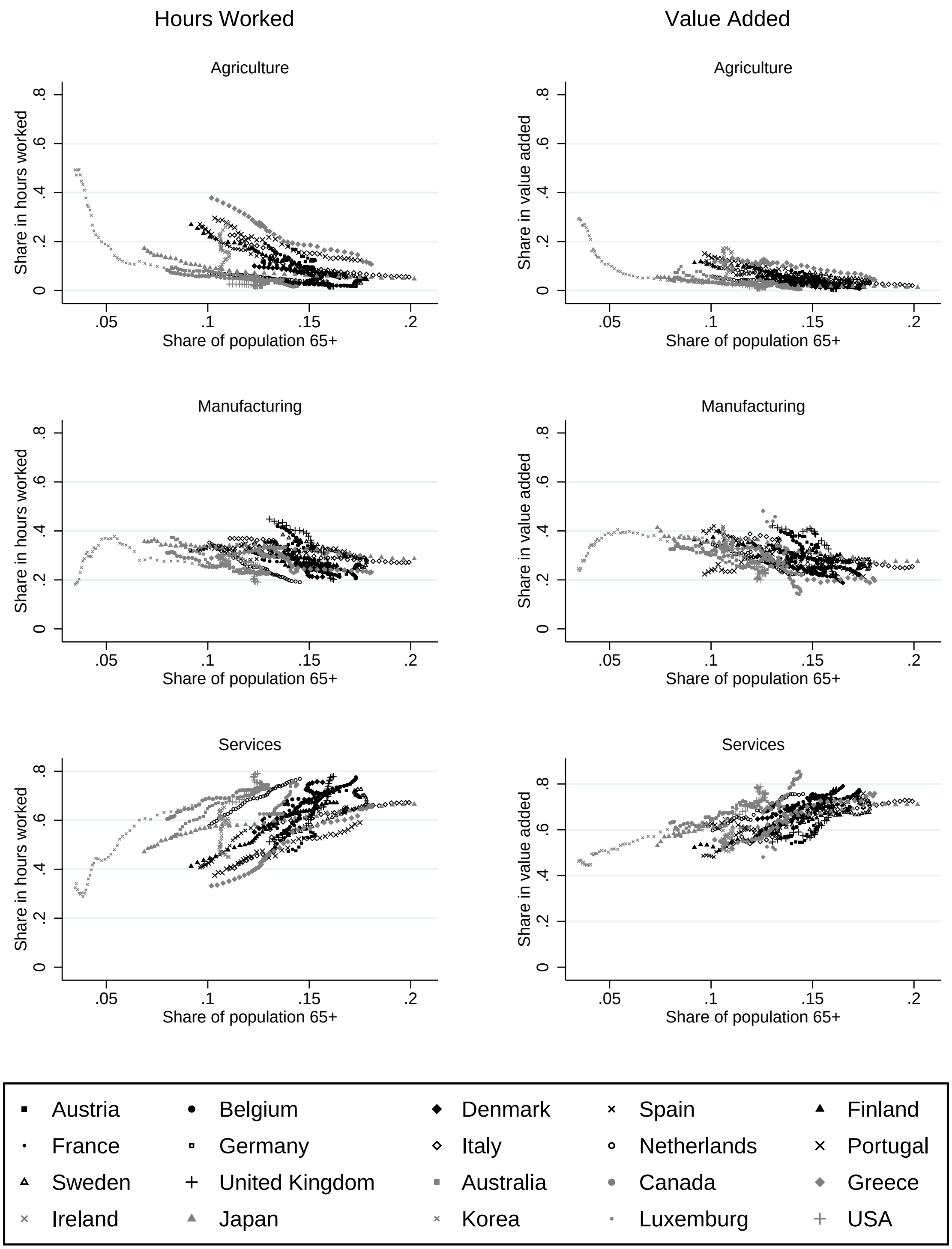
2.1.1 Changes in sectoral employment and value-added shares

Our main data source on sectoral employment and value-added shares is EU KLEMS, which is compiled by the Groningen Growth and Development Center. The database reports hours worked and value added by sector for a sample of 20 developed countries over the 1970-2007 period. The advantage of these data relative to the WDI and the UN data presented in Appendix A.2 is that employment is reported in terms of number of hours worked rather than in terms of the number of employed workers, and that the value-added data have been constructed from the national accounts of individual countries following a harmonized procedure that facilitates cross-country comparability. The disadvantage is that the data only cover 20 countries, which is why we repeat our analysis with a broader set of countries using the WDI and the UN data in the Appendix.

We conduct our analysis using two alternative measures of population age. First, we use the share of the population that is 65 or older, taken from the WDI. Alternatively, we use the average age in the country, computed from the World Bank's "Population estimates and projection" database. This database divides a country's population into 5-year age brackets. To compute the average age, we multiply the midpoint of each bracket (e.g. 2 in the 0-4 years old bracket) times its population, then add across age groups, and finally divide this by the total population.

The left panel of Figure 1 reports the sectoral shares of hours worked and the share of population over 65, for each country-year in EU KLEMS. The share of hours in Agriculture decreases as population ages, while the share of hours in Services increases. The employment share in Manufacturing is somewhat hump-shaped. The right panel in the figure shows that the same pattern emerges if we use sectoral value added instead of sectoral hours worked shares. These figures indicate that economic activity reallocates towards the service sector as the population ages. Appendix Figure A1 shows that these patterns persist if we use the average age in the population instead of the the share of population over 65 as our age measure.

Figure 1: Sectoral shares of employment and value added



Notes: Each dot represents a country-year. The x-axis reports the share of the population that is 65 and over (source: WDI). The y-axis reports the sectoral share in hours worked (left panel) and the sectoral shares in value added (right panel) using data from EU KLEMS.

Controlling for income: We now evaluate whether the correlation in Figure 1 is simply due to the fact that a country's population on average gets older as the country get richer. To do so, we establish whether the patterns in Figure 1 prevail after controlling for income per capita. With this in mind, we estimate the following regressions:

$$\omega^j_{i,t} \quad = \quad \alpha^j_i + \beta^j Age_{i,t} + \gamma^j gdp\_pc_{i,t} + \varepsilon^j_{i,t}. \tag{1}$$

Here, $\omega^j_{i,t}$ is the share of employment or value-added in sector j in country i in year t, α^j_i is a country fixed effect, $gdp\_pc_{i,t}$ is the log of GDP per capita in country i year t, and $Age_{i,t}$ is population age in country i in year t, measured either by the share of population that is over 65 or by the average age in the country. We cluster standard errors by country.

Table 1: Population aging and the sectoral shares of employment and value added

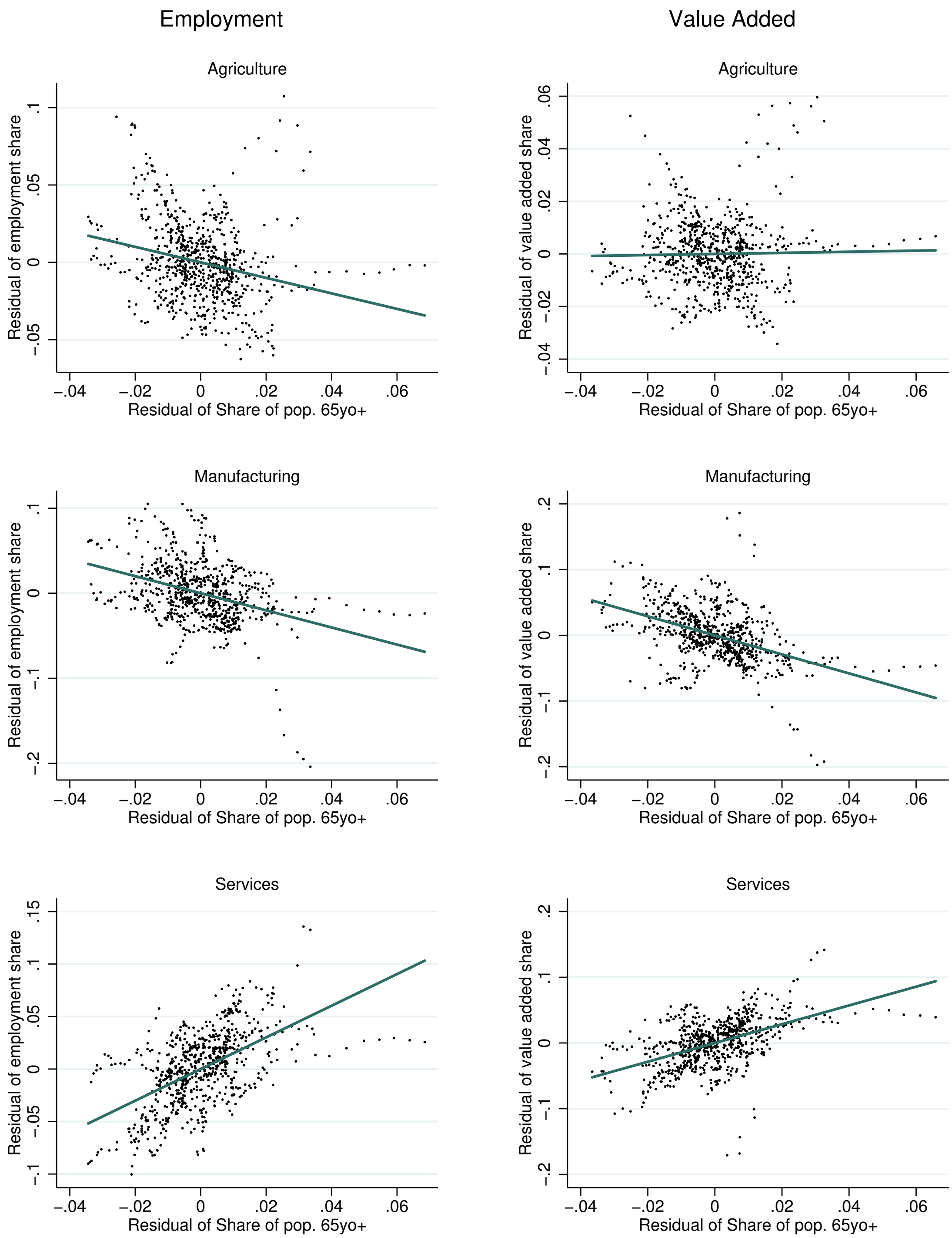
	Agriculture		Manufacturing		Services	
	(1)	(2)	(3)	(4)	(5)	(6)
Employment Share						
Share of pop 65+	-1.958***	-0.501	-1.321***	-1.006*	3.279***	1.507***
	(0.436)	(0.401)	(0.325)	(0.490)	(0.601)	(0.495)
Log GDP per capita		-0.133***		-0.0287		0.162***
		(0.0381)		(0.0482)		(0.0219)
R^2	0.802	0.908	0.487	0.503	0.824	0.923
Value Added Share						
Share of pop 65+	-1.012***	0.0207	-1.533***	-1.448**	2.545***	1.427***
	(0.261)	(0.184)	(0.297)	(0.511)	(0.353)	(0.398)
Log GDP per capita		-0.0935***		-0.00772		0.101**
		(0.0206)		(0.0574)		(0.0378)
R^2	0.700	0.902	0.579	0.580	0.772	0.841
Observations	707	707	707	707	707	707

Standard errors in parentheses clustered at the country level.
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table 1 reports the results of separately estimating equation (1) for each sector. Both the shares of hours worked and of value added are decreasing in income per capita in the Agriculture and Manufacturing sectors, but increasing in the Service sector, in line with the evidence surveyed by Herrendorf et al. (2014). The coefficient of interest β^j is negative for Agriculture and Manufacturing, and positive for Services, indicating that indeed aging is associated with a reallocation of economic activity towards services, even after controlling for changes in income. These findings are robust to measuring shares both in terms of value-added or employment, and to using either of our two measures of population age.

The patterns that underlie these results can be visualized in Figure 2. The y-axis plots the residuals of the regressions of the employment and value added shares on the log of GDP per capita and country fixed effects. The x-axis shows the residuals of the share of population that is over 65 on those same variables. The changes in sectoral shares that are orthogonal to the changes in income per capita are strongly correlated to the changes in population age that are orthogonal to income per capita. Appendix Figure A2 shows that these patterns are robust to using the average age in the population instead of the share of population over 65 as our age measure. In addition, Appendix Table A1 shows that we obtain very similar findings if we also control for potential non-linear effects of income per capita.

Figure 2: Residualized sectoral shares of employment and value added



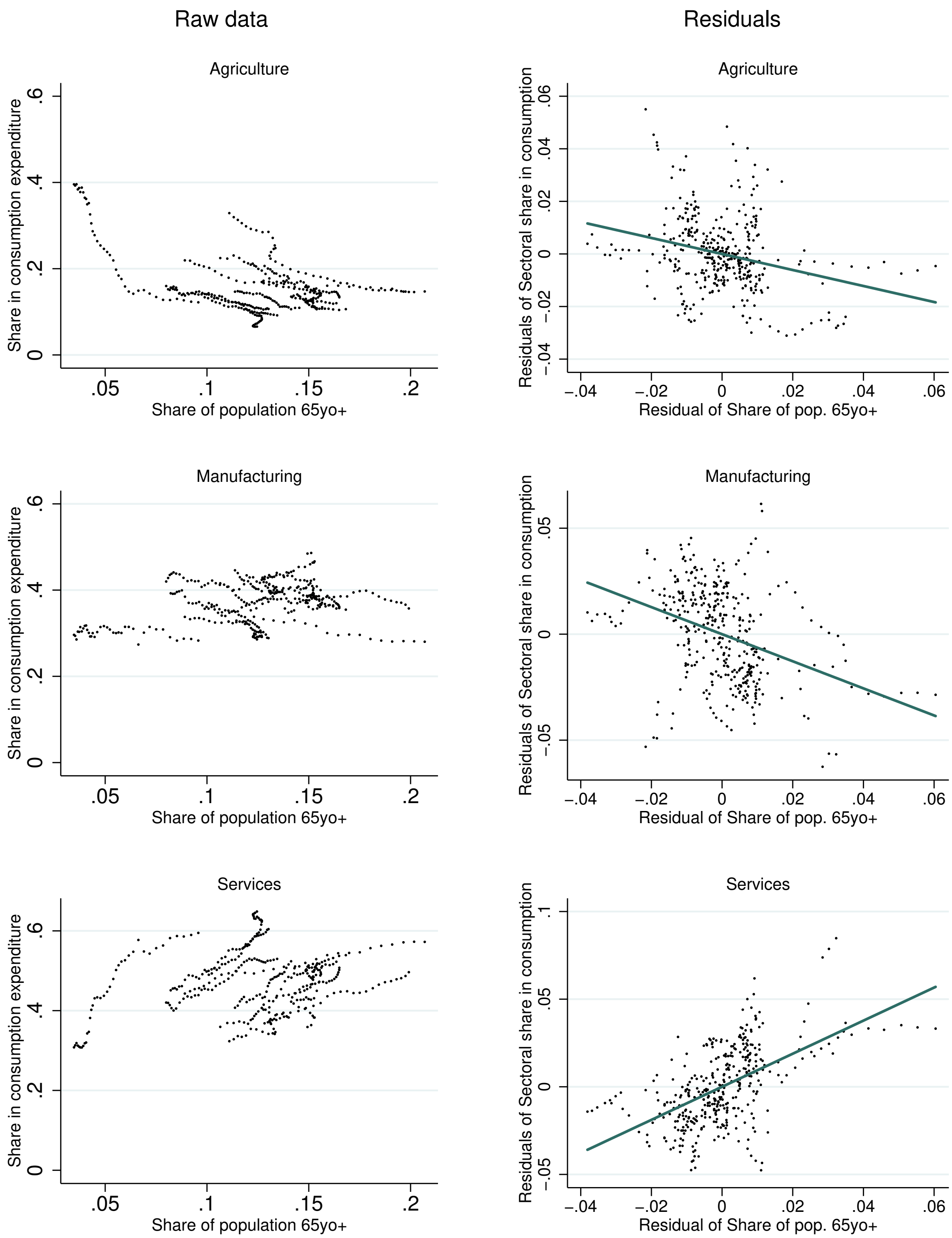
Notes: Each dot represents a country-year. The x-axis reports the residual of a regression of the share of the population that is 65 and over on GDP per capita and country fixed effects. The y-axis reports the residual of a regression of the sectoral share in hours worked (left panel) and the sectoral shares in value added (right panel) on GDP per capita and country fixed effects. Data sources are the same as in Figure 1.

2.1.2 Changes in consumption shares

This section documents how population aging relates to changes in sectoral consumption shares using data from the OECD Statistics. Consumption shares can differ from value added and employment shares since they do not include investment nor exports, and they do include imports. OECD statistics report consumption for 11 countries in 16 expenditure categories for the 1970-2007 period. We follow Herrendorf et al. (2014) and classify Food Consumption as Agriculture, Semi-, Durable-, and Non-Durable Goods minus Food Consumption as Manufacturing, and the remaining categories as Services.

The left panel in Figure 3 plots the sectoral consumption shares and share of population over 65 for each country-year pair in our sample. The right panel in the figure shows the residualized shares from a regression that controls for income per capita and country fixed effects, analogous to those in Figure 2. The figures show that consumption in Agriculture and Manufacturing products decline with population age, while the share of Service consumption increases with population age. This is true also after controlling for income (right panel). Appendix Table A2 reports the underlying regression coefficients. Appendix Figure A3 shows that the results are virtually unchanged if we use average age.

