“Population Aging and Structural Transformation”

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Online Appendix

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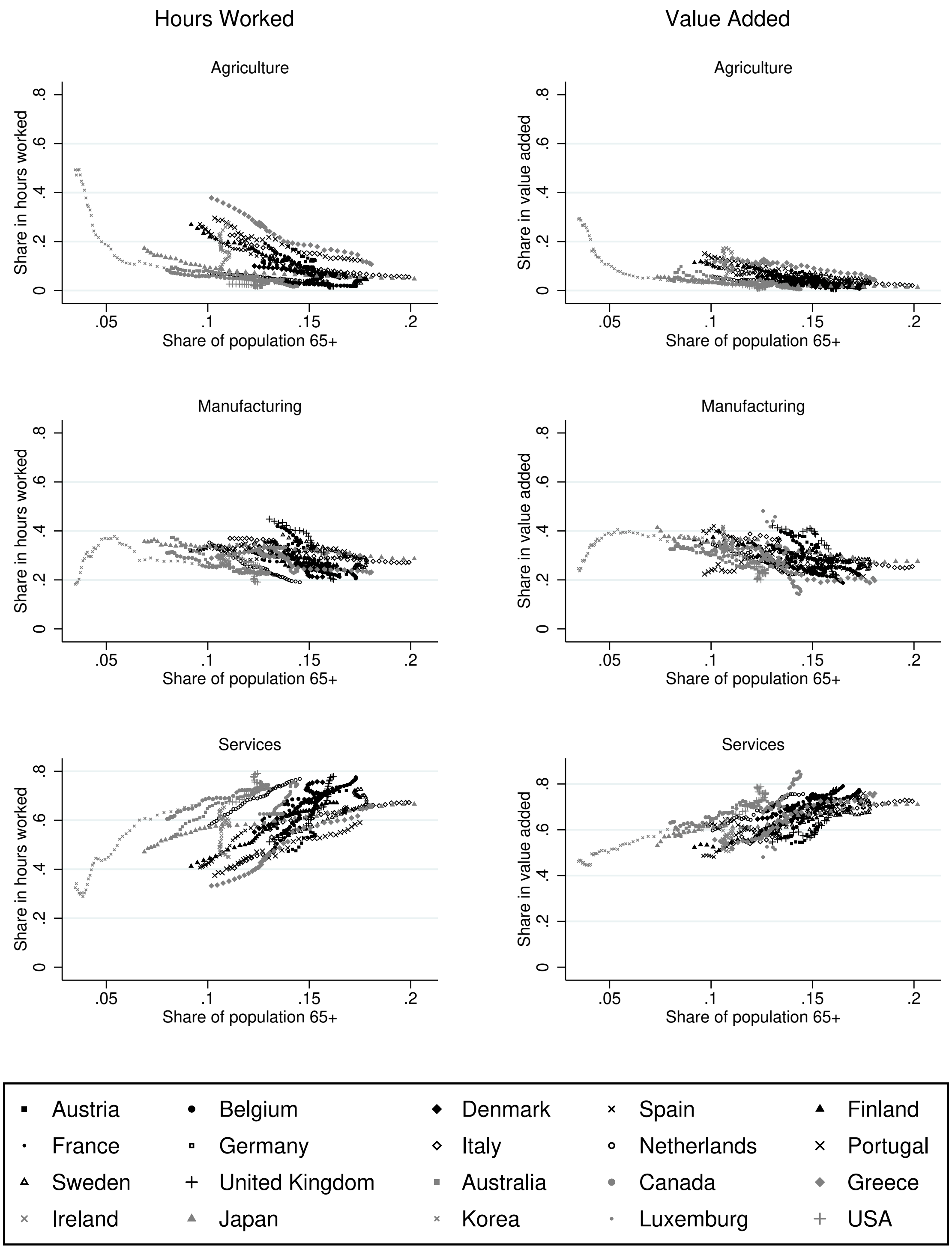
A Additional cross-country results

A.1 Unconditional patterns

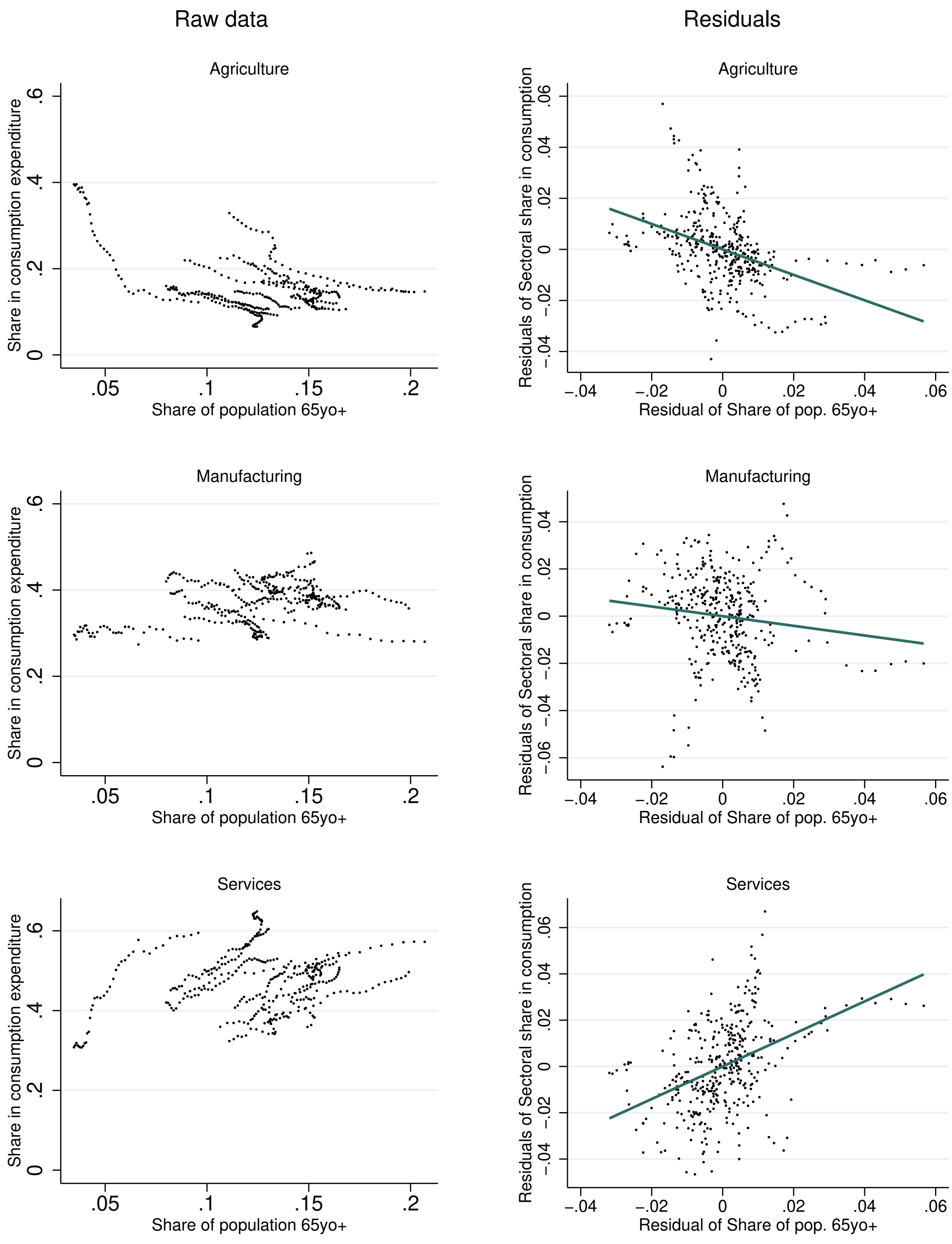
Figure A1 reports the unconditional sectoral shares of hours worked and the share of population over 65, for each country-year in EU KLEMS. The share of hours in Agriculture decreases as population ages, while the share of hours in Services increases. The employment share in Manufacturing is somewhat 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. The left panel in Figure A2 plots the unconditional sectoral consumption shares against the share of population over 65 for each country-year pair in our sample. These figures indicate that even in raw data, economic activity reallocates towards the service sector as the population ages.

Figure A1: 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.

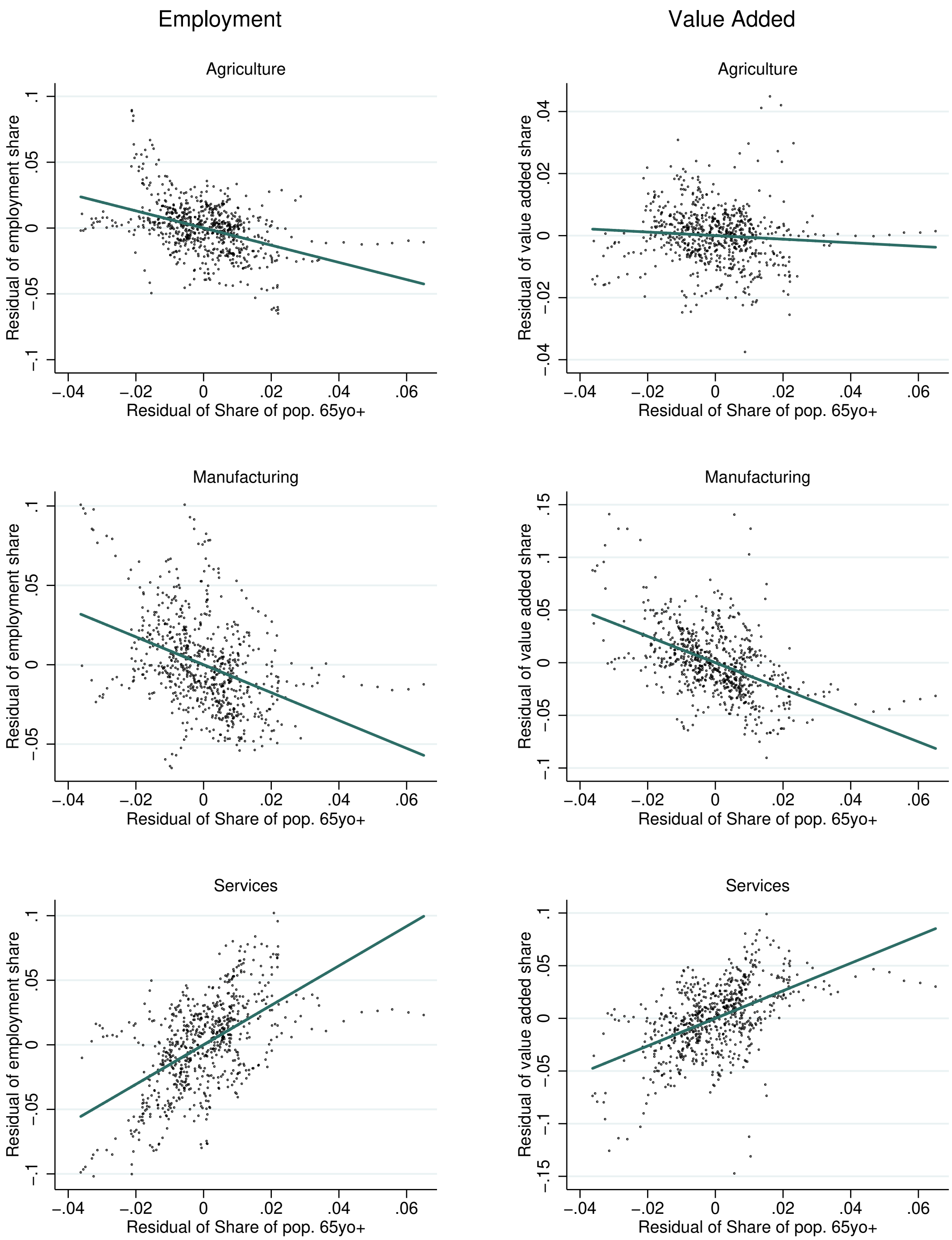
Figure A2: Sectoral consumption shares



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.

