Aging Consumers, Competition, and Growth

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Abstract

As people age, their preferences become less elastic and the opportunity cost of time drops post-retirement. Hence, demographic changes influence market competition and economic growth by altering the age composition of consumers and, consequently, their purchasing behavior. We identify this demand-side channel of demographic changes using unexpected shifts in the age composition of firms' foreign demand. We find that middle-aged consumers reduce competition with respect to younger and older consumers, resulting in lower production and higher prices. In a multi-sector general equilibrium search model we show that young consumers enhance between-varieties competition and old consumers enhance within-varieties competition. In contrast, middle-aged consumers temper competition on both margins, shifting demand toward less productive firms, which raises average prices and slows economic growth. In the United States, changes in the age composition of consumers led to an 8.7% reduction in GDP growth from 1995-2004 and a 10.3% increase from 2005-2019 as baby boomer cohort aged.

JEL classification: D10, D43, E21, J11, O49

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1 Introduction

The consumption behavior of agents varies over the life cycle driven by age-specific preferences and changes in the opportunity cost of time as elderly people enter retirement. In particular, the frequency at which the consumption basket is updated declines with age (Bornstein et al., 2018). Compared to young consumers, indeed, middle-aged and old consumers show stronger attachment to brands and compare fewer varieties, i.e., have more inelastic preferences (Lambert-Pandraud et al., 2005; Lambert-Pandraud and Laurent, 2010; Bornstein et al., 2018). Regarding the opportunity cost of time, while agents in the working age period face a higher opportunity cost of time represented by the forgone labor market revenues, elderly consumers can search for goods at a lower cost following retirement and eventually pay lower prices for a given variety of goods (Aguiar and Hurst, 2005, 2007).[1]

The age-specific consumption behavior of agents assumes macroeconomic relevance in the context of important demographic shifts. For instance, in the United States, the share of young adults (25-44) has decreased from 68% in 1995 to 58% in 2020, while the share of middle-aged (45-64) has been steadily increasing driven by the aging of the baby-boomer generation that will also determine a sharp increase in the share of old people (65+) in the years to come. These demographic shifts are even more dramatic in other advanced economies such as Japan and European countries, and are becoming an increasing concern also in China whose past demographic policies strongly contributed to determine the demographic composition of the population and its evolution in the decades to come. Due to the heterogeneity of preferences and search behavior of agents in different age categories, these demographic shifts imply changes in demand characteristics affecting the strategic behavior of firms with potentially large effects on macroeconomic trends.

While a large and growing literature has analyzed the macroeconomic implications of population aging mostly focusing on the supply side of the economy through its effects on the labor market (Maestas et al., 2023), adoption of automated technologies (Acemoglu and Restrepo, 2017, 2022; Abeliansky and Prettner, 2023), innovation (Aksoy et al., 2019; Jones, 2022), and the interest rate (Carvalho et al., 2016; Brand et al., 2018; Papetti, 2021; Bodnár and Nerlich, 2022), we focus our analysis on the demand side of the economy and study how demographic shifts affect the market structure through changes in the age composition of consumers, and, through this channel, the effect on economic growth.

[1] The marketing and psychology literature investigates further dimensions determining the age-specific consumption behavior such as the decline in cognitive ability (Gutchess, 2011; Peters, 2011), the shrinking of the social network size (East et al., 2014), and the reduction in the ability to use technology to search for information (Hargittai, 2001) as consumers become older.

At the sector level, our empirical evidence suggests that an aging demand has a non-monotonic effect on competition: while young and old consumers positively contribute to competition, middle-aged consumers reduce it. To clarify the mechanisms at play and to correctly account for substitution across sectors and other general equilibrium effects, we develop a multi-sector general equilibrium search model with three types of agents (young, middle-aged, and old), heterogeneous in search cost (within varieties) and elasticity of substitution (between varieties), in which firms compete both within and between sectors. Finally, using our empirical evidence and United States data, we calibrate the model to quantify the contribution of aging consumers to the United States GDP growth in the last decades.

To estimate the effect of a change in the age composition of consumers on prices and production, two main issues arise: 1) the multitude and the simultaneity of channels through which demographic shifts affect the economy, for instance, through the age composition of the labor force, aggregate savings in the economy, public spending, and other domestic channels, and 2) the predictability of demographic changes, leading to changes in the strategic behavior of firms based on expectations.

To identify the effect of population aging through the demand side of the economy (*age demand channel*), we use a *shift-share IV* identification approach and use the age composition of foreign demand as an instrument for the age composition of demand (*shift*), hence exploiting the wedge between the age composition of total (domestic + foreign) and domestic demand. We, therefore, disentangle the effect of changes in the age composition of demand from other domestic channels. Using a world input-output table, we account for both direct and indirect sales through the global value chain and obtain precise measures of the exposure of each sector in each country to the demand of each foreign trading (*share*). Accounting for indirect sales is relevant as shocks to final goods sectors propagate up the value chain as shown in Ferrari (2023). To address the predictability of demographic changes, we consider revisions in official demographic predictions as a proxy of unexpected demographic changes mechanically ensuring the independence of the shifts from the shares and providing the ground for a causal interpretation of our results.

We find that an increase in the share of middle-aged consumers reduces production (measured as the value added) and increases the average price while young and old have the opposite effect. These results contrast with the impact of standard demand shocks which are associated with variations in quantities and prices in the same direction. We interpret this negative co-movement as evidence of a change in the market structure driven by changes in the age composition of demand. Supporting this hypothesis, we observe that an increase in the share of middle-aged consumers is also associated with an increase in the profit shares at the sector level.