Figure 3: Sectoral consumption shares



Notes: Each dot represents a country-year. The x-axis reports the actual (left panel) and the residualized (right panel) share of the population that is 65 and over. The y-axis reports the sectoral share in actual (left panel) and the residualized (right panel) sectoral shares in consumption using data from OECD.

2.2 Household-level evidence

We now show how sectoral expenditure shares vary with household age using micro-data for the US. Our data come from the US Consumer Expenditure Survey (CES) and cover the 1982-2016 period. We use the Interview Module of the CES, which surveys about 12,000 households per year. The Interview Module collects households' responses about their purchases across 350 distinct expenditure categories, as well as other demographic information. Each household is interviewed for up to 4 consecutive quarters, and the expenditure data are collected at the household level. We use the average age of household members as the measure of age for our baseline analysis. Appendix B.1 shows that our results are robust to using the reference person's age, i.e. age of the household head.

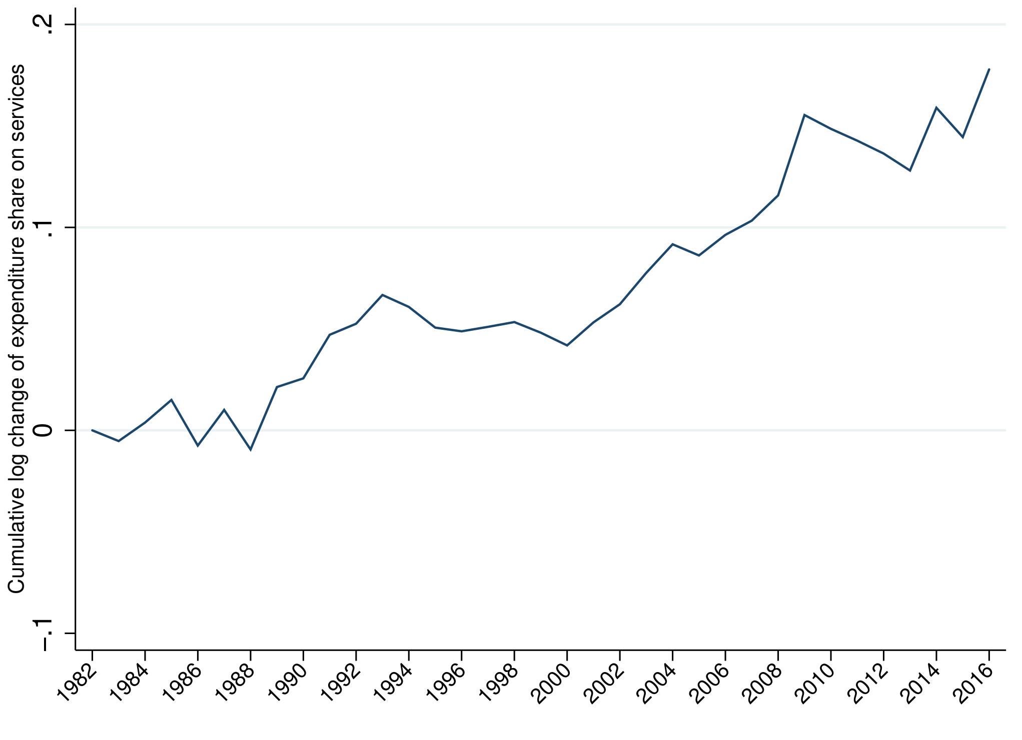
For the bulk of our analysis, we aggregate expenditures into goods and services following Aguiar and Bils (2015) and Comin et al. (2015).[2] We focus on how the share of non-housing service expenditures to the overall non-housing expenditures changes with household age. We do not include housing in expenditure because in the CES the rental value of owner-occupied housing is self-reported and thus may not be directly comparable to rent payments for renters. Since home ownership rates change substantially over the life cycle, the switches between owner-occupied implicit rent value and actual paid rent may complicate the comparison across age groups. Appendix B.1 reports results including housing in the analysis and shows that the treatment of housing does not alter the main conclusions.

Figure 4 plots the cumulative change in the aggregate expenditure share on services in the CES data. Consistent with the aggregate evidence on structural transformation, the service expenditure share rises in the CES, by about 18 log points over this period. Appendix Table A5 reports the trends in broad service expenditure categories. The rise in the healthcare is the main, but not the only, driver of the upward trend in the service expenditure. Other categories showing substantial proportional increases are Cash Contributions and Education. Food Away From Home, Utilities, and Domestic Services and Childcare also rise.

Figure 5 plots the expenditure share on services across households of different ages. Each line represents a different period for the data we work with. There is a clear positive monotonic relationship between the service expenditure share and the average age of the household members. The differences are large: service expenditure shares of households in their 60s are about 25 percent larger than for the households in their 30s (0.5 vs. 0.4).

[2] See Appendix Table A5 for the breakdown. We divide the sectors "Personal care" and "Other vehicle expenses" into their service and goods components. For instance, "Gasoline and motor oil" is considered a good, and "Public transport" and "Car maintenance, repairs and insurance" are considered services.

Figure 4: Service consumption in the CES



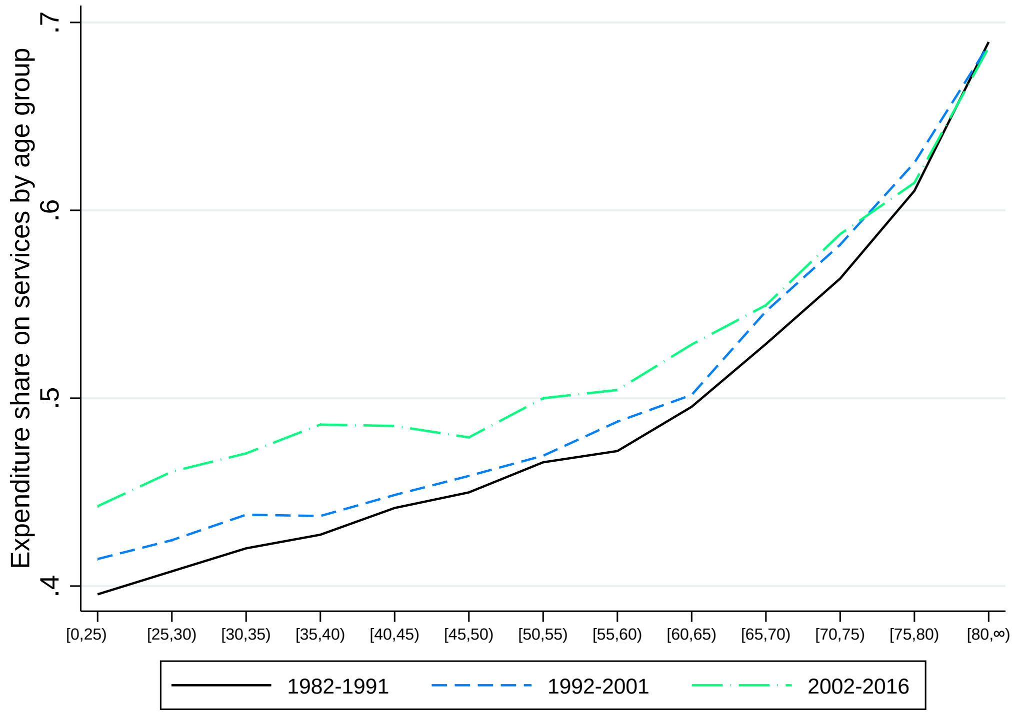
Notes: This figure displays the cumulative log change in the aggregate expenditure share on services in the CES.

Households in their 80s have expenditure shares in services that are almost 70% higher than those in their 30s (0.68 vs 0.40). These patterns are very stable over time. While later periods tend to feature higher service expenditure shares overall, the cross-age differences are pronounced in all time periods.

Controlling for income A potential caveat with the evidence in Figure 5 is that these patterns may arise from income differences across age groups. This section shows that this is not the case. Figure 6 plots the age-service expenditure share relationships separately for each quartile of the income distribution. It is clear that the relationship is about equally strong within broad income groups. Appendix Figure A6 shows a similar pattern if we group households by income deciles instead of quartiles.

To control for income more systematically, we estimate a regression that projects the service expenditure shares on age dummies, income decile dummies, and region-time fixed effects:

Figure 5: Service consumption by average age of household members



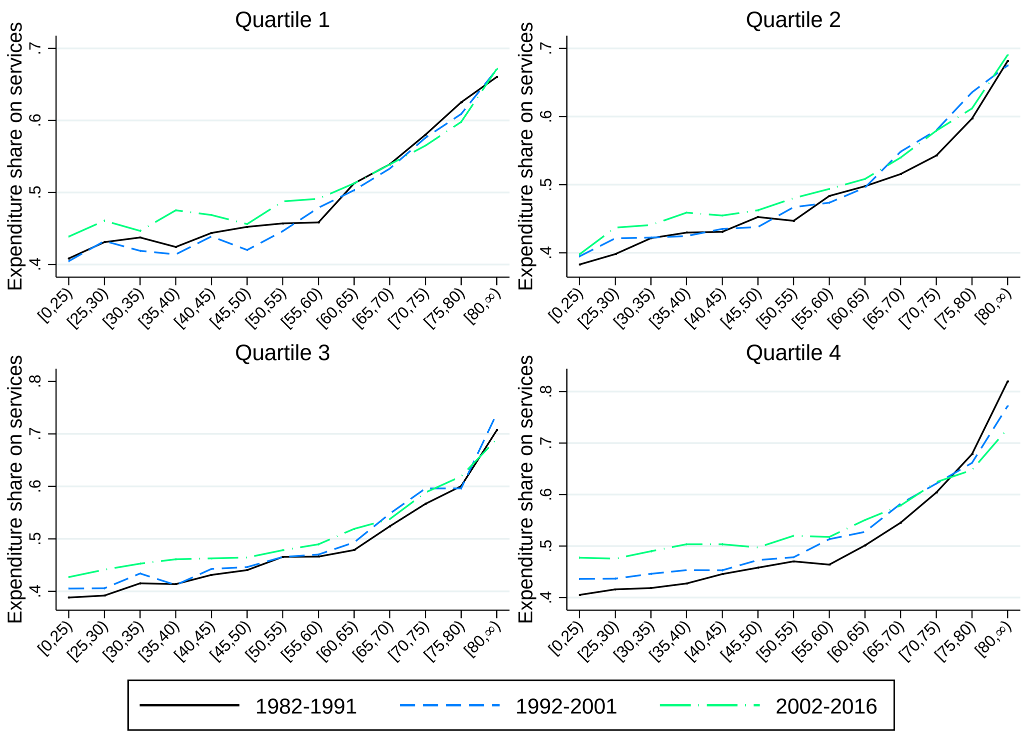
Notes: This figure displays the average household-level expenditure shares on services in the CES by age group (x-axis), for 3 time periods.

$$\omega_t^{s,h} \quad = \quad \delta^a + \delta^{inc} + \gamma X_{r,t}^h + \delta_{r,t} + \varepsilon_t^{s,h}. \tag{2}$$

Here $\omega_t^{s,h}$ is the service expenditure share of household h at time t, δ^a are household age group dummies and δ^{inc} are income decile dummies. X_{rt}^h are demographics dummies for the number of household members (2, 3-4, 5+) and dummies for the number of household earners (1, 2+). These are typically used in the literature (e.g. Aguiar and Bils, 2015). Following Comin et al. (2015) we also control for differences in household-specific prices by including region-time dummies, $\delta_{r,t}$. The implicit assumption behind this control is that households within a region face the same prices.

We estimate equation (2) separately for each decade for which the CES data are available. Figure 7 plots the age group dummies, which measure differences in service expenditure shares of the age group relative to age group 25-30. The 95% confidence bands based on standard errors clustered by household are depicted around the point estimates.

Figure 6: Service consumption by average age of household members and income

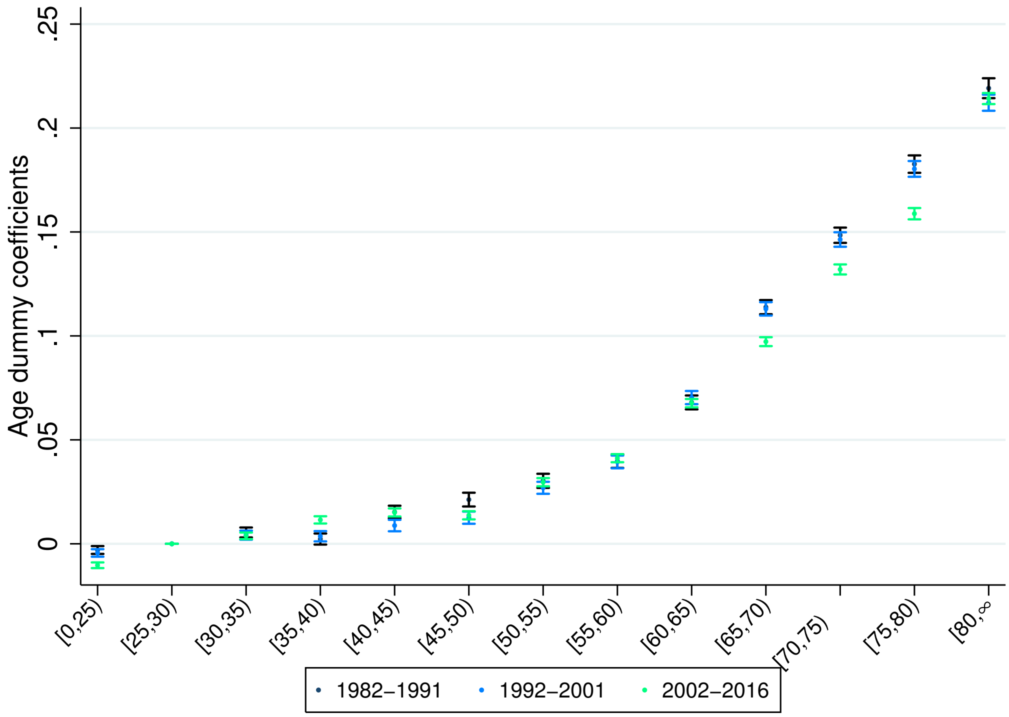


Notes: This figure displays the average household-level expenditure shares on services in the CES by age group (x-axis), for 3 time periods, and each income quartile.

The figure shows large differences in service expenditures across households of different ages, even conditioning on income and prices. These conditional differences are nearly as large as the unconditional ones reported in Figure 5. As in the raw data, households in their 60s have service expenditure shares 10-12 percentage points higher than households in their 30s, and households in their 80s' service expenditure shares are more than 20 points higher. The age dummies are precisely estimated, and quite stable over time. Appendix Figures A7 and A9 reproduce Figures 5 and 7 using the age of the reference person (i.e. household head) instead of average age in the household, and shows that the results are virtually unchanged. Additionally, Appendix Figures A8 and A10 replicate Figures 5 and 7 adding housing as part of the overall consumption and services.

Decomposing consumption differences Table 2 shows the differences in expenditure shares across young and old households for the main consumption categories. The table reports the difference in expenditure shares for each category for the 25-30 vs. the age

Figure 7: Age dummies (controlling for income decile)



Notes: Each dot represents the point estimate of the age dummies in Equation (2) for a particular decade in the CES data. The omitted dummy is that of age group 25-30. The bands report the 95% confidence intervals based on standard errors clustered at the household level.

groups starting at 60-65. Unsurprisingly, the largest disparity arises in health expenditures, where the consumption expenditure share of the 60-65 (80+) age group is 5.6 (15.3) percentage points larger than that of the 25-30 age group. The table shows that the elderly also spend relatively more on Cash Contributions, Domestic Services and Childcare, and Utilities. In contrast, for Vehicle Purchasing and Leasing, the expenditure share of the 60-65 (80+) age group is 3.8 (11.24) percentage points smaller than that of the 25-30 age group.