Controlling for income: The patterns that underlie Tables 1-2 can be visualized in Figure A3 and the right panel of Figure A2. The y-axis plots the residuals of the regressions of the employment and value added shares on the log of GDP per capita, log of GDP per capita squared 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. The figures show that consumption in Agriculture and Manufacturing products decline with population age, while the share of Service consumption increases with population age, after controlling for income and country effects.

Figure A3: Residualized sectoral shares of employment and value added

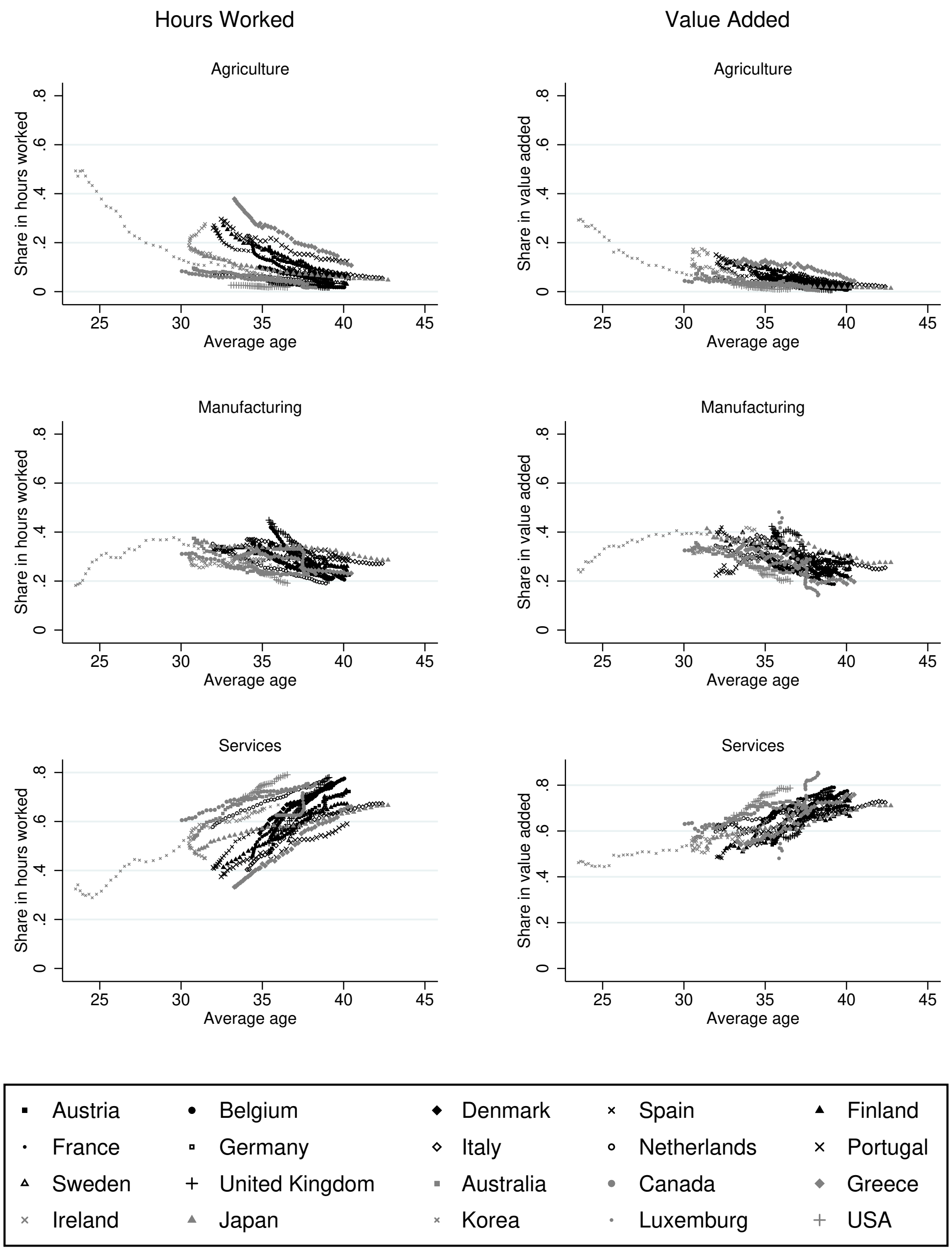


Notes: Each dot represents a country-year. The x-axis reports the residual of a regression of the share of the population that is 65 and over on GDP per capita, GDP per capita squared, and country fixed effects. The y-axis reports the residual of a regression of the sectoral share in hours worked (left panel) and the sectoral shares in value added (right panel) on GDP per capita, GDP per capita squared, and country fixed effects. Data sources are the same as in Figure A1.

A.2 Using average age

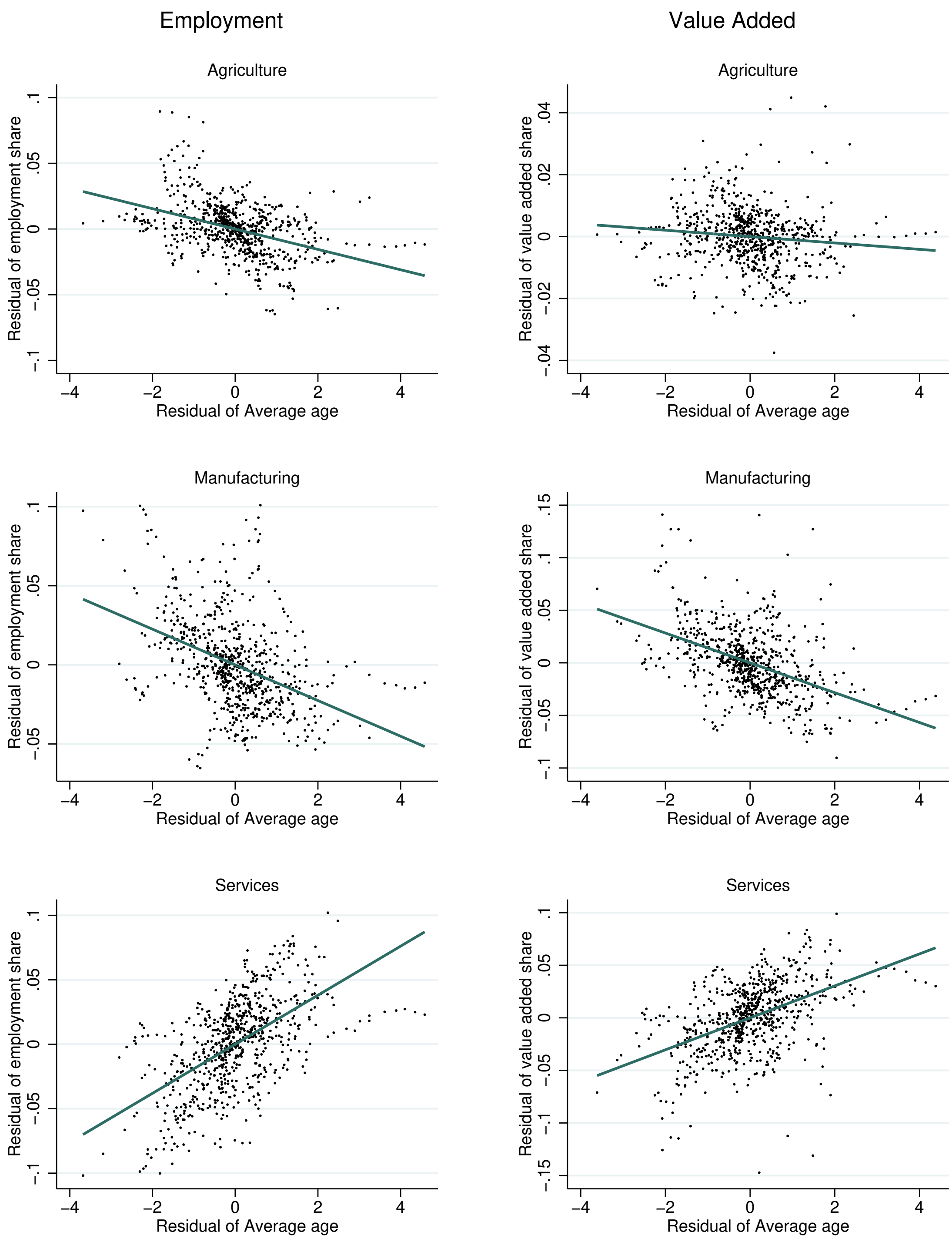
As an alternative measure of aging, we use the average age in the country, computed from the World Bank's "Population estimates and projection" database. This database divides a country's population into 5-year age brackets. To compute the average age, we multiply the midpoint of each bracket (e.g. 2 in the 0-4 years old bracket) times its population, then add across age groups, and finally divide this by the total population. Appendix Figures A4, A5, and A6 show that the patterns documented in the main text and in this Appendix persist if we use the average age in the population instead of the share of population over 65 as our age measure.