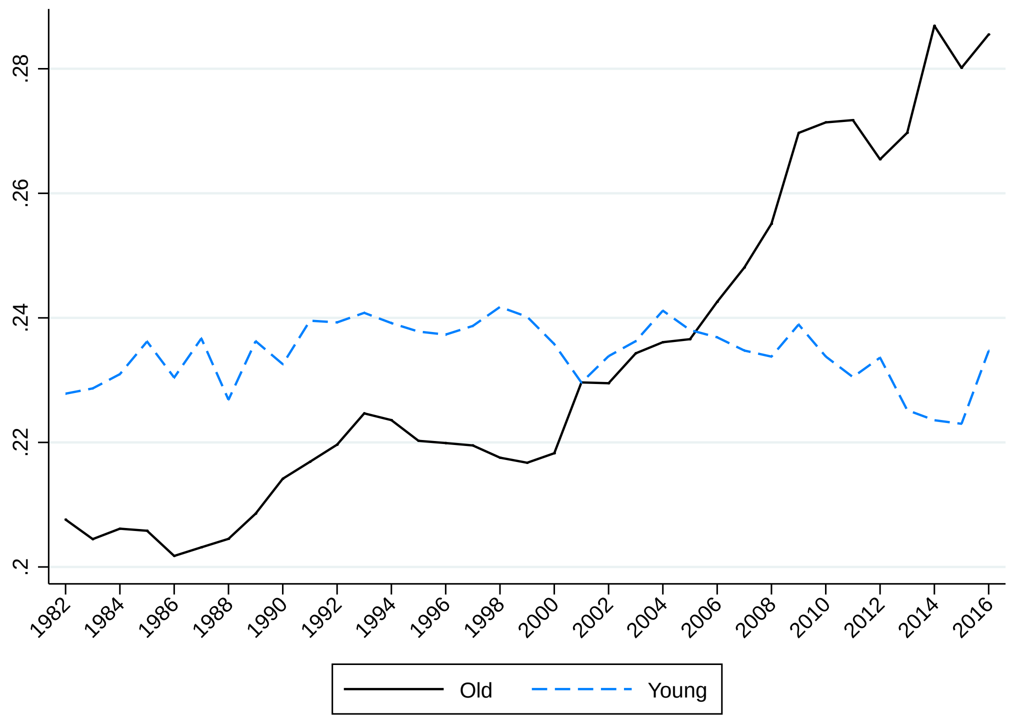
Table 2: Differences in expenditures by consumption category: 25-30 vs 60-65, 65-70, 70-75, 75-80 and 80+

	Age groups				
	60-65	65-70	70-75	75-80	80+
Health	5.62	7.90	10.17	12.42	15.25
Cash contributions	3.41	4.44	5.59	6.45	9.48
Domestic services and childcare	0.59	0.91	1.28	1.98	5.22
Utilities	1.06	1.23	1.88	2.57	3.41
Personal care services	0.13	0.20	0.30	0.36	0.44
Food at home	-0.89	-0.57	0.03	0.51	0.45
Personal care goods	-0.01	-0.01	-0.01	-0.02	-0.01
Public transport	0.37	0.36	0.25	0.18	-0.41
Tobacco	0.03	-0.17	-0.38	-0.58	-0.77
Shoes and other apparel	-0.37	-0.47	-0.58	-0.79	-0.85
Children's clothing	-0.76	-0.77	-0.88	-0.94	-1.03
Entertainment fees, adm., reading	-0.08	-0.14	-0.32	-0.61	-1.04
Alcoholic beverages	-0.33	-0.46	-0.64	-0.84	-1.04
Furnitures and Fixtures	-0.17	-0.30	-0.62	-0.83	-1.21
Appliances	0.14	-0.20	-0.49	-0.74	-1.36
Men's and women's clothing	-0.32	-0.57	-0.73	-1.13	-1.69
Car maintenance, repairs, insurance	-0.31	-0.55	-0.71	-0.78	-1.84
Food away from home	-0.55	-0.77	-1.17	-1.64	-2.26
Entertainment equipment	-0.20	-0.83	-1.78	-2.23	-2.80
Education	-2.63	-2.86	-2.90	-2.80	-2.99
Gas	-0.98	-1.41	-1.89	-2.48	-3.70
Vehicle purchasing, leasing	-3.75	-4.98	-6.41	-8.04	-11.24
Services	7.61	10.73	14.37	18.12	25.26

Notes: This table reports the differences in expenditure shares across the major consumption categories between age groups starting at 60-65 and households aged 25-30 in the CES.

Structural change within the service sector The rise in service expenditures has been concentrated in categories that are disproportionally consumed by older households. Figure 8 divides service categories into two groups: one for the categories that are disproportionally consumed by the old (Health, Utilities and Domestic Services and Childcare), and one for the remaining categories. The figure shows a dramatic increase in the aggregate expenditure share for Health, Utilities and Domestic Services and Childcare, the combined expenditure share in these categories goes from 21 to over 28 percent over our period. In contrast, there is no change in the expenditure share in the remaining service categories. Figure A17 shows that a similar pattern emerges in the Personal Consumption Expenditure data from the BEA: the increase in service consumption is concentrated among those categories that are disproportionally consumed by the old.

Figure 8: Evolution of expenditure shares on service categories in the CES



Notes: 'Old' displays the aggregate expenditure share in the CES on categories that are disproportionally consumed by the old: Health, Utilities, and Personal Services. 'Young' displays the expenditure share on the remaining service categories.

Accounting for differences between CES and National Accounts data It is well known that the aggregated expenditure shares in the CES do not match those in the Personal Consumption Expenditure module of the National Income and Product Accounts compiled by the BEA. One reason for this discrepancy is that the CES only reports out-of-pocket expenses by private households, which may differ from economy-wide aggregate consumption and misrepresent expenditure differences across households. This may be especially salient in healthcare, since the CES data do not include spending by Medicaid, Medicare, and private insurance for services rendered to the household. Appendix Table A9 reports the shares of out-of-pocket expenditures in total health expenditures in National Health Expenditure Survey (NHES) in the first and last year available in that survey, by broad age groups. Out-of-pocket expenditures represent a similar fraction of the total health expenditures across the age distribution. Thus, the relative health expenditure differences across the age distribution would persist after adding the non-out-of-pocket expenses.

To map our analysis to the National Accounts data, we augment the CES data with data from the Personal Consumption Expenditures (PCE) from the BEA. In particular, we rescale the expenditures in each consumption category to match aggregate consumption expenditures by category in the National Accounts (PCE BEA) data. These rescaled data reproduce the aggregate sectoral expenditure shares in the BEA, while preserving the heterogeneity across households present in the CES. Appendix B.2 details this procedure and replicates the results in this section and Section 3 using the rescaled dataset.[3]

3 Accounting for structural change in the US

This section quantifies the contribution of observed changes in the age distribution to the observed changes in sectoral consumption shares in the US between 1982 and 2016. We conduct this exercise using two alternative methodologies. The first is a shift-share decomposition of the increase in the share of services in total consumption into the part that arises from reallocation of expenditures between age groups vs. changes in expenditures within age groups. The second is a quantitative model of structural transformation that allows us to compare the contribution of population aging to the contributions of the income and price effects that have been the focus of most of the structural transformation literature.

3.1 Within-between decomposition

We start with a decomposition of the observed rise in the share of services in total consumption in the CES between 1982 and 2016. We can write the share of services in aggregate consumption as:

$$\Omega_t^s = \frac{\sum_a e_t^{s,a}}{\sum_a \sum_j e_t^{j,a}} = \sum_a \omega_t^{s,a} \times s_t^a, \tag{3}$$

[3]Rescaling the CES data using NHES is challenging because the expenditure categories in the CES do not map readily into those in NHES, as the former presents the expenses from the perspective of the household, whereas the latter records the sources of revenue of the healthcare provider. In addition, NHES by age group only goes back to 2002.

where $e_t^{j,a}$ are total consumption expenditures by age group a in consumption sector j, $\omega_t^{s,a} \equiv \frac{e_t^{s,a}}{\sum_j e_t^{j,a}}$ is the share of services in total expenditures by age group a, and $s_t^a \equiv \frac{\sum_j e_t^{j,a}}{\sum_a \sum_j e_t^{j,a}}$ is the share of age group a in aggregate expenditures. Letting $\Delta x \equiv x_1 - x_0$ and $\overline{x} \equiv [x_1 + x_0]/2$ denote the change and the average of a variable across periods $t = 1$ and $t = 0$ we can write:

$$\Delta\Omega^s = \underbrace{\sum_a \Delta\omega^{s,a} \cdot \overline{s}^a}_{\text{Within}} + \underbrace{\sum_a \overline{\omega}^{s,a} \cdot \Delta s^a}_{\text{Between}}. \tag{4}$$

Equation (4) expresses the change in the service share of expenditures as the sum of two terms. The term labeled 'Within' captures changes in the age-specific expenditure shares, $\Delta\omega^{s,a}$, while the term labeled 'Between' captures changes in the share of age group a in aggregate expenditures, Δs^a.

We take equation (4) to the data by breaking the US population into the 13 age groups as in Section 2.2, measuring age both by the average age of all household members and by the age of the household head. Table 3 reports the terms $\omega_t^{s,a}$ and s_t^a in equation (3) for each age group in 1982 vs. 2016. As already documented in Figure 5, older households allocate a significantly larger fraction of their expenditures towards services than younger ones: both in 1982 and 2016, the share of expenditure in services is more than 50% higher for households over 80 than for those aged 25-30. In addition, the table shows a large increase in the share of expenditures that is accounted for by older households: households 65 and older accounted for 10.4 percent of total expenditures in 1982, and 17.1 percent in 2016, a 64% increase. The share of expenditures that goes to households 80 and older nearly tripled, going from 1.2 to 3.4 percent. The counterpart of this increase is the decline in the share of expenditures that goes to households 30 and younger, from 47.3 to 31.6 percent.

Table 3: Population aging and the services share

	Pop $_{1982}$	s^{a}_{1982}	$\omega^{s,a}_{1982}$	Pop $_{2016}$	s^{a}_{2016}	$\omega^{s,a}_{2016}$
0-25	31.8	31.2	38.8	20.4	19.8	47.2
25-30	13.5	16.1	39.9	11.4	11.8	47.6
30-35	9.4	11.2	42.1	9.4	10.8	50.3
35-40	6.2	7.6	43.0	7.1	7.9	49.5
40-45	4.6	5.4	45.4	5.9	6.5	53.4
45-50	3.6	4.0	45.6	5.2	5.5	51.4
50-55	3.8	4.0	45.7	6.1	6.1	51.4
55-60	5.1	4.9	47.4	6.7	6.9	51.9
60-65	5.7	5.2	50.6	7.5	7.8	58.1
65-70	5.9	4.5	53.0	6.8	6.3	56.7
70-75	4.3	2.9	58.7	5.1	4.6	57.4
75-80	3.3	1.8	59.5	3.4	2.8	60.8
80+	2.9	1.2	67.5	5.0	3.4	69.6

Notes: 'Pop' reports the share of the population in each age group. s^a_t and ω^a_t are defined as in Equation (4).

Table 4 reports the results of the decomposition in equation (4). The share of services in total expenditures increased by 8.5 percentage points during the 1982-2016 period. The table shows that 1.85 percentage points, about a fifth of the increase, are attributed to between age group changes in expenditures. The remainder is attributed to changes in expenditure shares within groups. The table shows that the numbers are similar if we instead measure household age by the age of the household head. Appendix Table A6 shows that the results are somewhat smaller though still economically significant if we count housing as part of service expenditures.

Table 4: Within-between decomposition

	Average		Reference	
	Value	%	Value	%
Within	0.0663	78.2	0.0675	79.7
Between	0.0185	21.8	0.0172	20.3
Total	0.0848	100	0.0848	100

Notes: The table reports the results of the decomposition in equation (4). 'Average' uses the average age across all household member as the age of the household. 'Reference' uses the age of the head in the household.

3.2 Structural model

This section sets up a model to quantify the contribution of changes in population age, income, and relative prices to the structural transformation process in the US. We study an economy populated by N_t households indexed by h that are heterogeneous in their preferences and their expenditure levels e_t^h. Households consume goods (g) and services (s). The indirect utility of household h takes the form:

$$\mathcal{V}^h\left(P_t^s, P_t^g, e_t^h\right) = \frac{1}{\epsilon}\left[\frac{e_t^h}{P_t^s}\right]^{\epsilon} - \frac{\nu_t^h}{\gamma}\left[\frac{P_t^g}{P_t^s}\right]^{\gamma} - \frac{1}{\epsilon} + \frac{\nu_t^h}{\gamma}, \tag{5}$$

where P_t^s and P_t^g are the prices of goods and services, and the parameters satisfy $0 \leq \epsilon \leq \gamma \leq 1$ and $\nu_t^h \geq 0$. This utility function belongs to a subclass of Price Independent Generalized Linearity (PIGL) preferences (Muellbauer, 1975, 1976; Boppart, 2014), with household-specific taste shifters ν_t^h. Using Roy's identity, we can show that expenditure shares are given by:

$$\omega_t^{g,h} \equiv \frac{e_t^{g,h}}{e_t^h} = \nu_t^h \left[\frac{P_t^s}{e_t^h}\right]^{\epsilon}\left[\frac{P_t^g}{P_t^s}\right]^{\gamma}, \tag{6}$$

where $e_t^{j,h}$ is the expenditure by h on sector j, and $\omega_t^{s,h} \equiv \frac{e_t^{s,h}}{e_t^h} = 1 - \omega_t^{g,h}$. The aggregate expenditure shares on goods is:

$$\Omega_t^g \equiv \frac{\sum_h e_t^{g,h}}{\sum_h e_t^h} = \left[\frac{P_t^s}{e_t}\right]^{\epsilon}\left[\frac{P_t^g}{P_t^s}\right]^{\gamma}\frac{1}{N_t}\sum_h \nu_t^h\left[\frac{e_t^h}{e_t}\right]^{1-\epsilon},$$

where $e_t \equiv \frac{1}{N_t}\sum_h e_t^h$ denotes average expenditures per household. Aggregate shares depend on real per capita expenditures in units of services, $\frac{e_t}{P_t^s}$, the relative price of goods vs. services, $\frac{P_t^g}{P_t^s}$, the extent of income inequality, $\frac{e_t^h}{e_t}$, and the taste shifters, ν_t^h.

In what follows we assume that households can be grouped according to their age, and denote the number of households of age a by N_t^a, with $\sum_a N_t^a = N_t$. We further assume that the taste shifters take the form $\nu_t^h = \nu_t \mu^a \mu_t^h$, with $\frac{1}{N_t}\sum_h \mu_t^h = 1$. This implies that the household-specific taste shifter has an aggregate component ν_t, an age-specific component μ^a, and an idiosyncratic component μ_t^h. The aggregate expenditure share can then be written as:

$$\Omega_t^g = \left[\frac{P_t^s}{e_t}\right]^{\epsilon}\left[\frac{P_t^g}{P_t^s}\right]^{\gamma}\bar{\mu}_t\phi_t\nu_t. \tag{7}$$

Here, $\bar{\mu}_t \equiv \sum_a s_t^a \mu^a$ is the weighted average of the age-specific taste shifters, with weights given by expenditure shares $s_t^a = \frac{e_t^a N_t^a}{e_t N_t}$. The composite $\phi_t \equiv \frac{1}{N_t}\sum_h^{N_t} \frac{\mu^a}{\bar{\mu}_t}\left[\frac{e_t^h}{e_t}\right]^{1-\epsilon}$ is a measure of the inequality in the economy, weighted by household preferences.[4]

Parameterization We are interested in decomposing changes in expenditure shares into the components due to changes in real income per capita $\frac{e_t}{P_t}$, relative prices $\frac{P_t^g}{P_t^s}$, and changes in the share of expenditures that correspond to the different age groups in the population, $s_t^a \equiv \frac{e_t^a N_t^a}{e_t N_t}$. To conduct this exercise we need to parameterize the income and substitution effects governed by ϵ and γ, as well as the age effects captured by $\bar{\mu}_t$.

We follow Boppart (2014) and proceed in two steps. First we use the cross-section of households from the CES and estimate equation (6) in logs. The estimating equation is:

$$\ln \omega_t^{g,h} = \beta_0 + \beta_1 \ln e_t^h + D^a + \delta_{r,t} + \varepsilon_t^h, \tag{8}$$

where $\beta_0 + \delta_{r,t} = \ln\left(P_t^s\right)^{\epsilon-\gamma}\left(P_t^g\right)^{\gamma}$, $\beta_1 = -\epsilon$, and $\varepsilon_t^h = \ln \mu_t^h$.[5] $D_a = \ln \mu^a$ is an age dummy that captures the taste shifter of the age group relative to an omitted age group. Without loss of generality we normalize $\mu^a = 1$ for age group [25,30). Using these estimates for ϵ and μ^a, we can construct the time series of $\bar{\mu}_t$ and ϕ_t. We can then obtain the price elasticity γ from a regression of equation (7) in logs:

$$\ln \Omega_t^g = b_1 \ln P_t^g + b_2 \ln P_t^s + b_3 X_t + \ln \nu_t, \tag{9}$$

where $X_t \equiv \ln\left(e_t^{-\epsilon}\bar{\mu}_t\phi_t\right)$, $b_1 = \gamma$, and the other coefficients satisfy the restrictions $b_3 = 1$, and $b_2 = \epsilon - b_1$.

Columns 1 and 2 in Table 5 report the results of estimating (8) with OLS. To address measurement error in CES expenditure data, Columns 3 and 4 report the results of IV estimation with expenditure instrumented by income, as is customary in the literature (see, e.g. Boppart, 2014; Aguiar and Bils, 2015). Table 5 shows an income elasticity of $\epsilon = 0.12$,

[4]This assumes that within age groups income and idiosyncratic preferences are uncorrelated, $cov\left[\mu_t^h, e_t^h \mid a\right] = 0$.

[5]In practice our estimation controls for price effects with region-time dummies $\delta_{r,t}$ rather than time dummies, to absorb regional variation in relative prices of services. Allowing for region-specific price changes has almost no effect on the estimates of μ^a or ϵ.

which is somewhat smaller than the $\epsilon = 0.2$ found by Boppart (2014). Appendix Table A7 displays the estimates for the age dummies, and shows that our results are robust to using the age of the reference person. Appendix Table A8 shows that the results for ϵ are only slightly different even when considering housing as part of service consumption. The age dummies are relatively large and statistically different from zero, and decrease monotonically with age, indicating that older households spend relatively less on goods after controlling for real income.

Table 6 reports the estimation results for (9). To estimate it, we construct P_t^g and P_t^s by aggregating category-specific price series from NIPA Table 2.4.4, using the expenditure shares for each category within either goods or services. Our estimate for the γ is 0.15. Both γ and ϵ are precisely estimated and significantly different from zero, and satisfy the restriction $\gamma > \epsilon > 0$.