Figure A4: Sectoral shares of employment and value added



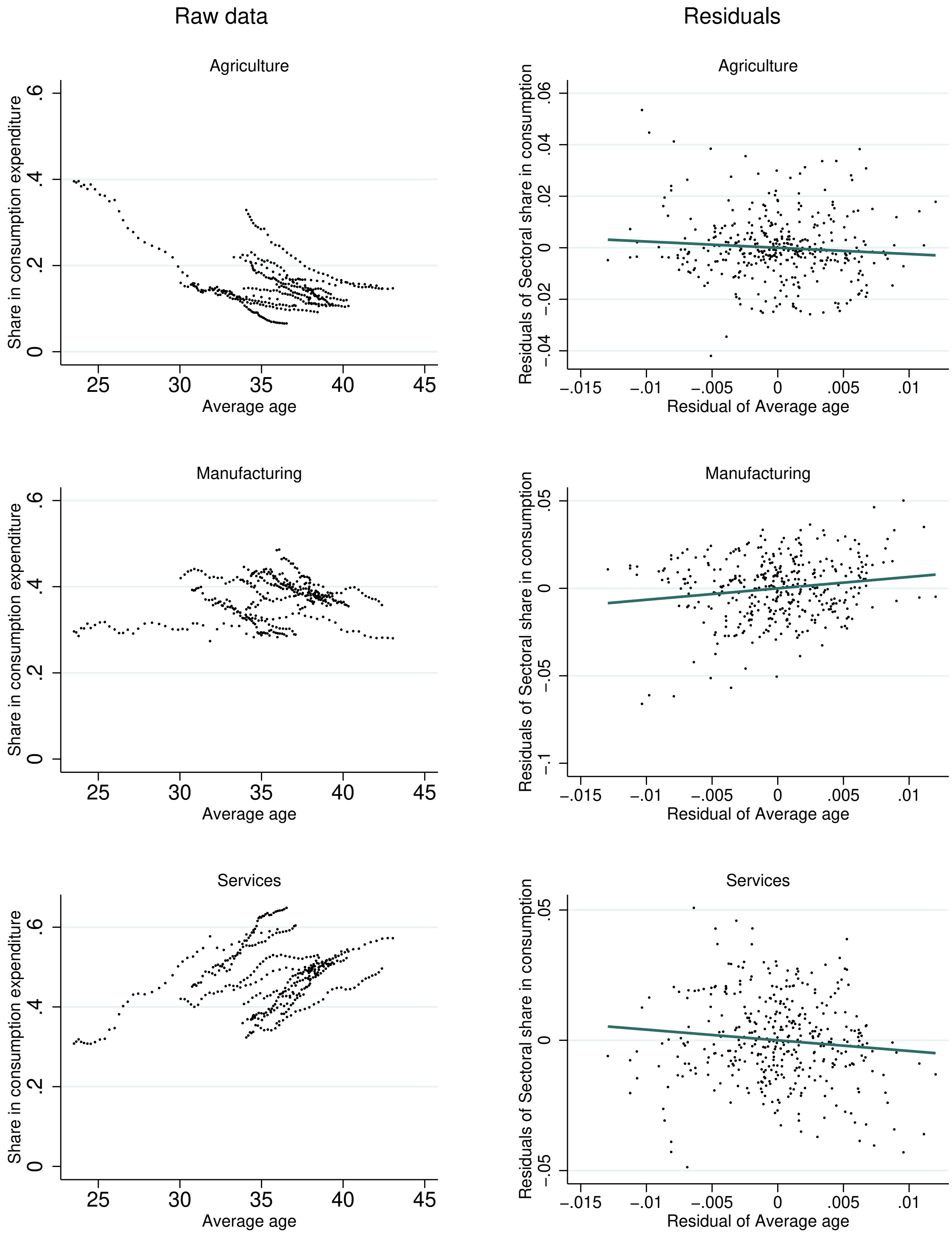
Notes: Each dot represents a country-year. The x-axis reports the average age in the population (source: WDI). The y-axis reports the sectoral share in hours worked (left panel) and the sectoral shares in value added (right panel) using data from EU KLEMS.

Figure A5: 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, GDP per capita squared, 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, GDP per capita squared, and country fixed-effects. Data sources are the same as in Figure A1.

Figure A6: 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.

A.3 Additional controls

Table A1 presents the main results for each of the three main outcome variables, controlling for (i) trade openness, (ii) investment/GDP ratio; (iii) government expenditures as a share of GDP, and (iv) the relative price of services. We take the controls (i)-(iii) from the World Development Indicators. The relative price of services was computed by aggregating sectorial price indexes from EU KLEMS. Sectors 15 to 37 in KLEMS were aggregated into Goods, and sectors G, H, 60 to 64, J, 70 to 74, L, M, N, O, P, Q were aggregated into Services. Following Herrendorf et al. (2013) and Bonadio et al. (2021), the indexes were aggregated using a cyclical expansion procedure. In particular, let Y_{it}, Q_{it}, and P_{it} denote the nominal output, the quantity index, and the price index for a sub-sector i at time t provided by KLEMS. Aggregate quantity indexes for Goods and for Services were computed as:

$$Q_t^j \equiv \sqrt{\frac{\sum_{i \in j} P_{it} Q_{it-1}}{\sum_{i \in j} Y_{it-1}} \frac{\sum_{i \in j} Y_{it}}{\sum_{i \in j} P_{it-1} Q_{it}}},$$

and the corresponding price indexes were computed as $P_t^j \equiv \sum_{i \in j} Y_{it} / Q_t^j$. We note that, since our regressions include country fixed effects, the price indexes are sufficient for the purposes of controlling for the within-country changes in the relative price of services over time. The coefficients on the age variable in these alternative specifications are similar to our baseline and statistically significant.

Table A1: Population aging and the services share in hours worked, value added and consumption

	Hours worked				Value added				Consumption			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
	$\omega_{i,t}^{Ser}$	$\omega_{i,t}^{Ser}$	$\omega_{i,t}^{Ser}$	$\omega_{i,t}^{Ser}$	$\omega_{i,t}^{Ser}$	$\omega_{i,t}^{Ser}$	$\omega_{i,t}^{Ser}$	$\omega_{i,t}^{Ser}$	$\omega_{i,t}^{Ser}$	$\omega_{i,t}^{Ser}$	$\omega_{i,t}^{Ser}$	$\omega_{i,t}^{Ser}$
Share of pop 65+	1.520***	0.828*	1.024*	1.547***	1.278***	0.791**	0.692**	1.385***	0.690***	0.239	0.511*	0.509**
	(0.479)	(0.434)	(0.511)	(0.501)	(0.348)	(0.364)	(0.294)	(0.380)	(0.204)	(0.169)	(0.230)	(0.206)
Log GDP p.c.	-0.023	0.247	-0.067	0.057	-0.890***	-0.638***	-0.901***	-0.555***	-0.200	-0.091	-0.328**	-0.297**
	(0.286)	(0.171)	(0.259)	(0.232)	(0.221)	(0.140)	(0.127)	(0.152)	(0.148)	(0.113)	(0.143)	(0.129)
(Log GDP p.c.)^2	0.010	-0.004	0.012	0.005	0.053***	0.040***	0.054***	0.031***	0.019*	0.014*	0.026**	0.022**
	(0.016)	(0.009)	(0.014)	(0.013)	(0.013)	(0.008)	(0.007)	(0.009)	(0.009)	(0.007)	(0.008)	(0.007)
Trade/GDP	-0.000				-0.000				0.000			
	(0.000)				(0.000)				(0.000)			
Investment/GDP		-0.006***				-0.005***				-0.005***		
		(0.001)				(0.001)				(0.001)		
Goverment/GDP			0.007**				0.009***				0.004*	
			(0.003)				(0.003)				(0.002)	
P_t^s / P_t^g				0.017				0.078***				0.074**
				(0.016)				(0.014)				(0.027)
Observations	707	707	707	707	707	707	707	707	377	377	377	369
R^2	0.924	0.953	0.934	0.924	0.874	0.902	0.901	0.893	0.949	0.964	0.952	0.959

Notes: This table reports the results of estimating equation (1) with additional controls. The outcome variables are hours worked, value added and consumption shares in services (*Ser*). Population age is proxied by the share of population 65 years or older. Additional controls Trade/GDP, Investment/GDP and Government/GDP come from WDI. Trade/GDP is the sum of imports and exports as a share of GPD. Control variable P_t^s / P_t^g is the ratio of the price of services to manufacturing goods in EU-KLEMS. All specifications include country fixed effects. Standard errors clustered at the country level in parentheses. *: significant at 10%; **: significant at 5%; ***: significant at 1%.

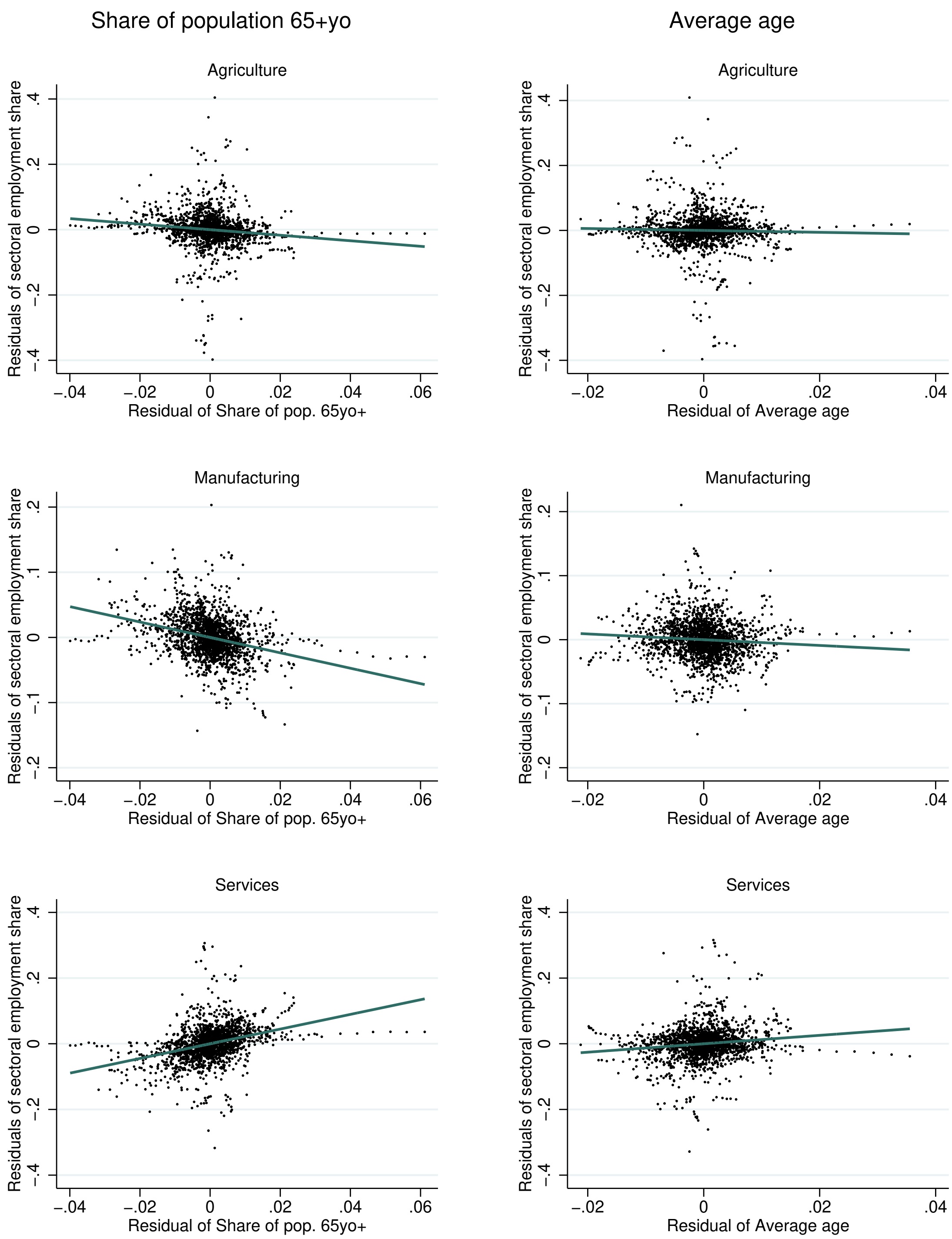
A.4 Evidence from the WDI and the UN Statistics Division

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 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 WDI yields an unbalanced sample of 157 countries covering 1980-2007, while the UN data cover 188 countries over 1970-2007.

We replicate the fact reported in Section 2.1 using these alternative data. Table A2 and Figure A7 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 A8 and Table A3 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 A7: Residualized sectoral employment shares: WDI data



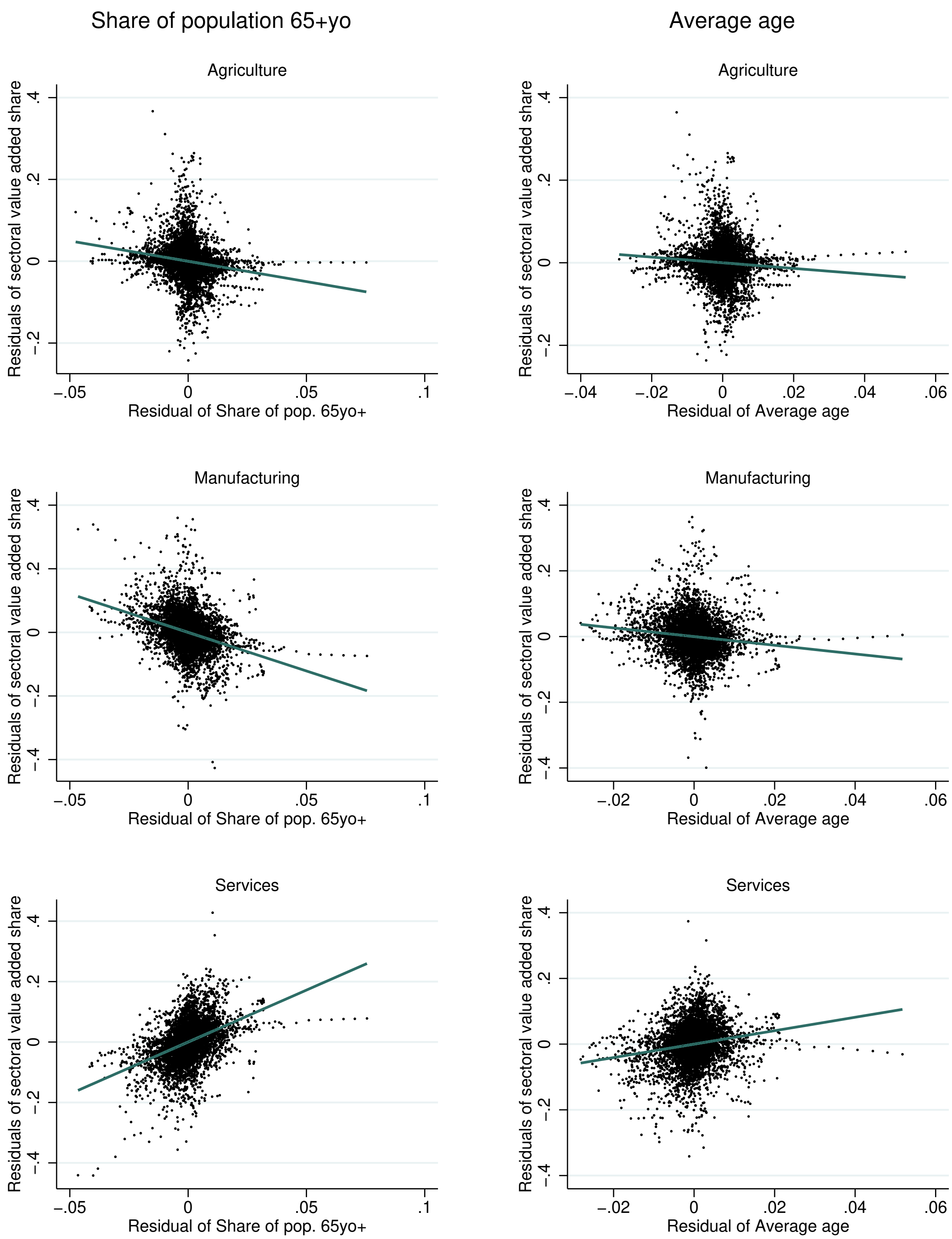
Notes: Each dot represents a country-year. The x-axis reports the residual of a regression of the share of the population that is 65 and over (left panel) or the average age of the population (right panel) on GDP per capita, GDP per capita squared, and country fixed effects. The y-axis reports the residual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

Table A2: Population aging and the services share in employment: WDI data

	(1)	(2)	(3)	(4)	(5)	(6)
	$\omega_{i,t}^{Agr}$	$\omega_{i,t}^{Agr}$	$\omega_{i,t}^{Man}$	$\omega_{i,t}^{Man}$	$\omega_{i,t}^{Ser}$	$\omega_{i,t}^{Ser}$
Average age	-0.0136***	-0.00807**	-0.0103***	-0.0110***	0.0249***	0.0189***
	(0.00232)	(0.00348)	(0.00239)	(0.00280)	(0.00240)	(0.00367)
Log GDP per capita		-0.404**		0.771***		-0.304**
		(0.155)		(0.167)		(0.153)
(Log GDP per capita)^2		0.0189**		-0.0416***		0.0194**
		(0.00830)		(0.00932)		(0.00843)
Observations	2206	2029	2214	2037	2214	2037
R^2	0.921	0.919	0.805	0.854	0.904	0.898

Notes: This table reports the results of estimating equation (1). The outcome variables are employment shares in agriculture (*Agr*), manufacturing (*Man*) and services (*Ser*). Population age is proxied by the average age. All specifications include country fixed effects. Standard errors clustered at the country level in parentheses. *: significant at 10%; **: significant at 5%; ***: significant at 1%.

Figure A8: 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 A3: Population aging and the services share in value-added: UN data

	(1) $\omega_{i,t}^{Agr}$	(2) $\omega_{i,t}^{Agr}$	(3) $\omega_{i,t}^{Man}$	(4) $\omega_{i,t}^{Man}$	(5) $\omega_{i,t}^{Ser}$	(6) $\omega_{i,t}^{Ser}$
Average age	-0.0117***	-0.00570***	-0.00648***	-0.0153***	0.0180***	0.0210***
	(0.00136)	(0.00143)	(0.00166)	(0.00267)	(0.00163)	(0.00282)
Log GDP pc		-0.380***		0.276***		0.113
		(0.0642)		(0.0783)		(0.0910)
(Log GDP pc)^2		0.0181***		-0.0105**		-0.00822
		(0.00360)		(0.00514)		(0.00563)
Observations	6509	6156	6547	6194	6547	6194
R^2	0.880	0.908	0.778	0.822	0.829	0.826

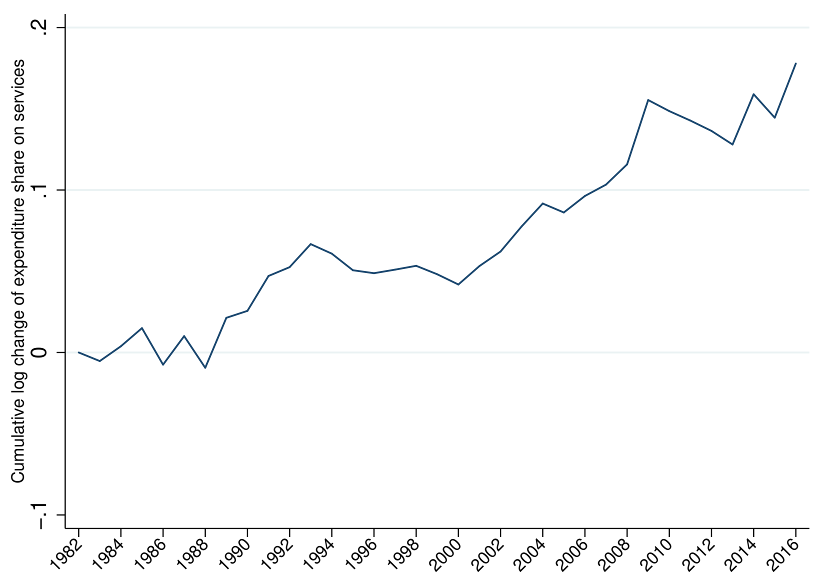
Notes: This table reports the results of estimating equation (1). The outcome variables are value added shares in agriculture (*Agr*), manufacturing (*Man*) and services (*Ser*). Population age is proxied by the average age. All specifications include country fixed effects. Standard errors clustered at the country level in parentheses. *: significant at 10%; **: significant at 5%; ***: significant at 1%.