Table 5: Estimates of equation (8)

	(1) $\log \omega_t^{g,n}$	(2) $\log \omega_t^{g,n}$	(3) $\log \omega_t^{g,n}$	(4) $\log \omega_t^{g,n}$
$\log e_t^n$	-0.0476***	-0.0478***	-0.116***	-0.117***
	(0.000642)	(0.000643)	(0.00178)	(0.00179)
Type	OLS	OLS	IV	IV
Time FE	Yes	No	Yes	No
Region-Time FE	No	Yes	No	Yes
Observations	1,324,874	1,319,092	1,226,096	1,220,472
R^2	0.122	0.125	0.099	0.100

Standard errors in parentheses clustered at the household level.
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table 6: Estimates of equation (9)

	(1) Ω_t^g	(2) Ω_t^g
$b_1 = \gamma$	0.145***	0.154***
	(0.00999)	(0.0100)
Age variable	Average	Reference
Observations	35	35
R^2	0.860	0.874

Standard errors in parentheses.
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Quantitative results Taking logs in equation (7) and rewriting everything in terms of share of consumption on services, we obtain:[6]

$$\hat{\Omega}_t^s \approx -\frac{\Omega_{82}^g}{\Omega_{82}^s}\left\{\underbrace{\epsilon\left[\hat{P}_t-\hat{e}_t\right]}_{\text{Income}}+\underbrace{\left[\gamma-\epsilon\Omega_t^g\right]\left[\hat{P}_t^g-\hat{P}_t^s\right]}_{\text{Substitution}}+\underbrace{\hat{\mu}_t}_{\text{Aging}}+\underbrace{\hat{\phi}_t+\hat{v}_t}_{\text{Residual}}\right\}, \tag{10}$$

where we used the notation $\hat{x}_t \equiv \ln x_t - \ln x_{82}$ to denote the cumulative log change of a variable between the first year in our sample and time t, and $\hat{P}_t \equiv \left[1-\Omega_t^g\right]\hat{P}_t^s + \Omega_t^g \hat{P}_t^g$ to denote the log change in the aggregate price index. Equation (10) shows that log-changes in the aggregate expenditure share of goods are additively separable into the effects of changes in 'Income', 'Substitution', 'Aging', and a residual.[7] This decomposition is plotted in Figure 9. The expenditure share in services grew by about 20 log points between 1982 and 2016 in the CES data. The contribution of population aging $\hat{\mu}_t$ was nearly 5 log points, about a fifth of the total change. About 40% of the total was due to the rise in the relative price of services (labeled 'Substitution'), and another 20% due to the income effect. The residual accounted for remaining roughly 5 log points. Appendix Figure A11 shows that the results are unchanged when using the age of the reference person as the household age variable. Appendix Figure A12 shows that the absolute contribution of aging stays unchanged when considering housing as part of service consumption.

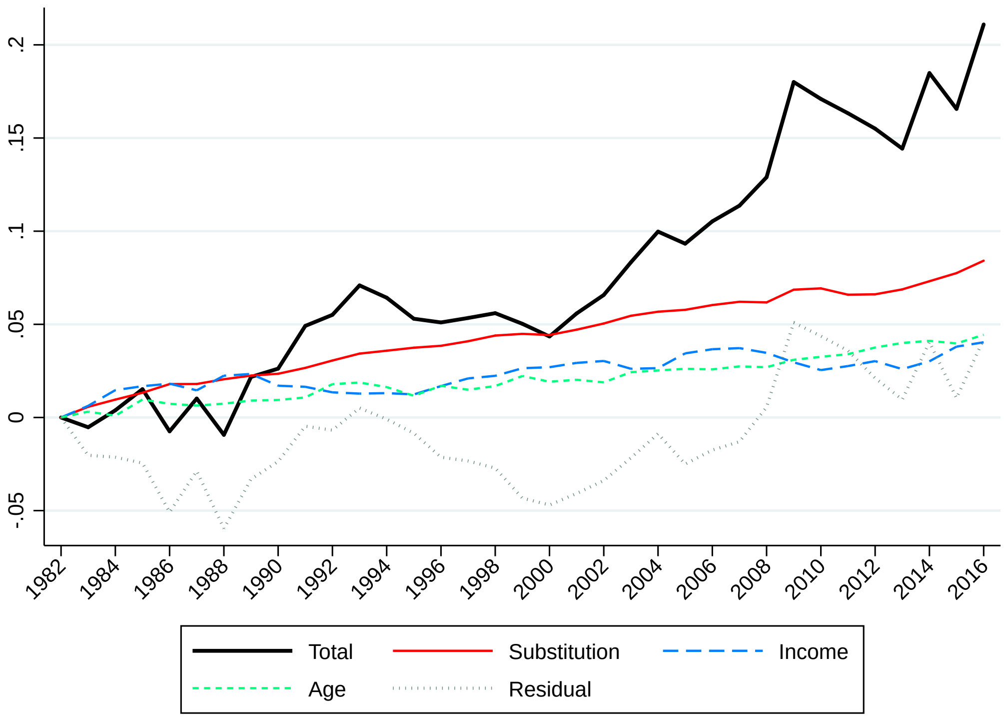
Projected changes in expenditure shares: To further illustrate the potential strength of aging as a driver of structural transformation, we compute the contribution of the projected changes in population structure to structural transformation in the future. To do this, we use the US population projections to the year 2050 from the World Bank's "Population estimates and projection" database. Because our estimates of the age taste shifters μ^a are at the household level, while the population projections are for population shares by age group, we fit the following regression to map population shares ($PopSh_t^a$) into household age shares:

$$\frac{N_t^a}{N_t} = \beta_1 PopSh_t^a + \beta_2 (PopSh_t^a)^2 + \varepsilon_t \qquad \text{for } t = 1982, ..., 2016.$$

[6]We use the approximation $\hat{\Omega}_t^s \approx -\frac{\Omega_{82}^g}{\Omega_{82}^s}\hat{\Omega}_t^g$. See the Appendix B.3 for the derivation.

[7]The residual includes both the change in the inequality measure $\hat{\phi}_t$ and the unexplained shifts in taste $\hat{v}_t$. In the data, the changes in the inequality term have a negligible effect on the aggregate service share the throughout the period.

Figure 9: Accounting for structural change in the US



Notes: This figure displays the decomposition (10) for the US from 1982 to 2016.

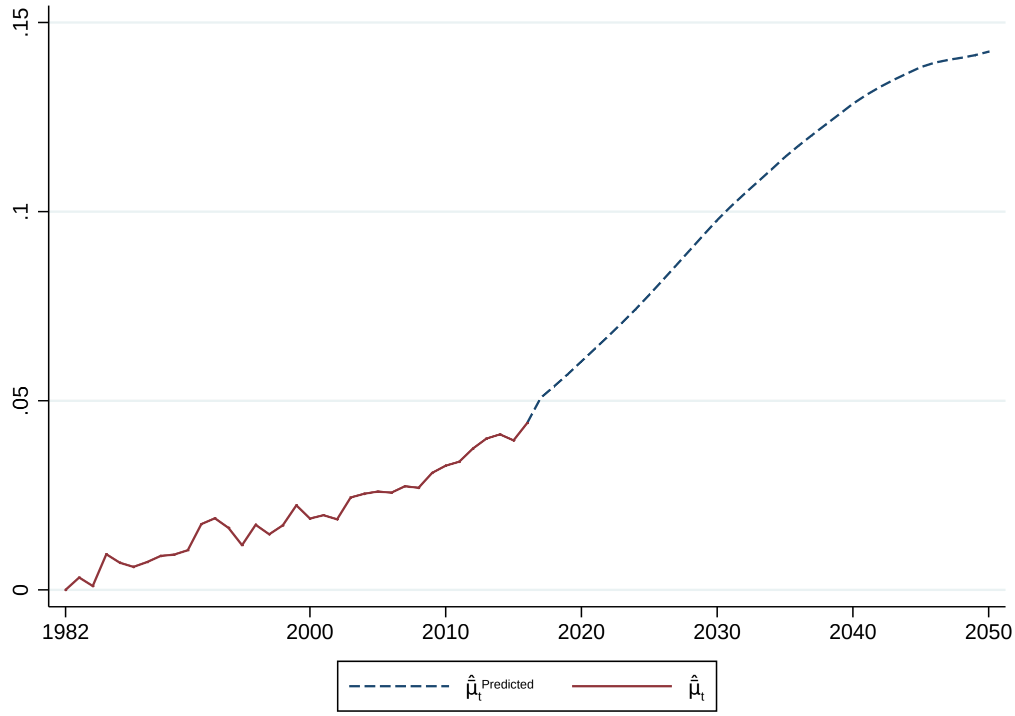
Then, for future years we construct $\widehat{s}_t^a$ putting together: $\frac{\widehat{N_t^a}}{N_t} = \widehat{\beta}_1 PopSh_t^a + \widehat{\beta}_2 (PopSh_t^a)^2$ for $t = 2017, ..., 2050$ and $\frac{\bar{e}^a_{2016}}{\bar{e}_{2016}}$ computed using data in 2016. Thus, $\hat{\mu}_t^{Predicted} = \sum_a \widehat{s}_t^a \mu^a$ for t =1982,...,2016.

Figure 10 reports the results. It turns out that the contribution of aging to structural change over the past 35 years is relatively modest compared to its projected future contribution. The service expenditure share will increase by a further 10 log points under the current population aging projections to 2050, even with price of services and real income held constant at today's values.

4 Conclusion

This paper proposed and quantified a novel mechanism behind the structural transformation process: older individuals devote a larger share of their expenditures to services, so the relative size of the service sector grows as the population ages. We show that, across a large sample of countries, the rise in the relative size of the service sector has coincided

Figure 10: Projected change in the service share due to aging in the US



Notes: This figure displays the estimated $\hat{\mu}_t$ from 1982 to 2016, and the projected $\hat{\mu}_t$ for 2017-2050 for the US.

with an increase in population age. We document large differences in sectoral expenditure shares across households of different ages in the US CES data, with older households spending relatively more on services. We then use a shift-share decomposition and a quantitative model to show that changes in the US population age accounted for about a fifth of the increase in the consumption share of service expenditures observed between 1982 and 2016. In our quantitative model, the contribution of population aging to the observed structural change in the US during this period is similar to the contribution of real income growth. Projections for the changes in the service expenditure share due to aging in the US suggest that the future impact of aging on structural transformation is, if anything, larger than its role to date.

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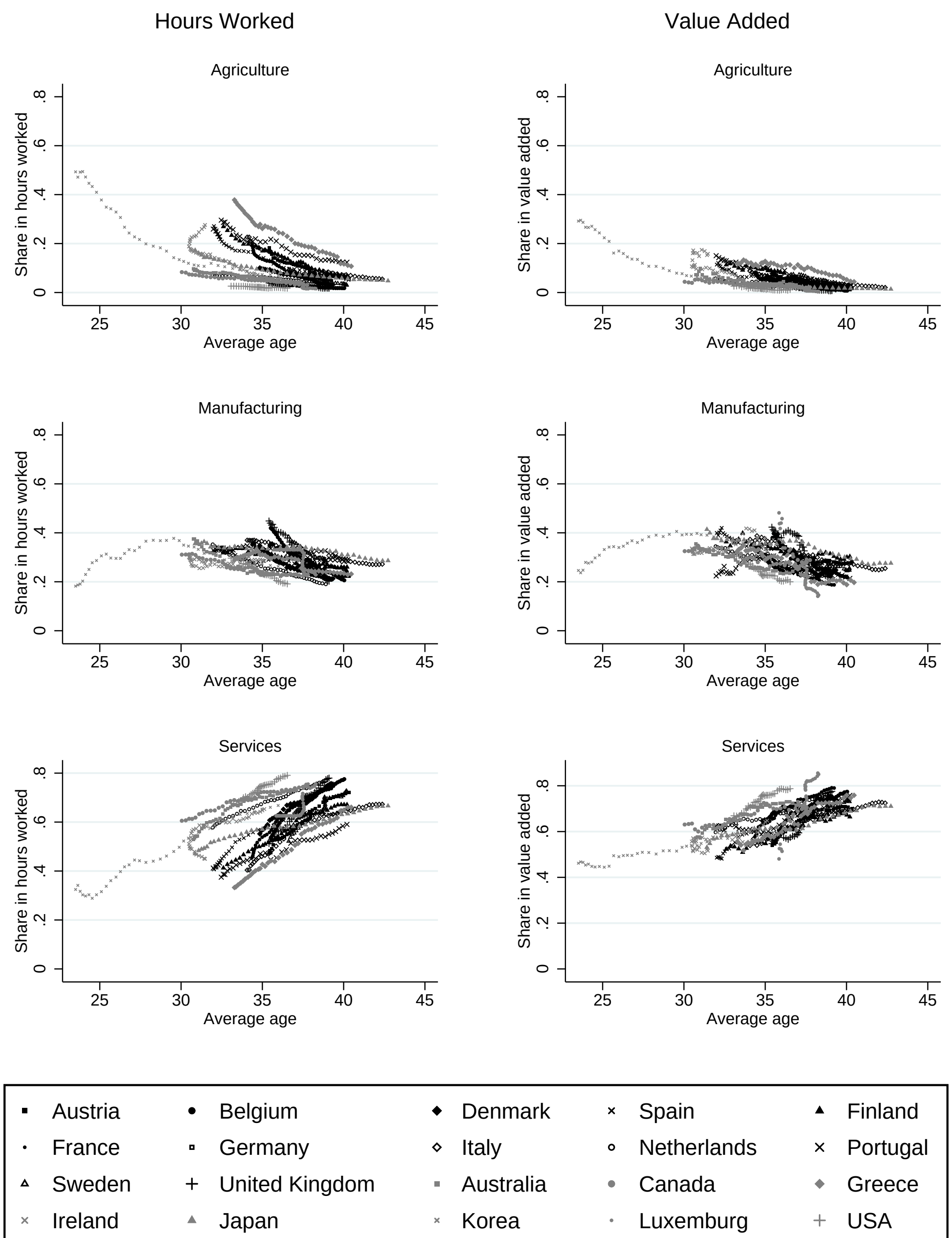
ONLINE APPENDIX
(NOT FOR PUBLICATION)