B Additional results, household-level data and model

B.1 Additional tables and figures, CES

Figure A9 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 0.18 log points over this period. Appendix Table A4 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.

Figure A9: Service consumption in the CES



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

Table A4: Expenditure shares on goods and services

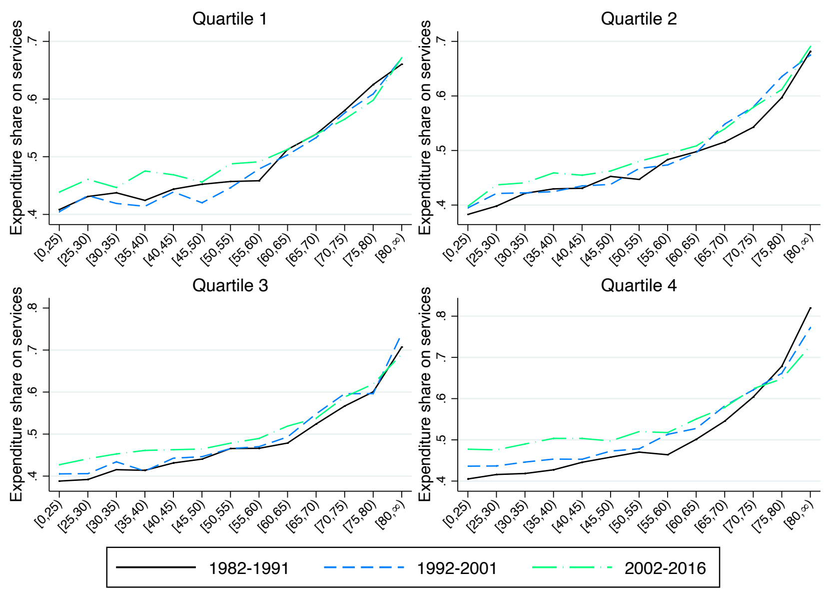
	Baseline			Baseline w/ housing			All expenditure in CES		
	82-91	92-01	02-16	82-91	92-01	02-16	82-91	92-01	02-16
Goods	*51.0*	*49.8*	*47.7*	*40.5*	*38.1*	*35.4*	*37.0*	*34.6*	*31.6*
Food at home	15.6	15.1	14.7	12.4	11.5	10.9	11.4	10.6	9.8
Vehicle purchasing, leasing	12.0	13.6	12.0	9.6	10.4	8.9	8.7	9.4	7.9
Gas	5.4	4.3	6.3	4.3	3.2	4.7	3.9	2.9	4.2
Entertainment equipment	4.1	4.7	5.3	3.2	3.6	3.9	2.9	3.3	3.5
Appliances	2.7	2.8	2.3	2.1	2.2	1.7	2.0	2.0	1.5
Men's and women's clothing	3.9	3.1	1.9	3.1	2.4	1.4	2.8	2.2	1.3
Furnitures and Fixtures	2.4	2.0	1.7	1.9	1.5	1.3	1.8	1.4	1.1
Alcoholic beverages	1.5	1.2	1.2	1.2	0.9	0.9	1.1	0.8	0.8
Shoes and other apparel	1.5	1.2	0.9	1.2	0.9	0.7	1.1	0.9	0.6
Tobacco	1.3	1.1	1.0	1.0	0.8	0.7	0.9	0.7	0.6
Children's clothing	0.6	0.6	0.4	0.5	0.5	0.3	0.4	0.4	0.3
Personal care goods	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Services	*49.0*	*50.2*	*52.3*	*59.5*	*61.9*	*64.6*	*63.0*	*65.4*	*68.4*
Health	9.1	10.1	12.1	7.2	7.7	9.0	6.8	7.2	8.2
Utilities	11.0	10.7	11.6	8.8	8.2	8.6	8.1	7.5	7.8
Cash contributions	4.9	5.1	5.7	3.9	3.9	4.3	3.7	3.7	3.9
Car maint, repairs	5.4	5.9	5.2	4.3	4.5	3.9	3.9	4.1	3.5
Food away from home	6.4	5.9	5.0	5.1	4.5	3.7	4.6	4.1	3.3
Domestic services	4.2	4.1	4.2	3.3	3.2	3.1	3.1	2.9	2.8
Education	1.4	1.7	2.7	1.1	1.3	2.0	1.0	1.2	1.8
Entertainment fees, adm., read.	2.9	3.0	2.5	2.3	2.3	1.8	2.1	2.1	1.6
Public transport	1.9	2.0	1.8	1.5	1.5	1.3	1.4	1.4	1.2
Personal care services	1.4	1.3	1.0	1.1	1.0	0.8	1.0	0.9	0.7
Childcare	0.3	0.4	0.5	0.3	0.3	0.4	0.2	0.3	0.3
Housing	.	.	.	20.6	23.5	25.7	18.9	21.5	23.0
Personal insurance	.	.	.	.	.	.	1.4	1.3	0.8
Pensions	.	.	.	.	.	.	6.7	7.3	9.4

Notes: This table reports the aggregate expenditure shares on broad categories of goods and services, in the three decades separately, in the baseline using the CES, including housing and using the entire Interview dataset in the CES.

Figure A10 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.

Structural change within the service sector The rise in service expenditures has been concentrated in categories that are disproportionally consumed by older households. Figure A11 divides service categories into two groups: one for the categories that are disproportionally consumed by the old (Health, Utilities, and Domestic Services), and one for the remaining categories. The figure shows a dramatic increase in the aggregate expenditure share for Health, Utilities, and Domestic Services, 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 A20 shows that a similar pattern emerges in the Personal Consumption Expenditure data from the

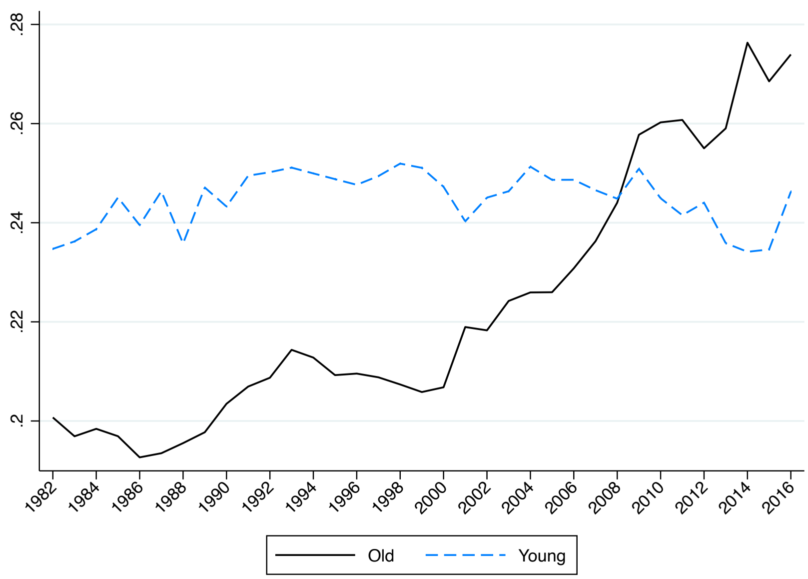
Figure A10: Service consumption by average age of household members and income



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.

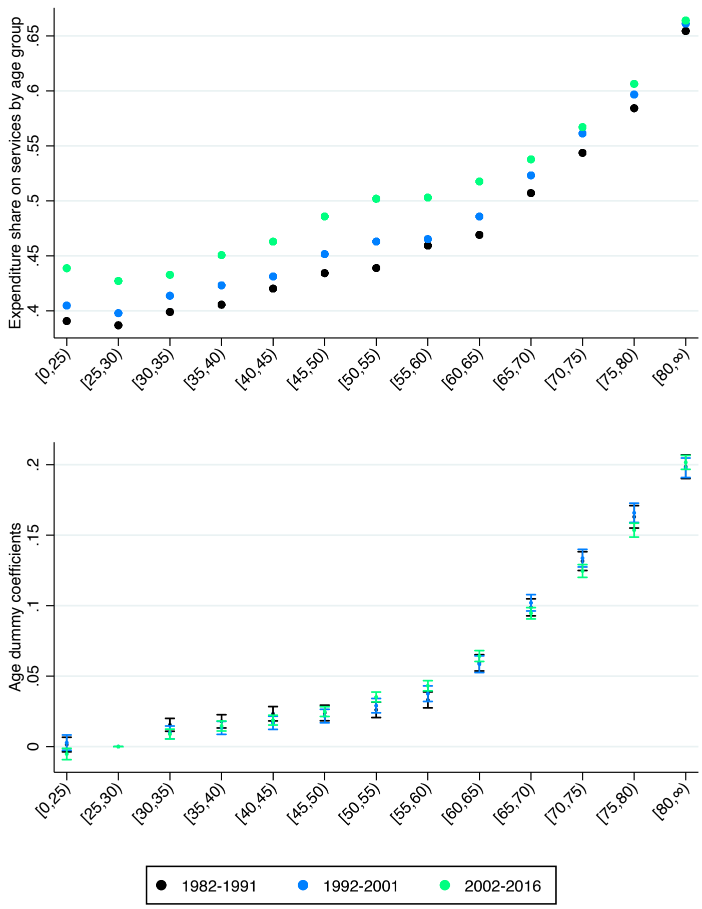
BEA: the increase in service consumption is concentrated among those categories that are disproportionally consumed by the old.

Figure A11: Evolution of expenditure shares on service categories in the CES



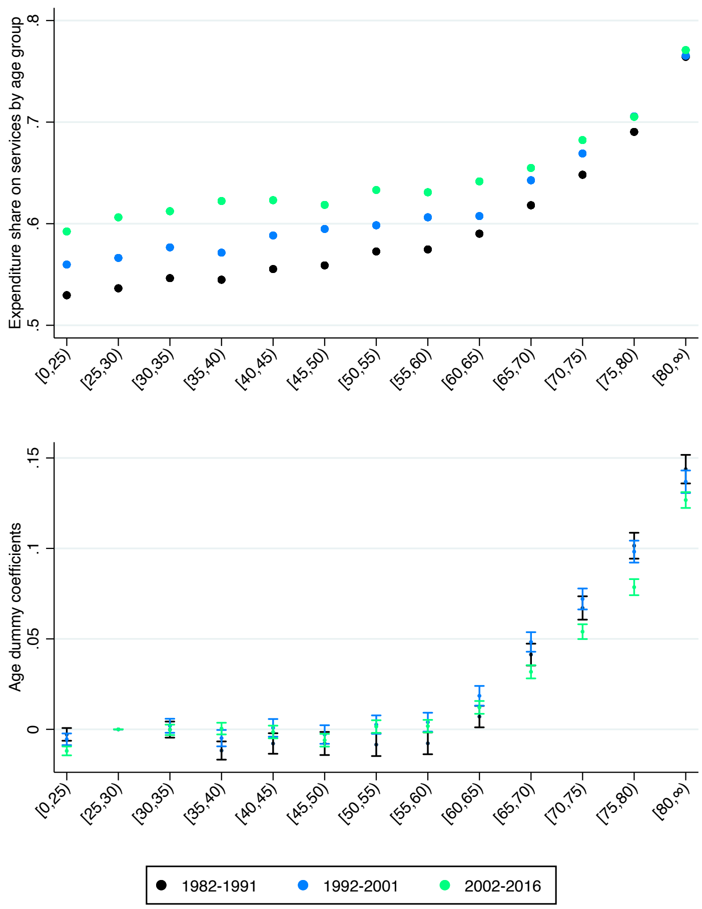
Notes: 'Old' displays the aggregate expenditure share in the CES on categories that are disproportionally consumed by the old: Health, Utilities, and Domestic Services (excluding Childcare). 'Young' displays the expenditure share on the remaining service categories.

Figure A12: Service consumption by age of the reference person



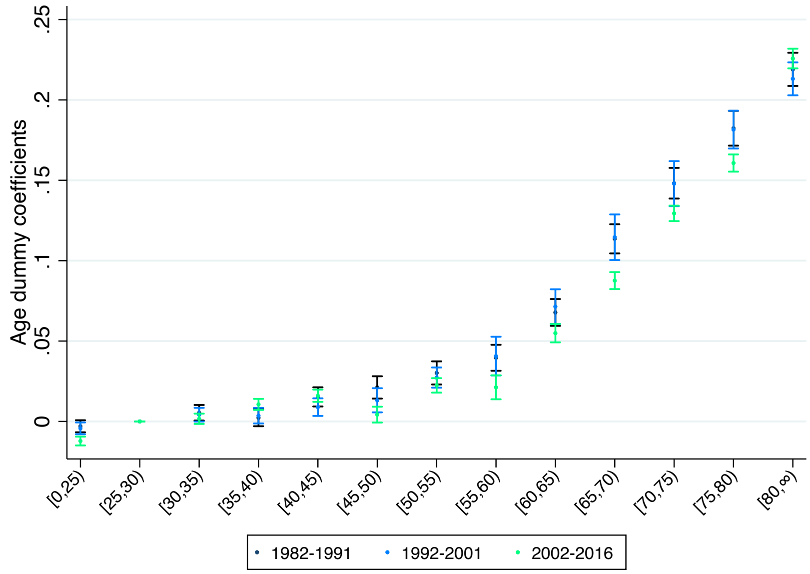
Notes: The top panel displays the average household-level expenditure shares on services in the CES by age group according to the age of the reference person (x-axis), for 3 time periods. The bottom panel displays the age dummies resulting from estimating equation (2). Each dot represents the point estimate of the age dummies 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 A13: Service consumption with housing by average age of household members



Notes: The top panel displays the average household-level expenditure shares on services in the CES by age group (x-axis), for 3 time periods. The bottom panel displays the age dummies resulting from estimating equation (2). Each dot represents the point estimate of the age dummies 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. Housing is included in expenditures.

Figure A14: Age dummies (controlling for income decile), including age-specific price indices



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 includes age-specific price indices as controls. 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 A5: Population aging and changes in the services share, including housing

Panel A: Expenditure shares across the age distribution

	Pop $_{1982}$	s^a_{1982}	$\omega^{s,a}_{1982}$	Pop $_{2016}$	s^a_{2016}	$\omega^{s,a}_{2016}$
0-25	31.8	31.6	51.8	20.4	20.0	61.2
25-30	13.5	16.1	52.1	11.4	12.0	61.9
30-35	9.4	11.3	54.3	9.4	10.8	63.4
35-40	6.2	7.5	53.9	7.1	7.9	62.7
40-45	4.6	5.3	55.2	5.9	6.5	65.5
45-50	3.6	3.9	55.6	5.2	5.5	63.7
50-55	3.8	3.9	56.0	6.1	6.1	63.7
55-60	5.1	4.8	57.2	6.7	6.8	63.6
60-65	5.7	5.2	60.1	7.5	7.5	67.7
65-70	5.9	4.5	62.1	6.8	6.2	67.4
70-75	4.3	2.8	66.9	5.1	4.4	67.4
75-80	3.3	1.8	68.0	3.4	2.7	70.2
80+	2.9	1.3	76.5	5.0	3.5	78.6

Panel B: Within-between decomposition

	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: In Panel A, 'Pop' reports the share of the population in each age group, and s^a_t and ω^a_t are defined as in Equation (4). Panel B 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. Housing is included in expenditures.

Table A6: 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 Additional tables and figures for Section 3.2

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

	(1)	(2)	(3)	(4)
Dep. var.: $\ln \omega_t^{g,n}$				
$\ln e_t^n$	-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

Notes: This table reports the results of estimating equation (8). The outcome variable is household expenditure share on goods. Standard errors clustered at the household level in parentheses. *: significant at 10%; **: significant at 5%; ***: significant at 1%.

Table A8: Estimates of equation (8) with housing

	(1)	(2)	(3)	(4)
Dep. var.: $\ln \omega_t^{g,n}$				
$\ln e_t^n$	-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

Notes: This table reports the results of estimating equation (8). The outcome variable is household expenditure share on goods including housing. Standard errors clustered at the household level in parentheses. *: significant at 10%; **: significant at 5%; ***: significant at 1%. Housing is included in expenditures.

Figure A15: 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 A16: 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.

B.3 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.[11] 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.

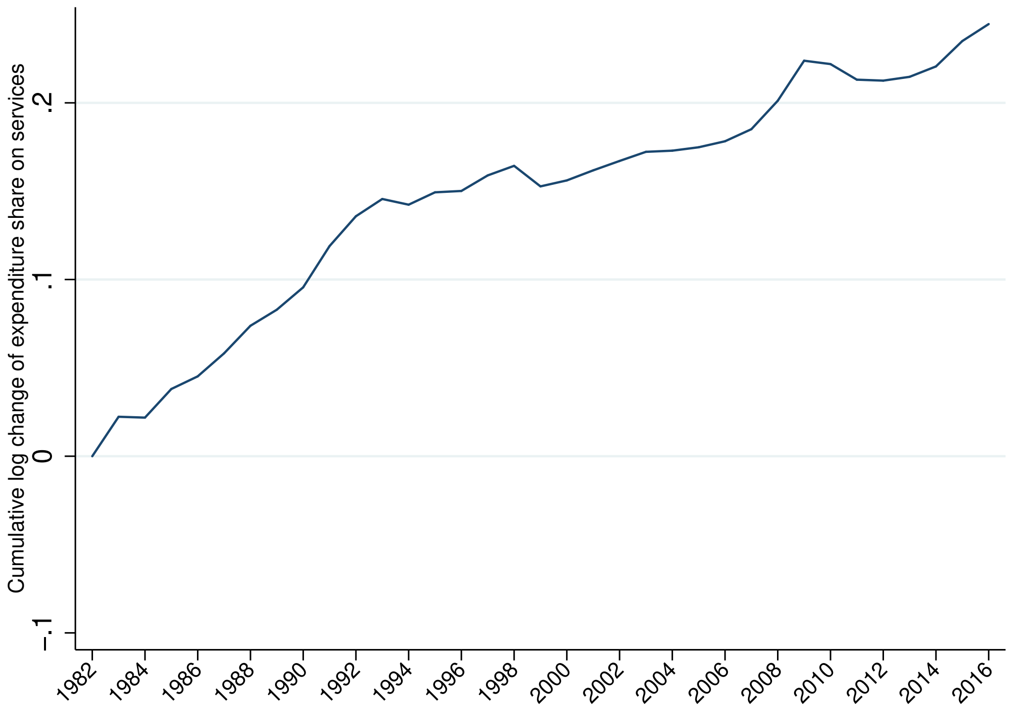
Using the rescaled expenditures, we compute the expenditure shares $\omega_t^{j,h} \equiv e_t^{j,h} / \sum_j e_t^{j,h}$, and the total expenditures by household: $e_t^h \equiv \sum_j e_t^{j,h}$. From this, we compute the new e_t^h / e_t. These steps give us all the elements of a new dataset, on which we repeat the household-level estimation in Section 2.2 and the quantitative analysis of Section 3. This approach relies on the assumption that the micro variation across households in the CES is an accurate reflection of the differences in spending patterns by age group. In the main text, we argued based on evidence from another survey that this is likely to be the case with healthcare, where the ratio to out-of-pocket to total expenditure is stable across age groups. Unfortunately, similar data on other categories of public expenditures by age group are not readily available. A particularly concerning category is education, which is a service consumed disproportionally by the young where public expenditures are large. We construct a lower bound for the effect of aging on the service share of consumption by adopting the extreme assumption that all of the public education expenditure goes to the younger (below 65) households.[12] The age profile of service consumption is quite similar to the baseline reported below.

Replication of main results using rescaled data Figure A17 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 0.24 log points. Figure A18 shows the service expenditure shares for households of different ages, and the three time periods. It also displays the age dummies controlling for income, as in equation (2). The magnitudes of the differences across households are similar to the baseline analysis. Figure A19 breaks down by income quartile. The results are quite similar to the baseline.