A Robustness, cross-country results

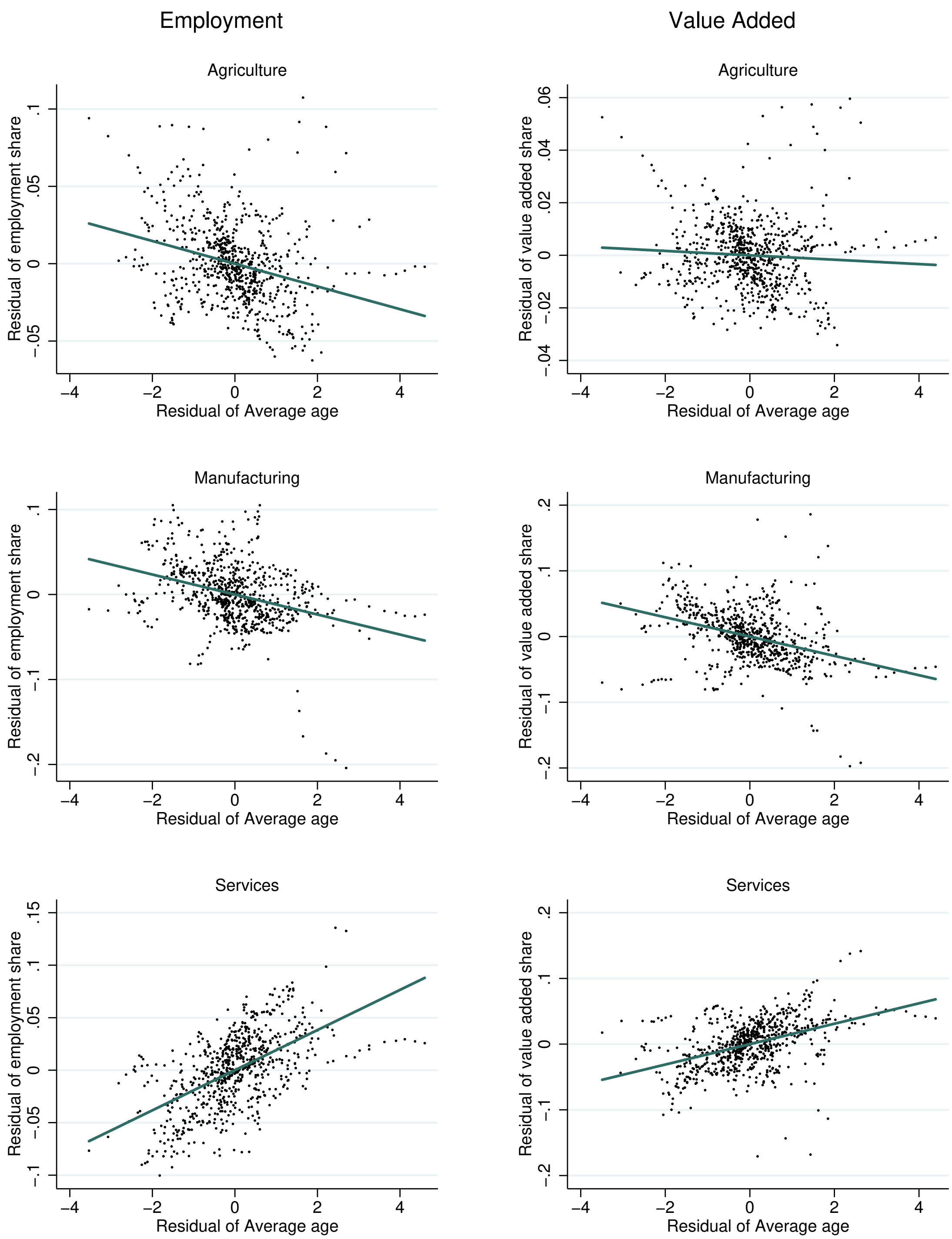
A.1 Additional results for Section 2.1

Figure A1: Sectoral shares of employment and value added



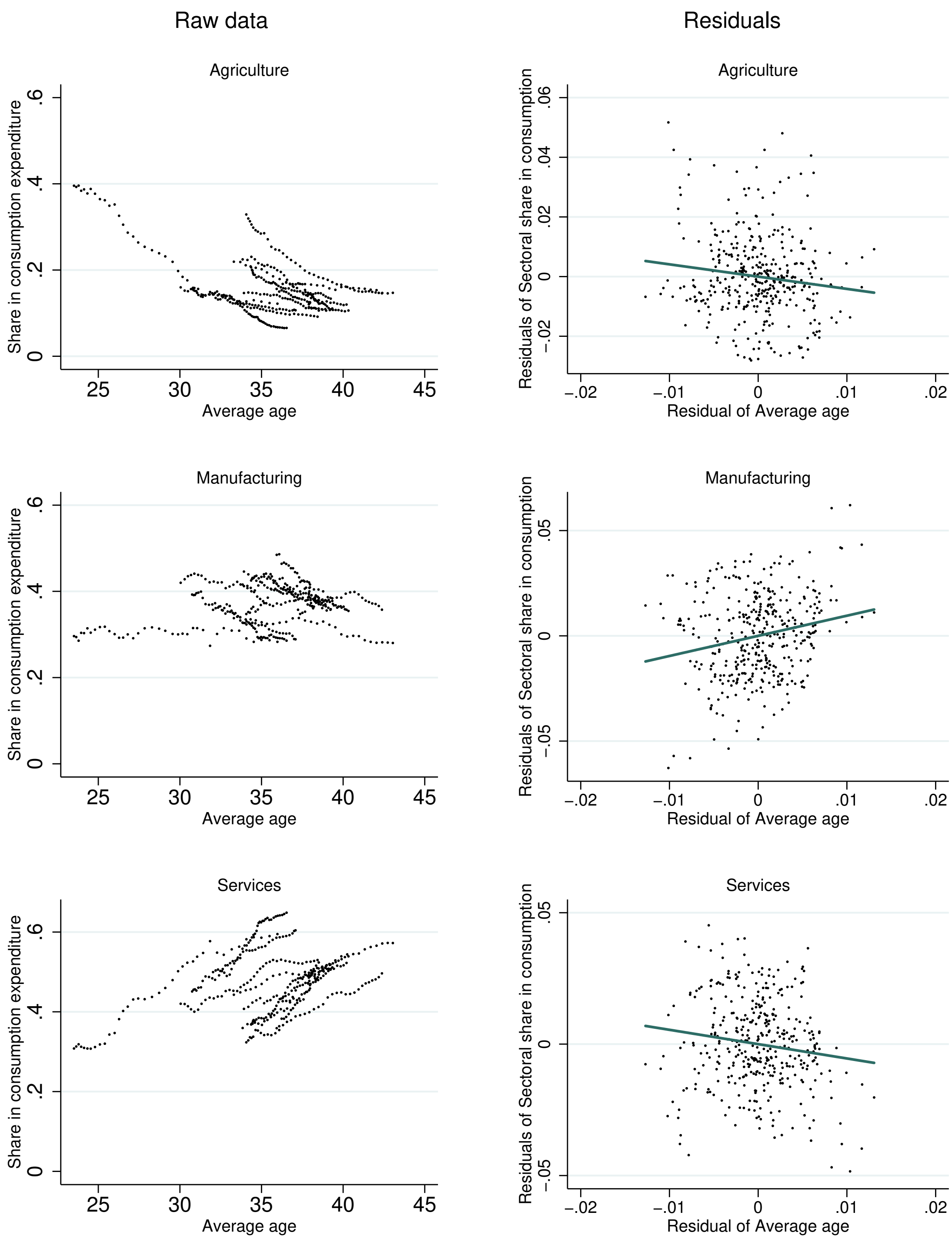
Notes: Each dot represents a country-year. The x-axis reports the average age in the population (source: WDI). The y-axis reports the sectoral share in hours worked (left panel) and the sectoral shares in value added (right panel) using data from EU KLEMS.

Figure A2: Residualized sectoral shares of employment and value added



Notes: Each dot represents a country-year. The x-axis reports the residual of a regression of the average age in the population on GDP per capita and country fixed-effects. The y-axis reports the residual of a regression of the sectoral share in hours worked (left panel) and the sectoral shares in value added (right panel) on GDP per capita and country fixed-effects. Data sources are the same as in Figure 1.

Figure A3: Sectoral consumption shares



Notes: Each dot represents a country-year. The x-axis reports the actual (left panel) and the residualized (right panel) average age in the population. The y-axis reports the sectoral share in actual (left panel) and the residualized (right panel) sectoral shares in consumption using data from OECD.

Table A1: Population aging and the services share, EU KLEMS

	Agriculture (1)	Manufacturing (2)	Services (3)
Employment Share			
Log GDP per capita	-0.201	7.617*	-7.416**
	(1.936)	(3.654)	(2.755)
(Log GDP per capita)^2	-0.0530	-0.754*	0.807**
	(0.209)	(0.389)	(0.295)
(Log GDP per capita)^3	0.00400	0.0245*	-0.0285**
	(0.00746)	(0.0136)	(0.0104)
Share of pop 65+	-0.606*	-0.604	1.210**
	(0.289)	(0.474)	(0.523)
R^2	0.952	0.701	0.929
Value added Share			
Log GDP per capita	0.0730	-0.191	0.118
	(1.034)	(3.748)	(2.955)
(Log GDP per capita)^2	-0.0512	0.103	-0.0522
	(0.111)	(0.399)	(0.315)
(Log GDP per capita)^3	0.00299	-0.00661	0.00362
	(0.00391)	(0.0140)	(0.0111)
Share of pop 65+	-0.0286	-1.315**	1.344***
	(0.124)	(0.481)	(0.428)
Observations	707	707	707
R^2	0.953	0.761	0.874

Standard errors in parentheses clustered at the country level
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table A2: Population aging and the sectoral consumption share, OECD

	Agriculture		Manufacturing		Services	
	(1)	(2)	(3)	(4)	(5)	(6)
Consumption share						
Share of pop 65+	-1.702**	-0.305	-0.793**	-0.639*	2.496***	0.943***
	(0.560)	(0.237)	(0.293)	(0.318)	(0.614)	(0.243)
Log GDP per capita		-0.130***		-0.0144		0.144***
		(0.0129)		(0.0268)		(0.0167)
Observations	377	377	377	377	377	377
R^2	0.767	0.951	0.803	0.806	0.789	0.942

Standard errors in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

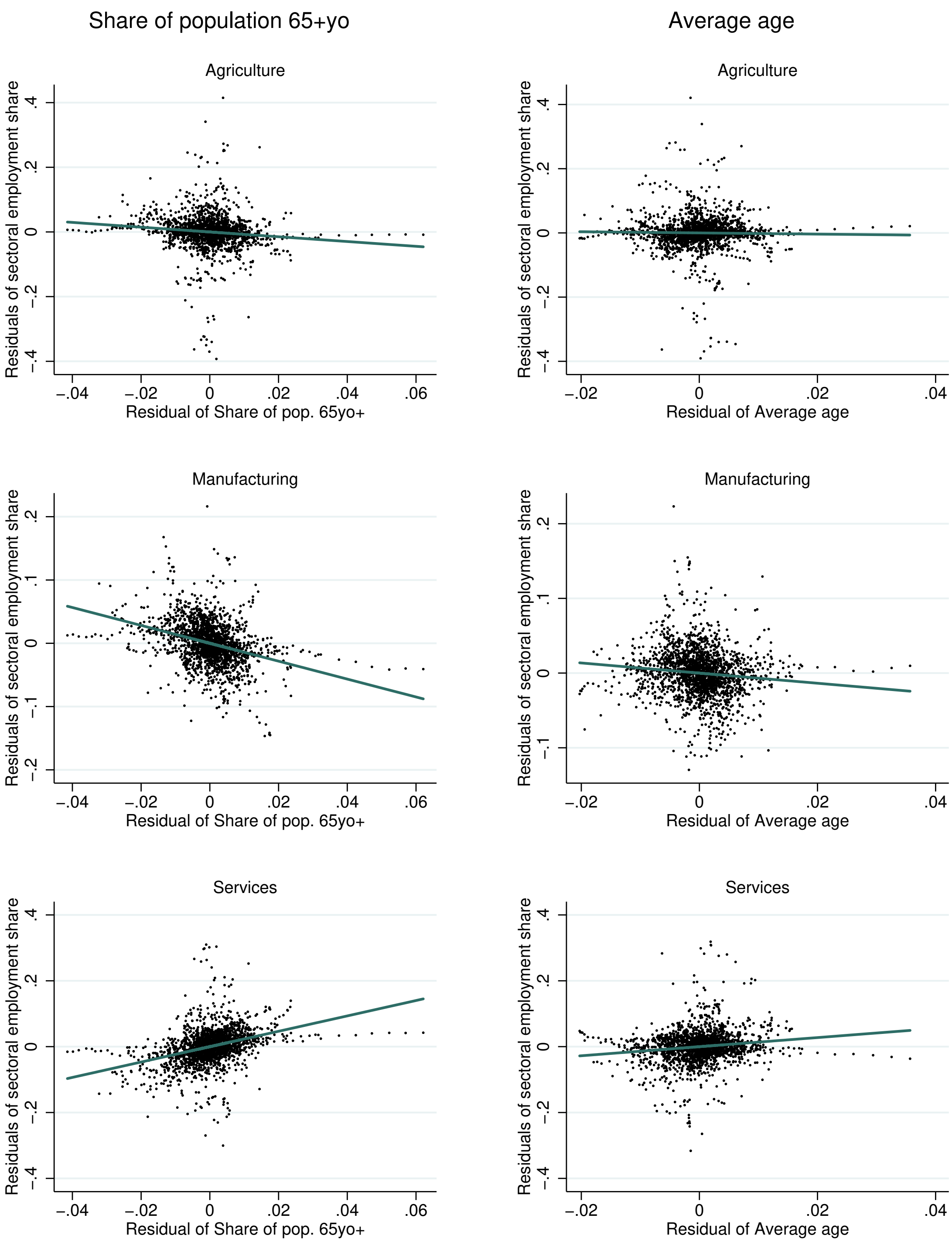
A.2 Evidence from the WDI and the UN Statistics Division

This section complements the evidence from Section 2.1 using employment data from the WDI and value-added data from the UN. Relative to the data presented in the main text, these sources cover a much broader sample of both developed and developing countries. On the other hand, unlike the the EU-KLEMS data, the WDI only reports number of employed persons as opposed to number of hours worked, and the value-added data from the UN are obtained from country-specific sources that are not necessarily harmonized. The data presents a balanced panel of countries that are covered for the 1970-2007 period. We follow Herrendorf et al. (2014) and restrict our sample to countries with average population above 1 million, exclude former communist countries, and exclude countries where the average ratio of oil rents to GDP is above 20 percent. This leaves a sample of 99 countries.

We replicate the fact reported in Section 2.1 using these alternative data. Table A3 and Figure A4 summarize the results from a regression analogous to Equation (1) that is estimated on the WDI data. They show that, after controlling for income, there is a clear negative relation between population age and the employment shares in Agriculture and Manufacturing, and a strong positive relation between population age and the share of employment in the Service sector. These relations are observed for each of our population age variables.

Figure A5 and Table A4 corroborate that the same patterns described in Section 2.1 are also present in the value-added data from the UN. After controlling for income, there is a clear negative relation between population age and the employment shares in Agriculture and Manufacturing, and a strong positive relation between population age and the share of employment in the service sector.

Figure A4: Residualized sectoral employment shares: WDI data



Notes: Each dot represents a country-year. The x-axis reports the residual of a regression of the share of the population that is 65 and over (left panel) or the average age of the population (right panel) on GDP per capita and country fixed effects. The y-axis reports the residual of a regression of the sectoral share in employment on GDP per capita and country fixed effects.

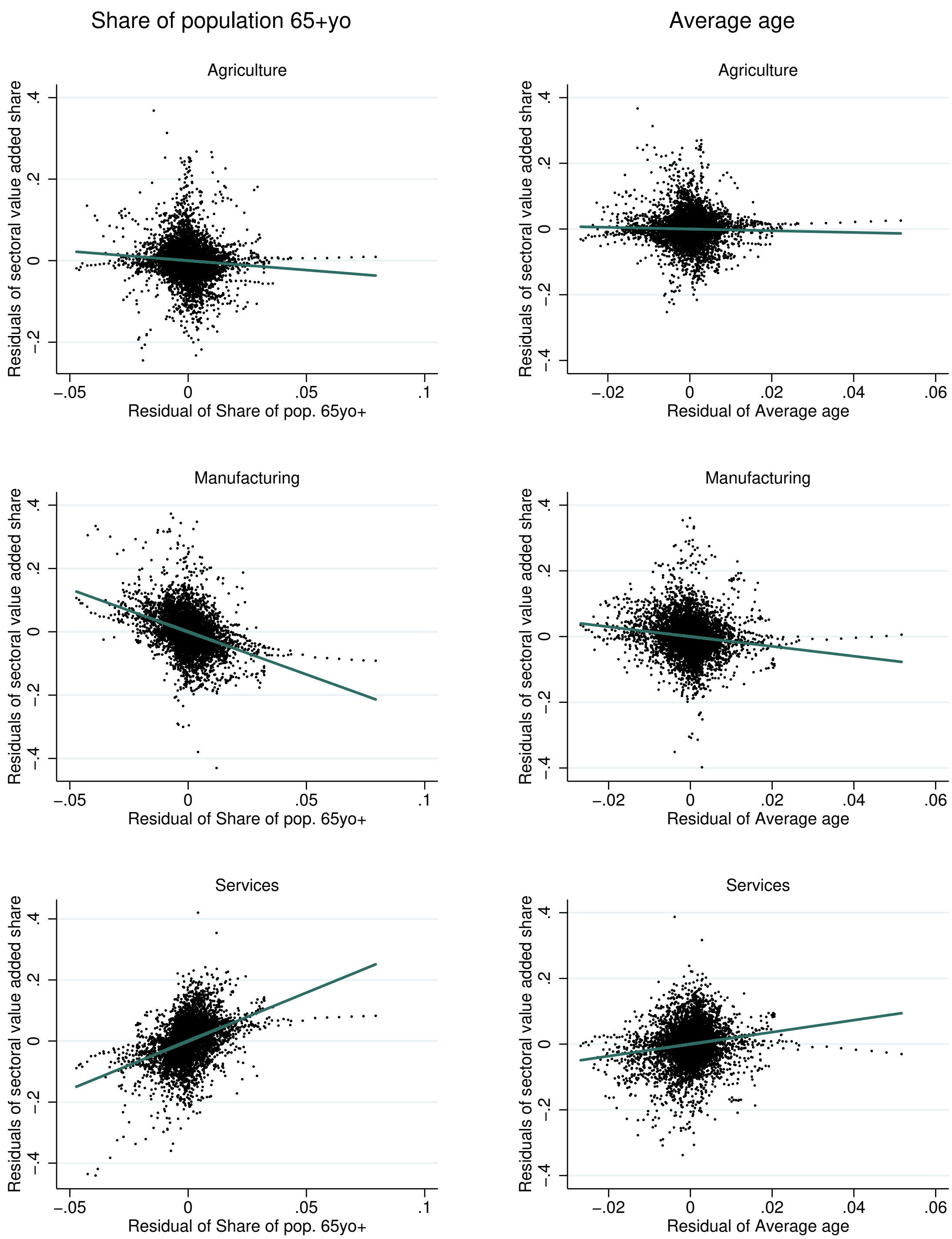
Table A3: Population aging and the services share in employment: WDI data

	Agriculture		Manufacturing		Services	
	(1)	(2)	(3)	(4)	(5)	(6)
Employment share						
Average age	-0.0136***	-0.00736**	-0.0103***	-0.0126***	0.0249***	0.0196***
	(0.00232)	(0.00349)	(0.00239)	(0.00331)	(0.00240)	(0.00372)
Log GDP per capita		-0.0639***		0.0248		0.0448*
		(0.0216)		(0.0223)		(0.0242)
Observations	2206	2029	2214	2037	2214	2037
R^2	0.921	0.918	0.805	0.826	0.904	0.896

Standard errors in parentheses clustered at the country level

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Figure A5: Residualized sectoral value-added shares: UN data



Notes: Each dot represents a country-year. The x-axis reports the residual of a regression of the share of the population that is 65 and over (left panel) or the average age of the population (right panel) on GDP per capita and country fixed effects. The y-axis reports the residual of a regression of the sectoral share in value added (second panel) on GDP per capita and country fixed effects.