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

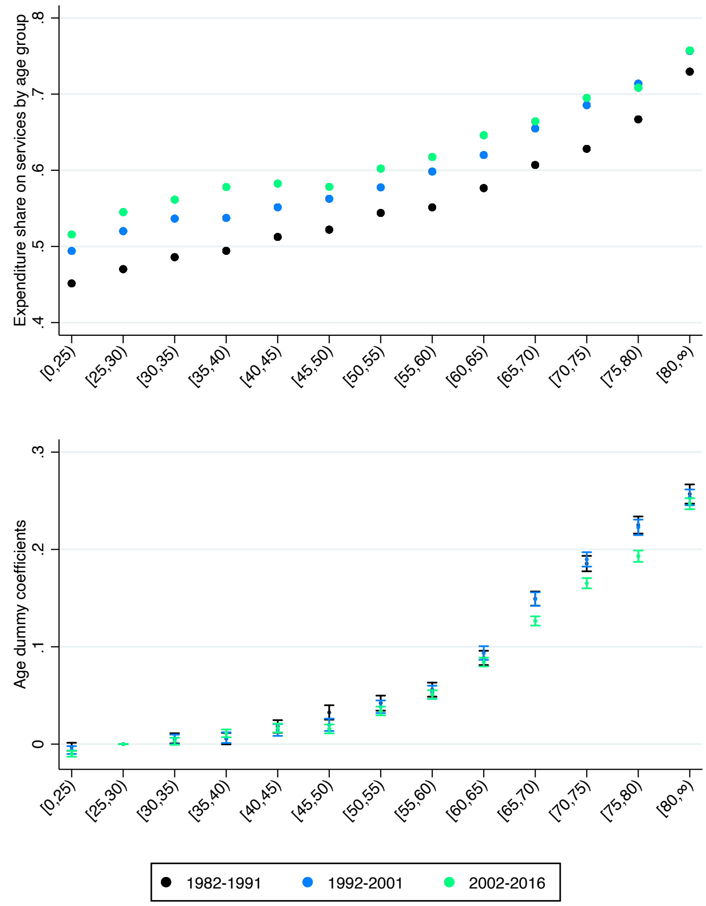
[12] That is, we rescale the CES data to match the BEA aggregates, assuming that the over-65s receive zero public education expenditure. This gives us an lower bound on the impact of aging on the service share, since education is a service and we are in effect increasing the service expenditure share of the young by more than the old.

Figure A17: Service consumption share, BEA



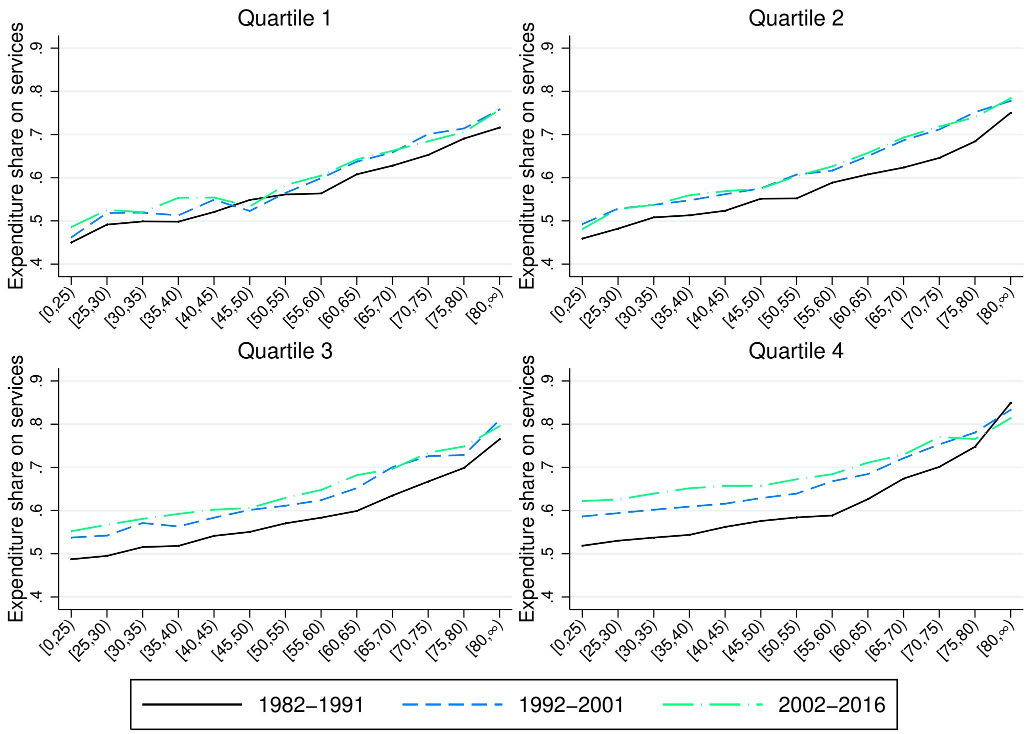
Notes: This figure displays the cumulative log change in the aggregate expenditure share on services in the BEA. Housing is excluded from expenditures.

Figure A18: Service consumption by average age of household members, rescaled to BEA



Notes:The top panel displays the average household-level expenditure shares on services in the CES, rescaled to BEA, by age group (x-axis), for 3 time periods. The bottom panel displays the age dummies resulting from estimating equation (2). Each dot represents the point estimate of the age dummies 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 A19: Service consumption by average age of household members and income, rescaled to BEA

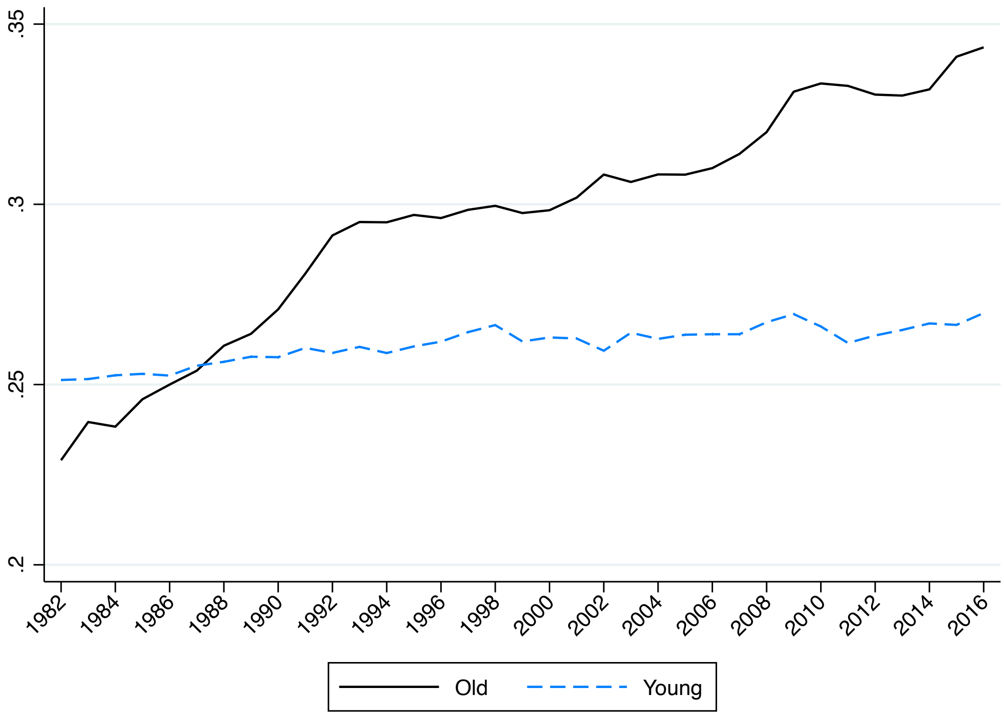


Notes: This figure displays the average household-level expenditure shares on services in the rescaled CES by age group (x-axis), for 3 time periods, and each income quartile.

Table A9 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, Table A10 reports 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 A20: 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 Domestic Services and Childcare. 'Young' displays the expenditure share on the remaining service categories.

Table A9: 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	9.65	13.70	17.53	21.63	25.75
Cash contributions	2.31	3.04	3.79	4.34	6.27
Domestic services	0.11	0.30	0.50	0.99	3.18
Utilities	-0.02	-0.04	0.12	0.31	0.45
Personal care services	-0.01	0.03	0.09	0.11	0.14
Personal care goods	-0.02	-0.01	-0.02	-0.02	-0.02
Public transport	0.07	0.05	-0.03	-0.07	-0.38
Tobacco	-0.11	-0.34	-0.56	-0.78	-0.97
Shoes and other apparel	-0.52	-0.63	-0.75	-0.95	-1.01
Children's clothing	-0.84	-0.86	-0.96	-1.01	-1.09
Alcoholic beverages	-0.55	-0.71	-0.91	-1.13	-1.34
Car maintenance, repairs	-0.53	-0.70	-0.83	-0.88	-1.45
Furnitures and Fixtures	-0.47	-0.64	-1.01	-1.24	-1.65
Personal Insurance	3.36	1.97	0.89	-0.90	-1.67
Appliances	-0.22	-0.62	-0.96	-1.24	-1.91
Men's and women's cloth.	-0.66	-0.94	-1.12	-1.50	-2.03
Entertainment fees, ...	-0.70	-0.90	-1.17	-1.63	-2.26
Entertainment equipment	-0.60	-1.05	-1.72	-2.01	-2.40
Education	-2.31	-2.48	-2.52	-2.45	-2.59
Food at home	-2.92	-2.88	-2.53	-2.18	-2.73
Gas	-1.05	-1.37	-1.70	-2.06	-2.82
Food away from home	-1.71	-2.10	-2.70	-3.30	-4.16
Vehicle purchasing, leasing	-2.26	-2.81	-3.42	-4.06	-5.30
Services	10.22	12.87	15.67	18.16	23.28

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 A10: Population aging and the services share, rescaled to BEA

Panel A: Expenditure shares across the age distribution

	Pop 1982	s^a_{1982}	$\omega^{s,a}_{1982}$	Pop 2016	s^a_{2016}	$\omega^{s,a}_{2016}$
0-25	31.8	30.3	42.3	20.4	18.5	54.4
25-30	13.5	15.6	44.7	11.4	11.5	56.7
30-35	9.4	11.1	46.4	9.4	10.5	59.2
35-40	6.2	7.5	48.0	7.1	7.7	58.7
40-45	4.6	5.4	49.7	5.9	6.6	62.4
45-50	3.6	4.0	52.2	5.2	5.6	61.3
50-55	3.8	4.0	49.9	6.1	6.0	60.8
55-60	5.1	5.1	52.2	6.7	7.2	64.2
60-65	5.7	5.6	55.3	7.5	8.1	67.0
65-70	5.9	4.9	58.5	6.8	6.9	67.2
70-75	4.3	3.1	61.8	5.1	5.0	68.9
75-80	3.3	1.9	61.8	3.4	2.9	69.6
80+	2.9	1.4	69.3	5.0	3.6	75.4

Panel B: Within-between decomposition

	Average		Reference	
	Value	%	Value	%
Within	0.1181	88.8	0.1036	77.8
Between	0.0150	11.2	0.0295	22.2
Total	0.1331	100.0	0.1331	100.0

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

Tables A11-A12 re-estimate the model parameters on the BEA-rescaled data, while Figure A21 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 0.05 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 A11: Estimates of equation (8), rescaled to BEA

	(1)	(2)	(3)	(4)
Dep. var.: $\ln \omega_t^{g,n}$				
$\log e_t^n$	-0.138***	-0.138***	-0.225***	-0.226***
	(0.000722)	(0.000720)	(0.00194)	(0.00195)
Type	OLS	OLS	IV	IV
Time FE	Yes	No	Yes	No
Region-Time FE	No	Yes	No	Yes
Observations	1,325,402	1,319,609	1,226,453	1,220,823
R^2	0.198	0.202	0.170	0.173

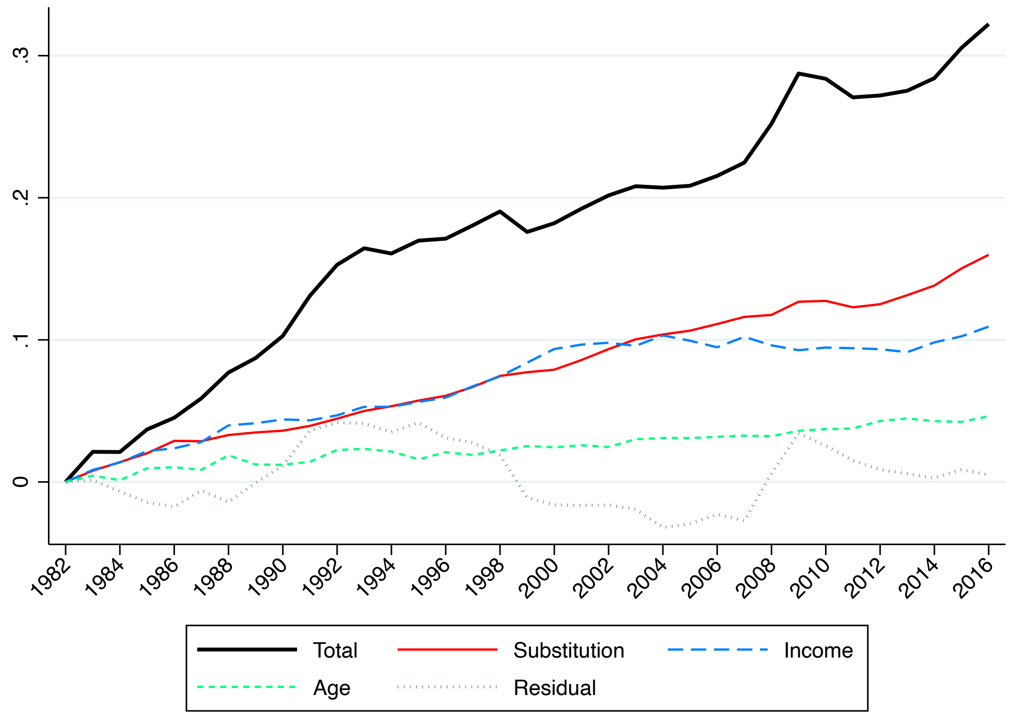
Notes: This table reports the results of estimating equation (8). The outcome variable is household expenditure share on goods. Standard errors clustered at the household level in parentheses. *: significant at 10%; **: significant at 5%; ***: significant at 1%.

Table A12: Estimates of equation (9), rescaled to BEA

	(1)	(2)
Dep. var.: $\ln \Omega_t^g$		
$b_1 = \gamma$	0.296***	0.309***
	(0.00933)	(0.00925)
Age variable	Average	Reference
Observations	35	35
R^2	0.967	0.970

Notes: This table reports the results of estimating equation (9). The outcome variable is aggregate expenditure share on goods. Standard errors in parentheses. *: significant at 10%; **: significant at 5%; ***: significant at 1%.

Figure A21: 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.4 Changes in relative number of households vs. relative income

The results in Section 3 arise from changes in the share of each age group in total expenditures across time. The share of age group a in aggregate expenditures can be written as:

$$s_t^a \equiv \frac{\sum_j e_t^{j,a}}{\sum_a \sum_j e_t^{j,a}} \;=\; n_t^a \times \tilde{e}_t^a,$$

where $n_t^a \equiv N_t^a / \sum_a N_t^a$ is the share of households that are in age group a, and $\tilde{e}_t^a \equiv \frac{\sum_j e_t^{j,a} / N_t^a}{\sum_a \sum_j e_t^{j,a} / \sum_a N_t^a}$ are the expenditures per household of age group a relative to expenditures per household in the economy. This appendix explores how large is the contribution of aging to structural change if we instead focus solely on the shares of households component of changing expenditure shares, n_t^a.

B.4.1 Within-between decomposition

To focus on the role of changes in the share of households that are in age group a, we perform a within-between decomposition on the *average* service expenditure share across household age groups, rather than on the *aggregate* service expenditure share in the economy. The average expenditure share in services across age groups is defined as

$$\omega_t^s \;\equiv\; \sum_a n_t^a \omega_t^{s,a},$$

and can be decomposed into

$$\Delta\omega^s = \underbrace{\sum_a \Delta\omega^{s,a} \cdot \overline{n}^a}_{\text{Within}} + \underbrace{\sum_a \overline{\omega}^{s,a} \cdot \Delta n^a}_{\text{Between}}, \tag{B.1}$$

where ω^s is the cross-age group average share of services expenditure. The average ω_t^s and aggregate Ω_t^s shares are very similar, and thus experienced very similar changes over this period (ω^s went from 0.447 in 1982 to 0.524 in 2016, whereas Ω^s went from 0.435 to 0.520). So the decomposition of the average (B.1) should still be informative, while at the same time focusing purely on the population changes Δn^a rather than expenditure share changes Δs^a. Table A13 below presents the results of the decomposition (B.1). The results are quite similar to the baseline. The contribution of the Between effect is still about 20% of the total.

Table A13: Within-between decomposition

	Average		Reference	
	Value	%	Value	%
Within	0.0636	81.8	0.0660	83.7
Between	0.0141	18.2	0.0128	16.3
Total	0.0777	100	0.0789	100

Notes: The table reports the results from the decomposition in equation (B.1). '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.

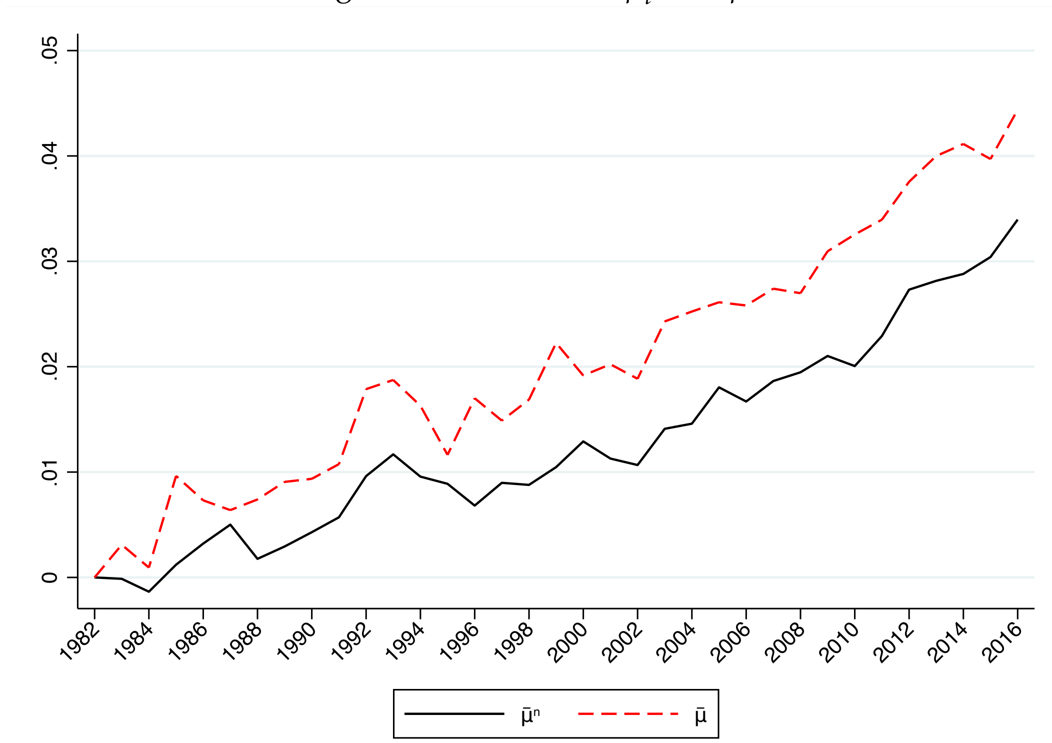
B.4.2 Structural model

To focus purely on changes in household numbers by age group, we implement an alternative version of equation (7):

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

with $\bar{\mu}_t^n \equiv \sum_a n_t^a \mu^a$ and $\phi_t^n \equiv \frac{1}{N_t} \sum_h^{N_t} \frac{\mu^a}{\bar{\mu}_t^n} \left[\frac{e_t^h}{e_t}\right]^{1-\epsilon}$. Note that this alternative simply redefines the aggregate aging term $\bar{\mu}_t$ to sum over number of households shares n_t^a instead of expenditure shares s_t^a. While this affects the inequality term ϕ_t, it leaves the rest of the decomposition unchanged, and thus the Income and Substitution terms in (10) are the same as in the Baseline. Figure A22 plots the original Aging component of (10), $\hat{\bar{\mu}}_t$, alongside the alternative $\hat{\bar{\mu}}_t^n$. The two are quantitatively similar, though the latter has a somewhat smaller contribution.

Figure A22: Measures $\bar{\mu}_t^n$ and $\bar{\mu}_t$



Notes: This figure displays the changes across time of two different aging measures from the structural model. $\bar{\mu}_t \equiv \sum_a s_t^a \mu^a$ and $\bar{\mu}_t^n \equiv \sum_a n_t^a \mu^a$.

B.5 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:

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

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:

$$\left(\gamma - \epsilon\Omega_t^g\right)\left[\hat{P}_t^g - \hat{P}_t^s\right]. \tag{B.2}$$

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

$$\hat{\Omega}_t^s \approx -\frac{\Omega_{82}^g}{\Omega_{82}^s}\left\{\epsilon\left[\hat{P}_t^s - \hat{e}_t\right] + \gamma\left[\hat{P}_t^g - \hat{P}_t^s\right] + \hat{\mu}_t + \hat{\phi}_t + \hat{\nu}_t\right\}. \tag{B.3}$$

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.2) to isolate the two effects separately, leading to (10).