Table A4: Population aging and the services share in value-added: UN data

	Agriculture		Manufacturing		Services	
	(1)	(2)	(3)	(4)	(5)	(6)
Value added share						
Average age	-0.0117***	-0.00289	-0.00648***	-0.0169***	0.0180***	0.0197***
	(0.00136)	(0.00190)	(0.00166)	(0.00238)	(0.00163)	(0.00277)
Log GDP per capita		-0.0916***		0.109***		-0.0185
		(0.0145)		(0.0162)		(0.0200)
Observations	6509	6156	6547	6194	6547	6194
R^2	0.880	0.903	0.778	0.819	0.829	0.824

Standard errors in parentheses clustered at the country level

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

B Additional results, household-level data and model

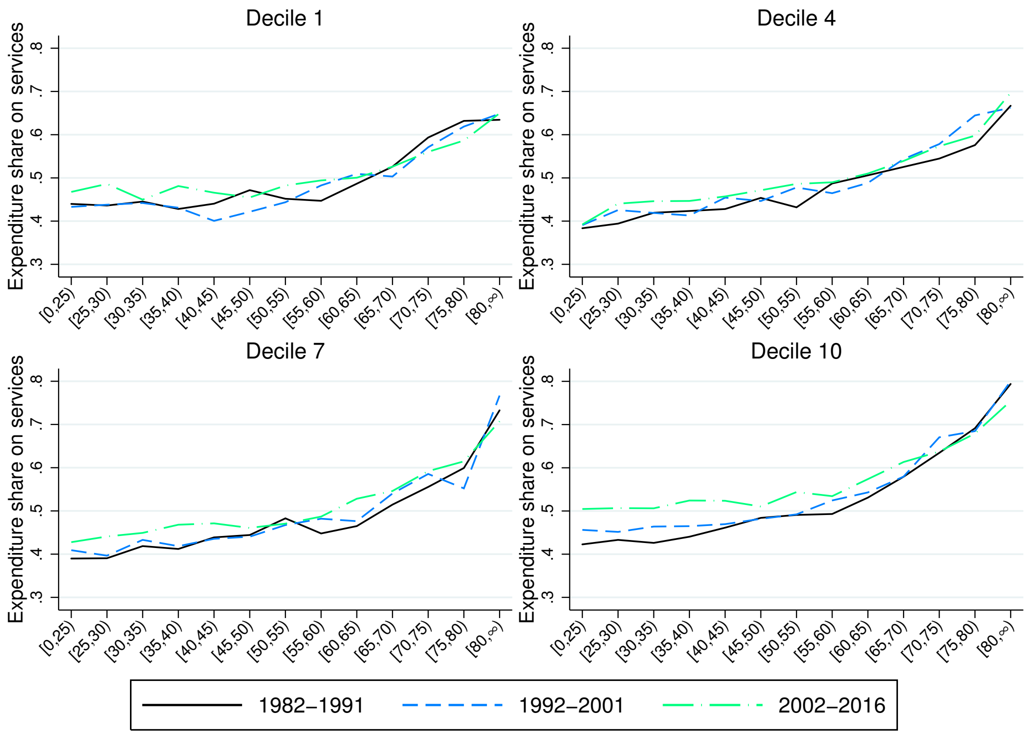
B.1 Additional tables and figures, CES

Table A5: Expenditure shares on goods and services

	1982-1991	1992-2001	2002-2016
Goods	*51.1*	*49.8*	*47.7*
Food at home	15.6	15.1	14.7
Vehicle purchasing, leasing	12.1	13.6	12.0
Gas	5.4	4.3	6.3
Entertainment equipment	4.1	4.8	5.3
Appliances	2.7	2.8	2.3
Men's and women's clothing	3.9	3.1	1.9
Furnitures and Fixtures	2.4	2.0	1.7
Alcoholic beverages	1.5	1.2	1.2
Shoes and other apparel	1.5	1.2	0.9
Tobacco	1.3	1.1	1.0
Children's clothing	0.6	0.6	0.4
Personal care goods	0.0	0.0	0.0
Services	*48.9*	*50.2*	*52.3*
Health	9.1	10.1	12.1
Utilities	11.0	10.7	11.6
Cash contributions	4.9	5.1	5.7
Car maintenance, repairs, insurance	5.4	5.9	5.2
Food away from home	6.4	5.9	5.0
Domestic services and childcare	4.5	4.5	4.7
Education	1.4	1.8	2.7
Entertainment fees, adm., reading	2.9	3.0	2.5
Public transport	1.9	2.0	1.8
Personal care services	1.4	1.3	1.0

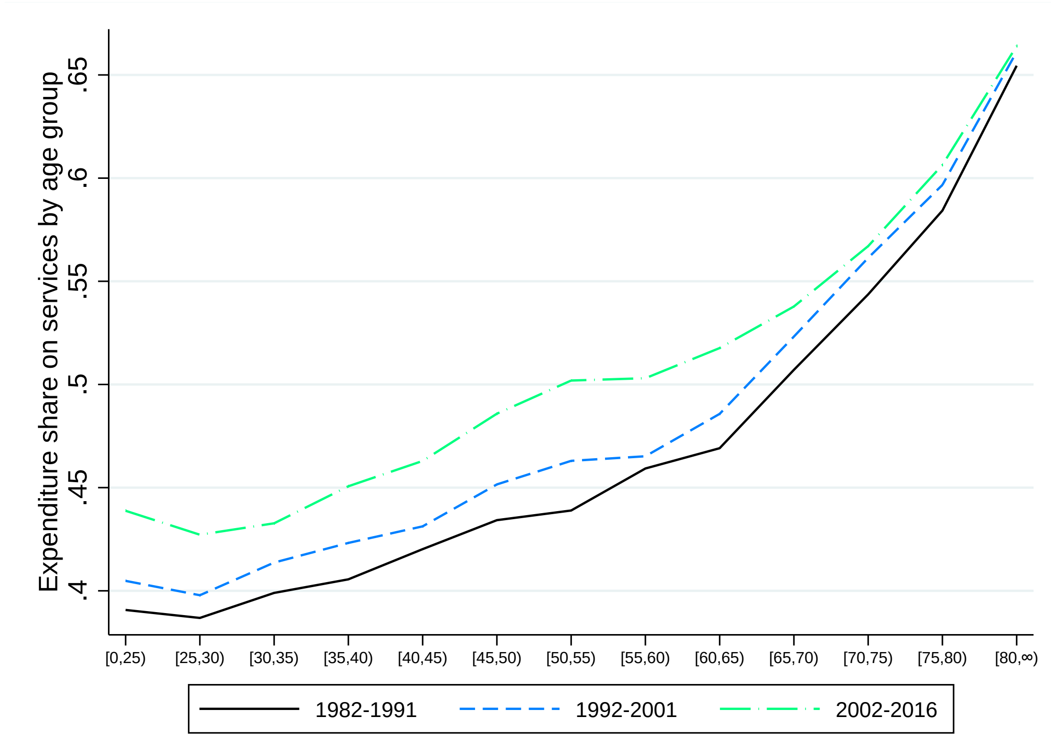
Notes: This table reports the aggregate expenditure shares on broad categories of goods and services, in the three decades separately, in the CES. Housing is excluded from expenditures.

Figure A6: Service consumption by average age of household members and income decile, selected deciles



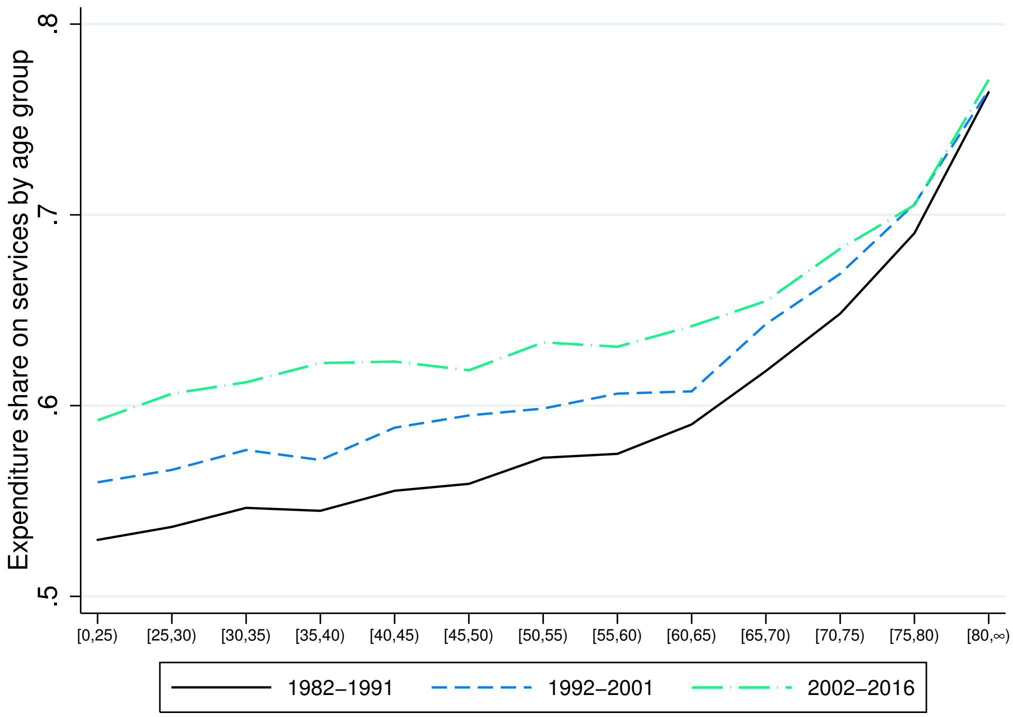
Notes: This figure displays the average household-level expenditure shares on services in the CES by age group (x-axis), for 3 time periods, and selected income deciles.

Figure A7: Service consumption by age of the reference person



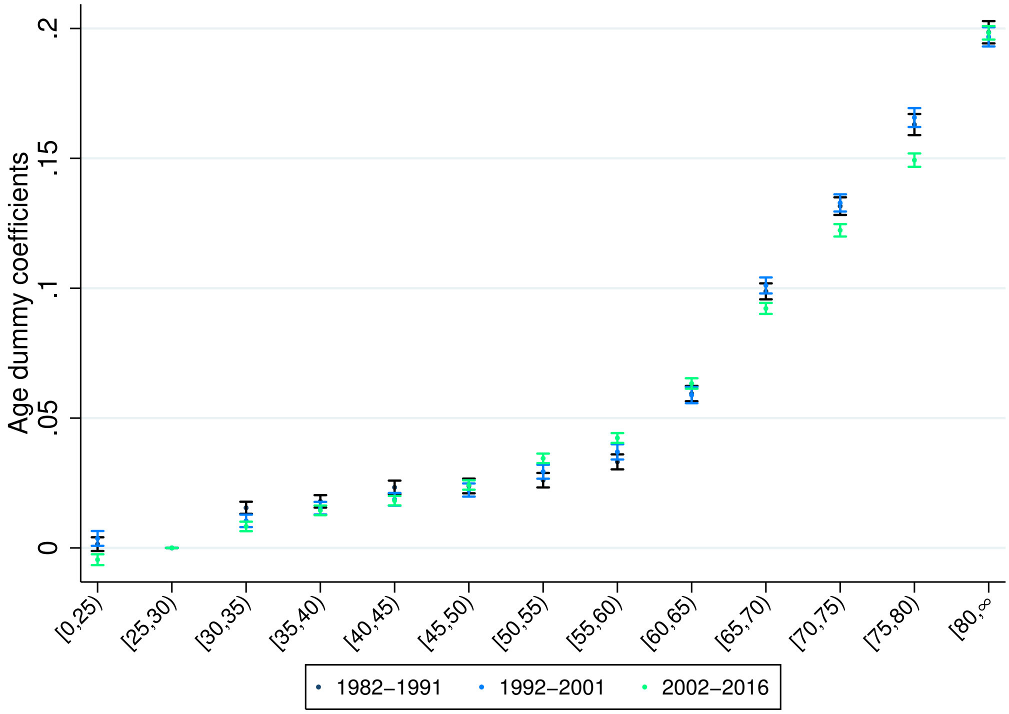
Notes: This figure displays the average household-level expenditure shares on services in the CES by age group according to the age of the reference person (x-axis), for 3 time periods.

Figure A8: Service consumption with housing by average age of household members



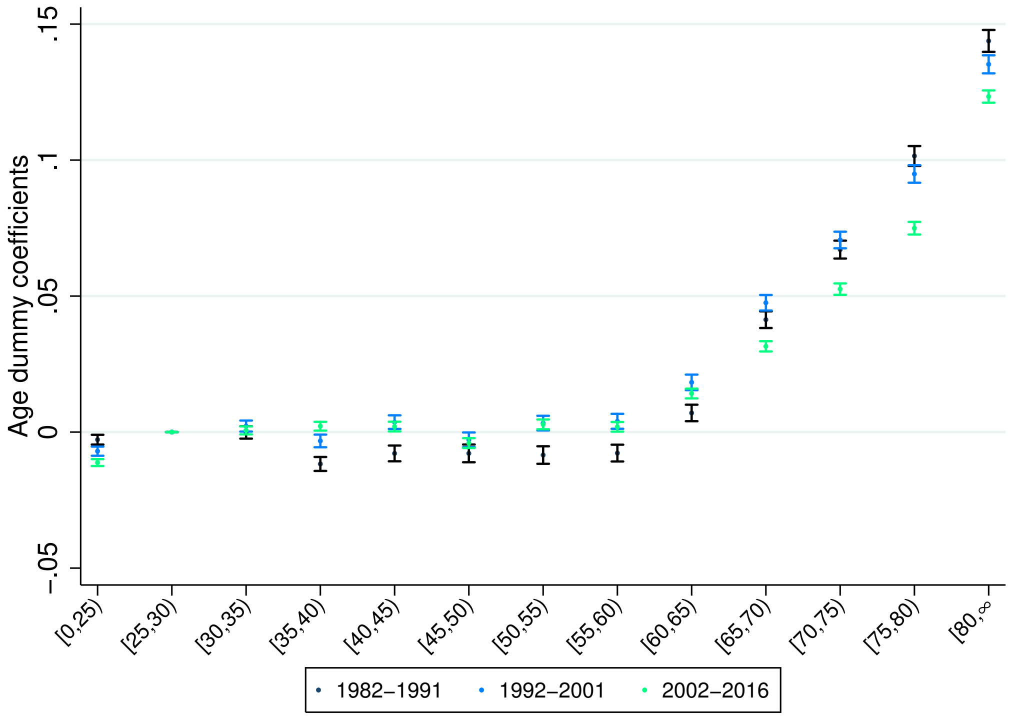
Notes: This figure displays the average household-level expenditure shares on services in the CES by age group (x-axis), for 3 time periods. Housing is included in expenditures.

Figure A9: Age dummies (controlling for income decile), by age of the reference person



Notes: Each dot represents the point estimate of the age dummies in Equation (2) for a particular decade in the CES data. The omitted dummy is that of age group 25-30. The bands report the 95% confidence intervals based on standard errors clustered at the household level.

Figure A10: Age dummies (controlling for income decile)



Notes: Each dot represents the point estimate of the age dummies in modified Equation (2)for a particular decade in the CES data. The modified equation considers housing as a part of service consumption. The omitted dummy is that of age group 25-30. The bands report the 95% confidence intervals based on standard errors clustered at the household level.

Table A6: Within-between decomposition: including housing

	Average		Reference	
	Value	%	Value	%
Within	0.0811	86.3	0.0834	88.7
Between	0.0129	13.7	0.0107	11.3
Total	0.0940	100	0.0940	100

Notes: The table reports the results from the decomposition in equation (4) taking housing expenditures into account. 'Average' uses the average age across all household member as the age of the household. 'Reference' uses the age of the reference person in the household.

Table A7: Estimates of equation (8) for different age measures

	(1)	(2)	(3)	(4)
	$\log \omega_t^{g,n}$	$\log \omega_t^{g,n}$	$\log \omega_t^{g,n}$	$\log \omega_t^{g,n}$
$\log e_t^n$	-0.116***	-0.117***	-0.118***	-0.119***
	(0.00178)	(0.00179)	(0.00191)	(0.00191)
$D^{[0,25)}$	0.0139***	0.0141***	-0.0557***	-0.0555***
	(0.00206)	(0.00206)	(0.00330)	(0.00331)
$D^{[30,35)}$	-0.0150***	-0.0155***	0.000930	0.000256
	(0.00254)	(0.00254)	(0.00275)	(0.00275)
$D^{[35,40)}$	-0.0258***	-0.0266***	0.00153	0.000858
	(0.00283)	(0.00283)	(0.00278)	(0.00279)
$D^{[40,45)}$	-0.0454***	-0.0461***	-0.00562**	-0.00629**
	(0.00313)	(0.00314)	(0.00286)	(0.00286)
$D^{[45,50)}$	-0.0562***	-0.0575***	-0.0264***	-0.0270***
	(0.00325)	(0.00326)	(0.00292)	(0.00293)
$D^{[50,55)}$	-0.0932***	-0.0930***	-0.0594***	-0.0597***
	(0.00332)	(0.00333)	(0.00302)	(0.00302)
$D^{[55,60)}$	-0.118***	-0.118***	-0.0879***	-0.0888***
	(0.00326)	(0.00326)	(0.00316)	(0.00317)
$D^{[60,65)}$	-0.172***	-0.173***	-0.142***	-0.142***
	(0.00338)	(0.00338)	(0.00335)	(0.00336)
$D^{[65,70)}$	-0.255***	-0.255***	-0.224***	-0.225***
	(0.00360)	(0.00360)	(0.00349)	(0.00349)
$D^{[70,75)}$	-0.340***	-0.341***	-0.309***	-0.310***
	(0.00402)	(0.00403)	(0.00397)	(0.00397)
$D^{[75,80)}$	-0.435***	-0.436***	-0.406***	-0.407***
	(0.00483)	(0.00482)	(0.00462)	(0.00462)
$D^{[80,\infty)}$	-0.592***	-0.592***	-0.551***	-0.552***
	(0.00548)	(0.00548)	(0.00508)	(0.00508)
Age variable	Average	Average	Reference	Reference
Time FE	Yes	No	Yes	No
Region-Time FE	No	Yes	No	Yes
Observations	1,226,096	1,220,472	1,226,096	1,220,472
R^2	0.099	0.100	0.085	0.087

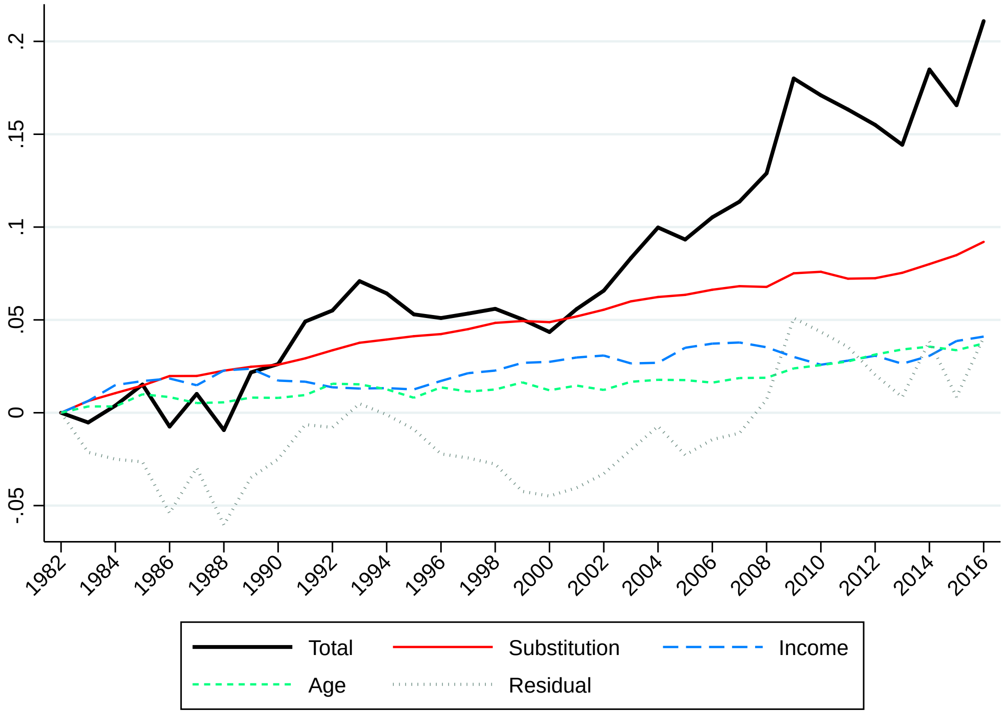
Standard errors in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table A8: Estimates of equation (8) with housing

	(1)	(2)	(3)	(4)
	$\log \tilde{\omega}_t^{g,n}$	$\log \tilde{\omega}_t^{g,n}$	$\log \tilde{\omega}_t^{g,n}$	$\log \tilde{\omega}_t^{g,n}$
$\log \tilde{e}_t^n$	-0.0906***	-0.0869***	-0.0893***	-0.0847***
	(0.00218)	(0.00219)	(0.00238)	(0.00239)
$D^{[0,25)}$	0.0344***	0.0345***	-0.00426	-0.000668
	(0.00254)	(0.00253)	(0.00397)	(0.00396)
$D^{[30,35)}$	-0.0152***	-0.0151***	-0.000360	-0.00143
	(0.00320)	(0.00318)	(0.00343)	(0.00341)
$D^{[35,40)}$	-0.0155***	-0.0157***	0.00620*	0.00525
	(0.00358)	(0.00355)	(0.00348)	(0.00347)
$D^{[40,45)}$	-0.0370***	-0.0366***	0.0139***	0.0126***
	(0.00394)	(0.00393)	(0.00354)	(0.00352)
$D^{[45,50)}$	-0.0360***	-0.0372***	0.00962***	0.00802**
	(0.00404)	(0.00404)	(0.00361)	(0.00360)
$D^{[50,55)}$	-0.0684***	-0.0692***	-0.0132***	-0.0143***
	(0.00408)	(0.00408)	(0.00371)	(0.00370)
$D^{[55,60)}$	-0.0723***	-0.0734***	-0.0263***	-0.0283***
	(0.00397)	(0.00396)	(0.00384)	(0.00383)
$D^{[60,65)}$	-0.106***	-0.108***	-0.0617***	-0.0630***
	(0.00401)	(0.00400)	(0.00399)	(0.00398)
$D^{[65,70)}$	-0.178***	-0.178***	-0.128***	-0.128***
	(0.00414)	(0.00414)	(0.00408)	(0.00408)
$D^{[70,75)}$	-0.251***	-0.252***	-0.202***	-0.203***
	(0.00453)	(0.00455)	(0.00452)	(0.00452)
$D^{[75,80)}$	-0.351***	-0.351***	-0.299***	-0.299***
	(0.00531)	(0.00532)	(0.00512)	(0.00513)
$D^{[80,\infty)}$	-0.560***	-0.558***	-0.487***	-0.484***
	(0.00657)	(0.00659)	(0.00612)	(0.00614)
Age variable	Average	Average	Reference	Reference
Time FE	Yes	No	Yes	No
Region-Time FE	No	Yes	No	Yes
Observations	1,226,096	1,220,472	1,226,096	1,220,472
R^2	0.078	0.084	0.064	0.070

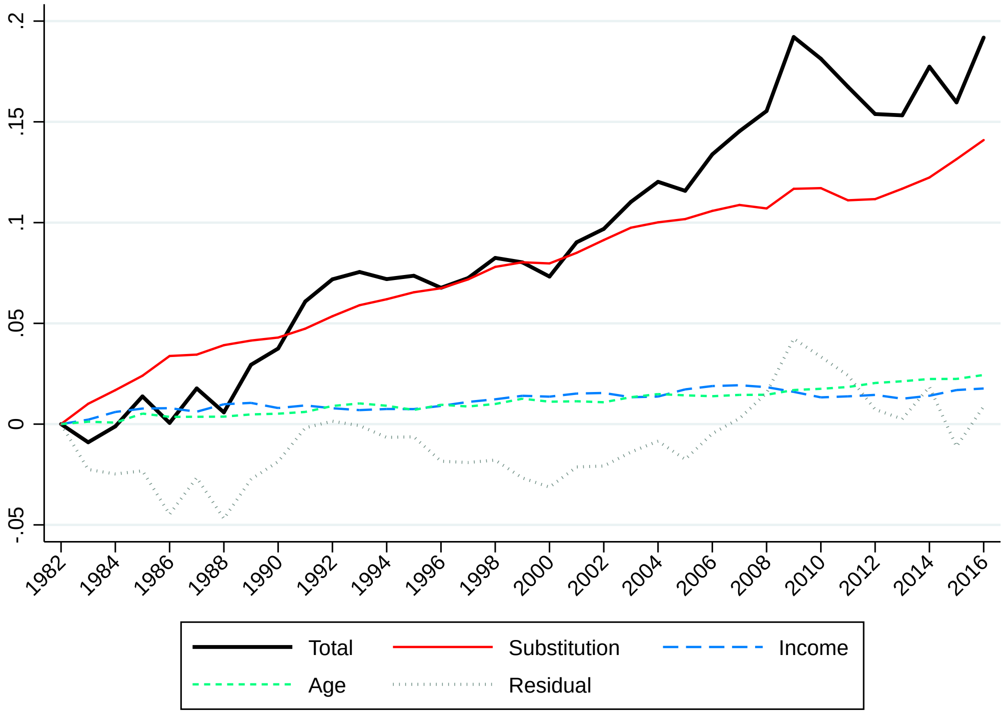
Standard errors in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Figure A11: Accounting for structural change in the US, using reference person's age



Notes: This figure displays the decomposition (10) for the US from 1982 to 2016, using the age of the reference person as the age variable.

Figure A12: Accounting for structural change in the US, using housing as service



Notes: This figure displays the decomposition (10) for the US from 1982 to 2016, using the average age of members as the age variable and including housing as part of service consumption.

Table A9: Share of out-of-pocket expenses in total personal healthcare expenses, NHES

Age group	2002	2014
0-44	0.144	0.112
45-64	0.164	0.121
65+	0.173	0.153

Notes: This table reports the ratios of out-of-pocket to total personal healthcare expenditures by broad age group from the National Health Expenditure Survey.

B.2 Rescaling CES expenditure data to aggregate data

Rescaling procedure This section rescales the expenditure data in the Consumption Expenditure Survey to match the aggregate Personal Consumption Expenditure (PCE) shares reported by the BEA. In principle, these data need not coincide, since they are collected from different sources that use very different methodologies.[8] After concording the expenditure categories in the CES to PCE items in the BEA data, we compute total expenditures in the CES, $e_t^{j,CES}$, for each category j and year t. We then create the scaling factor for each category that reflects the discrepancy in the aggregate expenditure between the CES and the BEA: $X_t^j = e_t^{j,BEA} / e_t^{j,CES}$. Then, we rescale the consumption expenditure of each household by this factor: $e_t^{j,h} = e_t^{j,h,CES} \times X_t^j$. In this way, the aggregate expenditure on each category in each year in the CES in the rescaled data match the BEA aggregates in every category and year.

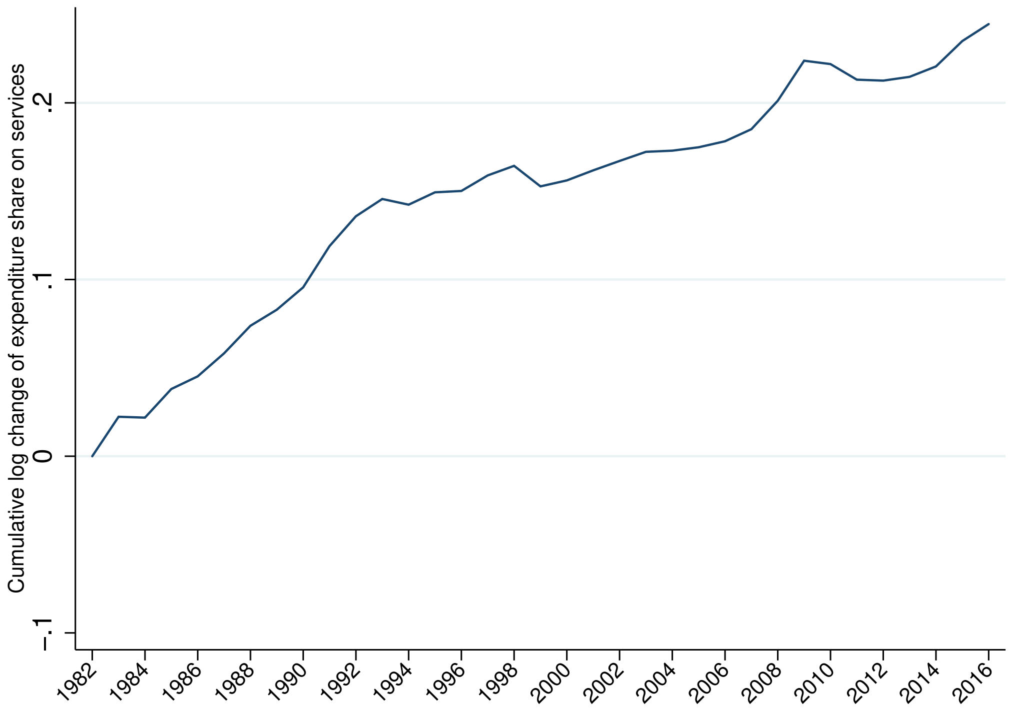
Using the rescaled expenditures, we compute the expenditure shares $\omega_t^{j,h} \equiv e_t^{j,h} / \sum_j e_t^{j,h}$, and the total expenditures by household: $e_t^h \equiv \sum_j e_t^{j,h}$. From this, we compute the new e_t^h / e_t. These steps give us all the elements of a new dataset, on which we repeat the household-level estimation in Section 2.2 and the quantitative analysis of Section 3.

This approach is valid under the assumption that the micro variation across households in the CES is an accurate reflection of the differences in spending patterns by age group, and only the aggregate shares are inaccurate.

Replication of main results using rescaled data Figure A13 plots the cumulative log change in the aggregate expenditure share on services in the BEA PCE data. These data show a somewhat larger change than the CES, with the expenditure share of services rising by 24 log points. Figure A14 shows the service expenditure shares for households of different ages, and the three time periods. The magnitudes of the differences across households are similar to the baseline analysis. Figure A15 breaks down by income quartile, while Figure A16 reports the age dummies controlling for income, as in equation (2). The results are quite similar to the baseline.

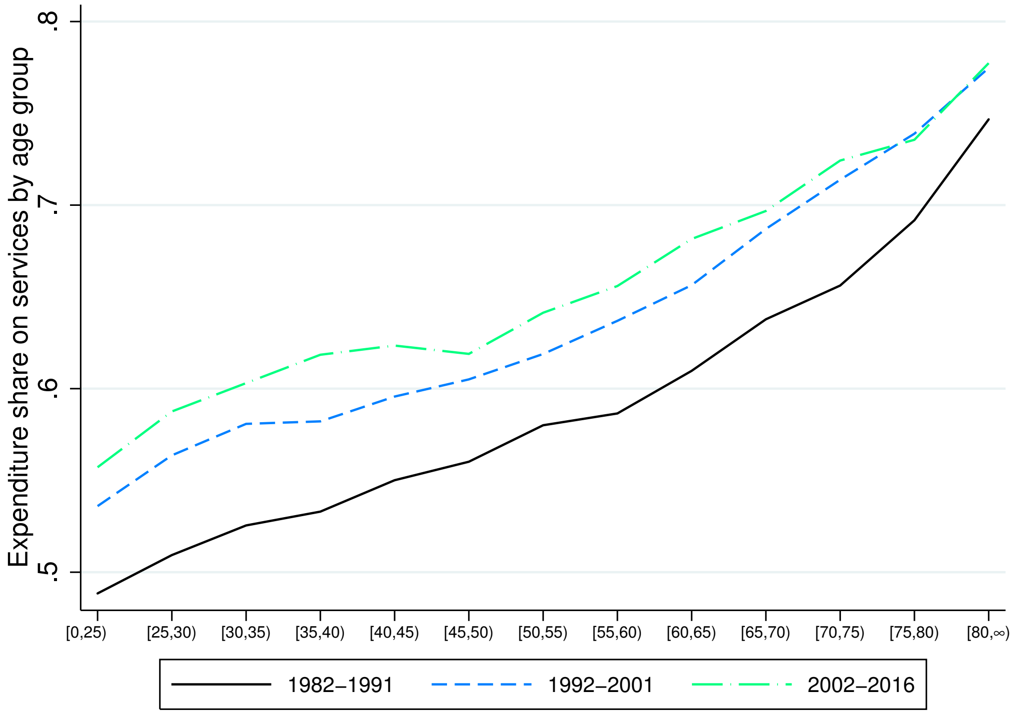
[8]The CES collects expenditures from households surveys, while the BEA final sales made by businesses in a way that is consistent with the consistent with the National Income and Product Accounts.

Figure A13: Service consumption share, BEA



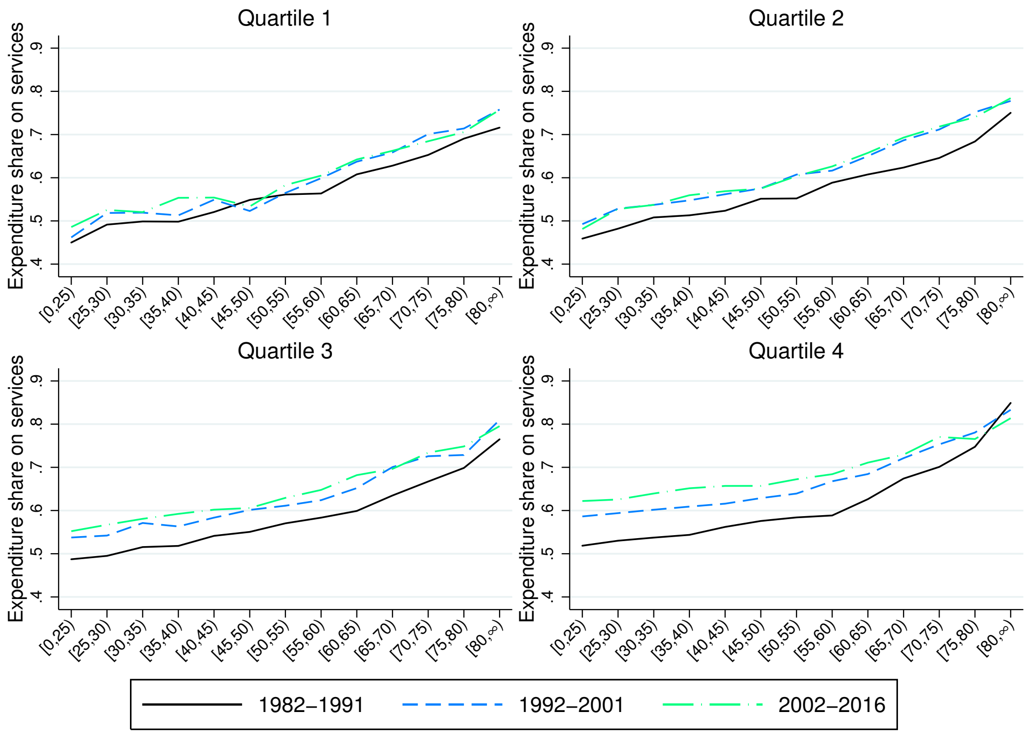
Notes: This figure displays the cumulative log change in the aggregate expenditure share on services in the BEA. Housing is excluded from expenditures.

Figure A14: Service consumption by average age of household members, rescaled to BEA



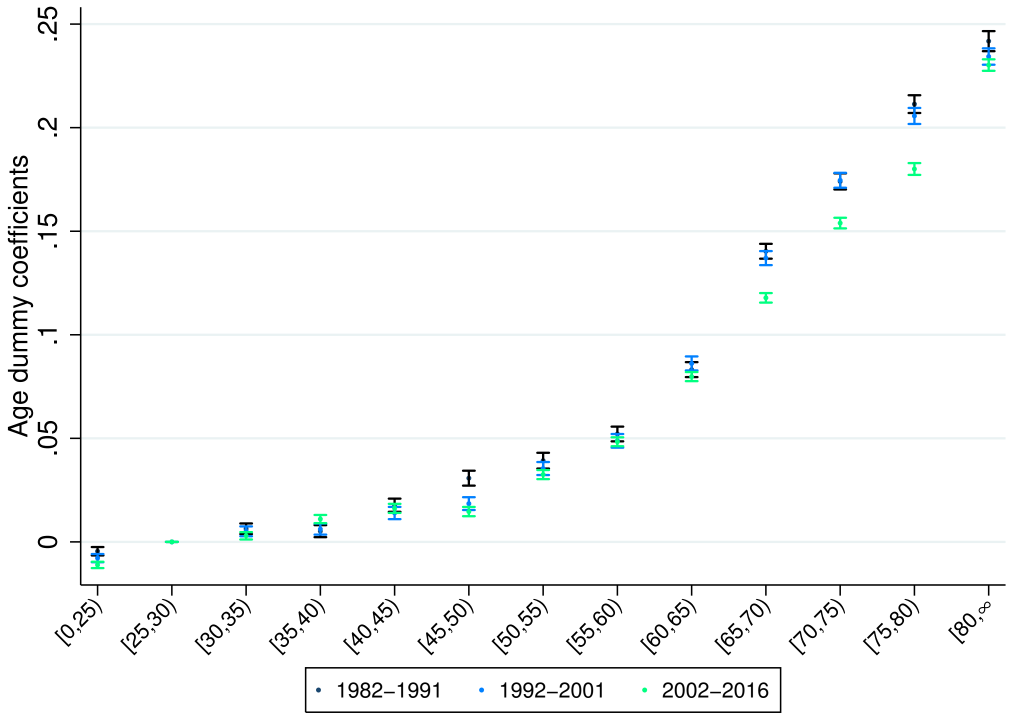
Notes: This figure displays the average household-level expenditure shares on services in the rescaled CES by age group (x-axis), for 3 time periods.

Figure A15: Service consumption by average age of household members and income, rescaled to BEA



Notes: This figure displays the average household-level expenditure shares on services in the rescaled CES by age group (x-axis), for 3 time periods, and each income quartile.

Figure A16: Age dummies rescaled to BEA

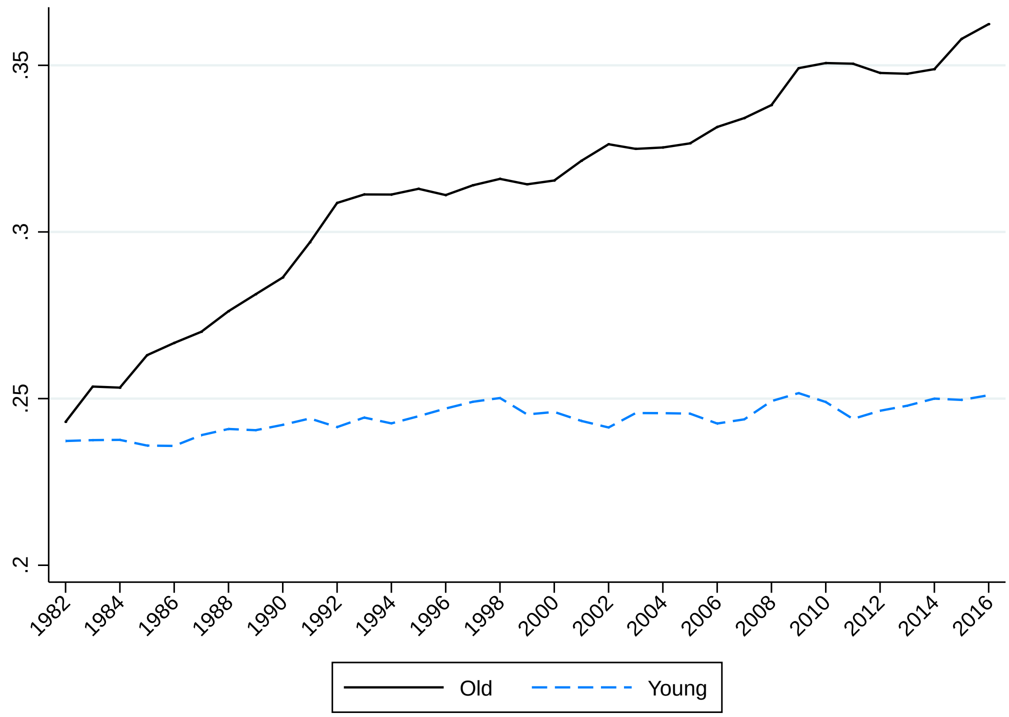


Notes: Each dot represents the point estimate of the age dummies in Equation (2) for a particular decade in the CES data. The omitted dummy is that of age group 25-30. The bands report the 95% confidence intervals based on standard errors clustered at the household level.

Table A10 reports the differences in consumption expenditures by category for older households, expressed as a difference relative to the households aged 25-30. While the ranking of categories according to young-old expenditure share differences is similar, the BEA-rescaled data show larger absolute differences in Healthcare.

Moving on to the replication of the results in Section 3, Tables A11-A12 report the changes in the services expenditure shares and income shares, and the within-between decomposition. In the BEA-rescaled data, the absolute size of the between effect due to population aging is slightly larger than in the baseline. However, because the change in the aggregate service expenditure share is also larger in the BEA, the between effect represents 14.3% of the total rise in the service expenditure share.

Figure A17: Evolution of expenditure share on selected service categories using CES and re-scaling to BEA



Notes: 'Old' displays the aggregate expenditure share in the BEA on categories that are disproportionally consumed by the old: Health, Utilities, and Personal Services. 'Young' displays the expenditure share on the remaining service categories.

Table A10: Differences in expenditures by consumption category: 25-30 vs 60-65, 65-70, 70-75, 75-80 and 80+, rescaled to BEA

	Age groups				
	60-65	65-70	70-75	75-80	80+
Health	9.47	13.40	17.07	20.98	24.95
Cash contributions	2.28	2.98	3.70	4.23	6.11
Domestic services and childcare	0.10	0.28	0.47	0.93	3.07
Utilities	-0.06	-0.09	0.11	0.36	0.56
Personal care services	-0.01	0.03	0.08	0.10	0.12
Personal care goods	-0.01	-0.01	-0.01	-0.01	-0.01
Public transport	0.10	0.07	-0.07	-0.15	-0.67
Tobacco	-0.12	-0.34	-0.56	-0.77	-0.96
Furnitures and Fixtures	-0.29	-0.38	-0.60	-0.73	-0.98
Shoes and other apparel	-0.52	-0.63	-0.75	-0.94	-1.00
Children's clothing	-0.83	-0.85	-0.95	-1.00	-1.08
Appliances	-0.13	-0.37	-0.57	-0.73	-1.12
Alcoholic beverages	-0.55	-0.71	-0.91	-1.12	-1.33
Personal Insurance	3.29	1.90	0.82	-0.96	-1.71
Men's and women's clothing	-0.66	-0.94	-1.13	-1.50	-2.02
Entertainment fees, adm., reading	-0.71	-0.91	-1.19	-1.66	-2.28
Entertainment equipment	-0.60	-1.05	-1.72	-2.01	-2.41
Car maintenance, repairs	-0.91	-1.21	-1.43	-1.53	-2.47
Education	-2.29	-2.46	-2.49	-2.43	-2.57
Gas	-1.05	-1.36	-1.70	-2.05	-2.80
Food at home	-2.93	-2.91	-2.61	-2.32	-2.88
Food away from home	-1.71	-2.11	-2.71	-3.32	-4.16
Vehicle purchasing, leasing	-1.87	-2.32	-2.82	-3.36	-4.36
Services	9.54	11.88	14.35	16.56	20.95

Notes: This Table reports the differences in expenditure shares across the major consumption categories between households aged 60-65 (first panel) or 80+ (second panel) and households aged 25-30. Source: authors' calculations based on the CES, rescaled to BEA.

Table A11: Population aging and the services share, rescaled to BEA

	Pop_{1982}	s^a_{1982}	$\omega^{s,a}_{1982}$	Pop_{2016}	s^a_{2016}	$\omega^{s,a}_{2016}$
0-25	31.8	30.2	45.6	20.4	18.4	58.5
25-30	13.5	15.5	48.1	11.4	11.5	60.7
30-35	9.4	11.1	49.6	9.4	10.5	63.2
35-40	6.2	7.5	51.2	7.1	7.7	62.7
40-45	4.6	5.4	52.9	5.9	6.6	66.1
45-50	3.6	4.0	55.4	5.2	5.6	65.1
50-55	3.8	4.0	53.4	6.1	6.0	64.7
55-60	5.1	5.2	55.3	6.7	7.2	68.1
60-65	5.7	5.6	58.5	7.5	8.1	70.3
65-70	5.9	5.0	61.1	6.8	6.9	70.6
70-75	4.3	3.1	64.2	5.1	5.0	72.1
75-80	3.3	2.0	64.3	3.4	3.0	72.5
80+	2.9	1.4	70.9	5.0	3.6	77.4

Notes: Authors' calculations based on the CES, rescaled to BEA. 'Pop' reports the share of the population in each age group. s^a_t and ω^a_t are defined as in Equation (4).

Table A12: Within-between decomposition, rescaled to BEA

	Average		Reference	
	Value	%	Value	%
Within	0.1187	85.7	0.1198	86.5
Between	0.0197	14.3	0.0187	13.5
Total	0.1385	100	0.1385	100

Notes: The table reports the results from the decomposition in equation (4). 'Average' uses the average age across all household member as the age of the household. 'Reference' uses the age of the reference person in the household.

Tables A13-A14 re-estimate the model parameters on the BEA-rescaled data, while Figure A18 reports the decomposition of the US structural change. The income effect plays a higher role compared to the baseline results, but none of the substantive conclusions change when using these data. Population aging still contributes about 5 log points to the change in the service share since 1982, same as in the baseline. This absolute contribution is smaller as a proportion of the total, since the aggregate service share rises by more in the BEA than the CES..

Table A13: Estimates of equation (8), rescaled to BEA

	(1)	(2)	(3)	(4)
	$\log \omega_t^{g,n}$	$\log \omega_t^{g,n}$	$\log \omega_t^{g,n}$	$\log \omega_t^{g,n}$
$\log e_t^n$	-0.143***	-0.143***	-0.234***	-0.236***
	(0.000732)	(0.000730)	(0.00199)	(0.00200)
Type	OLS	OLS	IV	IV
Time FE	Yes	No	Yes	No
Region-Time FE	No	Yes	No	Yes
Observations	1,325,614	1,319,821	1,226,650	1,221,020
R^2	0.198	0.202	0.168	0.171

Standard errors in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

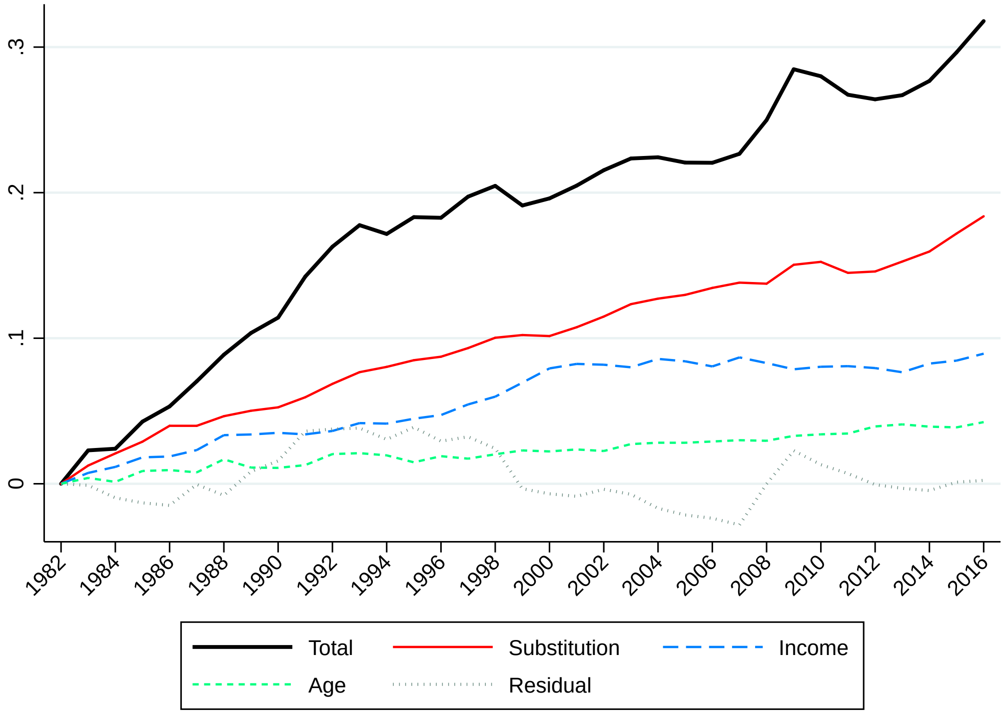
Table A14: Estimates of equation (9), rescaled to BEA

	(1)	(2)
	Ω_t^g	Ω_t^g
$b_1 = \gamma$	0.346***	0.360***
	(0.00799)	(0.00790)
Age variable	Average	Reference
Observations	35	35
R^2	0.982	0.984

Standard errors in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Figure A18: Accounting for structural change in the US, rescaled to BEA.



Notes: This figure displays the decomposition (10) for the US from 1982 to 2016, using data rescaled to BEA.

B.3 Derivation of equation (10)

We are interested in computing the elasticity of the expenditure share on goods with respect to the relative price of goods $\frac{P_t^g}{P_t^s}$. To compute this elasticity, solve for e_t^h to obtain the expenditure function associated with the utility level $\mathcal{V}^h$:

$$\begin{aligned}
\frac{1}{\epsilon}\left[\frac{e_t^h}{P_t^s}\right]^{\epsilon} &= \mathcal{V}^h + \frac{\nu_t^h}{\gamma}\left[\frac{P_t^g}{P_t^s}\right]^{\gamma} + \frac{1}{\epsilon} - \frac{\nu_t^h}{\gamma} \\
e_t^h &= P_t^s\left\{\epsilon\left[\mathcal{V}^h + \frac{\nu_t^h}{\gamma}\left(\frac{P_t^g}{P_t^s}\right)^{\gamma} + \frac{1}{\epsilon} - \frac{\nu_t^h}{\gamma}\right]\right\}^{\frac{1}{\epsilon}}.
\end{aligned}$$

By Roy's identity, the demand for goods is:

$$c_t^{g,h} = \frac{\nu_t^h\left[\frac{P_t^g}{P_t^s}\right]^{\gamma}\frac{1}{P_t^g}}{\left[\frac{e_t^h}{P_t^s}\right]^{\epsilon-1}\frac{1}{P_t^s}} = \frac{\nu_t^h\left[\frac{P_t^g}{P_t^s}\right]^{\gamma}\frac{e_t^h}{P_t^g}}{\left[\frac{e_t^h}{P_t^s}\right]^{\epsilon}},$$

and therefore the goods spending share is:

$$\omega_t^{g,h} = \frac{\nu_t^h\left(\frac{P_t^g}{P_t^s}\right)^{\gamma}}{\epsilon\left[\mathcal{V}^h + \frac{\nu_t^h}{\gamma}\left(\frac{P_t^g}{P_t^s}\right)^{\gamma} + \frac{1}{\epsilon} - \frac{\nu_t^h}{\gamma}\right]}.$$

The elasticity of this share with respect to $\frac{P_t^g}{P_t^s}$ is:

$$\gamma - \epsilon\omega_t^{g,h}.$$

Then at the household level, the substitution effect is defined as

$$\left(\gamma - \epsilon\omega_t^{g,h}\right)\left[\hat{P}_t^g - \hat{P}_t^s\right].$$

As Muellbauer (1975, 1976) shows, this economy admits a representative agent, defined as the household that exhibits the aggregate expenditure shares. In our framework, this is the household with income $e_t^{rep} \equiv e_t\left(\bar{\mu}_t\phi_t\nu_t\right)^{-\frac{1}{\epsilon}}$. This allows us to define the aggregate substitution effect as just the substitution effect of the representative consumer, or:

$$\left(\gamma - \epsilon\Omega_t^g\right)\left[\hat{P}_t^g - \hat{P}_t^s\right]. \tag{B.1}$$

The log change in the aggregate expenditure share (7) is:

$$\hat{\Omega}_t^s \approx -\frac{\Omega_{82}^g}{\Omega_{82}^s} \left\{ \epsilon \left[\hat{P}_t^s - \hat{e}_t \right] + \gamma \left[\hat{P}_t^g - \hat{P}_t^s \right] + \hat{\mu}_t + \hat{\phi}_t + \hat{\nu}_t \right\} . \tag{B.2}$$

The first two terms, $\epsilon \left[\hat{P}_t^s - \hat{e}_t \right] + \gamma \left[\hat{P}_t^g - \hat{P}_t^s \right]$ can be thought of as capturing the sum total of the income and substitution effects. They can be combined with (B.1) to isolate the two effects separately, leading to (10).