Our findings can be interpreted as the result of distinct mechanisms documented in the literature. On one hand, young consumers are less loyal to specific brands and have more elastic preferences across goods relative to middle-aged and old consumers leading to higher competition across varieties (Bornstein et al., 2018). On the other hand, old consumers have more time to search for goods relative to consumers in the working age period (young and middle-aged) and, therefore, increase competition within a variety (Aguiar and Hurst, 2007). Middle-aged consumers, instead, reduce both between and within variety competition since possess relatively inelastic preferences across goods and have a high opportunity cost of time.

We develop a multi-sector general equilibrium model to clarify these mechanisms and correctly capture the substitution across sectors and other general equilibrium effects. Then, calibrating the model using our empirical estimates, we 1) estimate the *general equilibrium dampening factor* allowing us to interpret our empirical estimates accounting for effects not captured by the empirical model, and 2) the contribution of the age demand channel on output growth in the last decades in the US.

As age-specific characteristics of agents do not evolve linearly with age, we consider a model with three types of consumers, namely young, middle-aged, and old, heterogeneous in both search costs and preferences: young and middle-aged consumers pay a positive search cost to observe prices in each market while old consumers pay no cost; middle-aged and old consumers have a lower elasticity of substitution across goods relative to young consumers. On the supply side, we consider a continuum of sectors. Within sectors, a finite number of firms produce a homogeneous variety of goods and decide on prices and (cost-reducing or productivity-enhancing) technology investments. This framework implies between- and within-varieties competition both of which are affected by changes in the demographic composition of agents due to their heterogeneity in search costs, affecting within-varieties competition, and preferences across goods, affecting between-varieties competition.

The demographic process, defined as a change in the age composition of consumers, affects the economy in two ways: 1) by reallocating demand across firms, and 2) by the endogenous response of firms in terms of their pricing and technology strategies. An increase in the share of consumers with higher search costs (young and middle-aged) reduces competition among firms within the same sector. An increase in the share of consumers with a lower elasticity of substitution (middle-aged and old) reduces between-sectors competition. Since middle-aged consumers have both high search costs and low elasticity of substitution, an increase in the share of the middle-aged leads to an overall reduction in competition which materializes into lower incentives to invest in technology, higher average prices, lower total output, and higher equilibrium profits.

Using our sector-level empirical estimates as targets, we calibrate the sector model keeping the general equilibrium variables constant. By comparing the general equilibrium model outcomes with those of the sector model, we estimate a general equilibrium dampening factor for production of around 87%, allowing us to interpret our empirical results accounting for substitution across sectors and other general equilibrium effects. Accounting for these effects, we observe that a standard deviation increase (2.21%) in the share of middle-aged consumers determines a ten-year cumulative reduction in GDP growth of around 2.76 percentage points.

Finally, using United States demographics, we estimate that changes in the age composition of consumers have contributed to a reduction in GDP growth of 8.7% in the period 1995-2004 and an increase of 10.3% in the period 2005-2019, compared to a counterfactual in which the United States demography would have remained unchanged at the 1995 level. While the reduction in GDP between 1995-2004 is due to the increase in the share of middle-aged consumers due to baby-boomer aging, the increased GDP in the following period is due to the baby-boomer generation retiring and progressively contributing to increasing overall competition in the economy.

This paper contributes to three strands of the literature. First, this work contributes to the growing literature analyzing the macroeconomic implications of population aging on the economy. In this direction, several recent studies have focused on the effect of population aging on the labor market and its effects on the adoption of automated technologies (Acemoglu and Restrepo, 2017, 2022; Abeliansky and Prettner, 2023; Gehringer and Prettner, 2019; Abeliansky et al., 2020). However, the emphasis given by the literature on the effect of an aging workforce has overshadowed the economic impact through a complementary channel: the change in the age composition of consumers. We contribute to this literature by providing empirical evidence showing that the demand side of the economy is also importantly affected by demographic changes and significantly contributes to macroeconomic trends.

Second, more specifically, our paper contributes to the literature studying the age-specific heterogeneities of consumers such as in Aguiar and Hurst (2007) which shows that since old consumers have a lower opportunity cost of time relative to working-age consumers, they tend to face lower prices. While this literature documents age-specific heterogeneities in consumption and purchase behavior mostly at the micro-level, we provide evidence of the macroeconomic implications of these heterogeneities in the context of important demographic shifts. Our paper also aims to overcome the apparent contradiction between and Aguiar and Hurst (2007) result of lower opportunity cost of time faced by old consumers potentially increasing competition, and those of Bornstein et al. (2018) showing that the aging of consumers leads to a reduction in competition and, therefore, to higher prices due to the higher consumption inertia of middle-aged and old consumers. Our empirical evidence shows that the effect of aging consumers on the competition level is, indeed, non-monotonic. Our theoretical model, incorporating the two dimensions of heterogeneity highlighted in Aguiar and Hurst (2007), i.e. the opportunity cost of time, and in Bornstein et al. (2018), i.e., preferences, replicates the non-monotonic effect of aging consumers on the competition level and production growth observed in the data.

Finally, this work contributes to the strand of the literature studying search frictions in the goods market. Seminal contribution include Butters (1977), Varian (1980), Burdett and Judd (1983) and Stahl (1989). We build on the latter and introduce sequential search in a general equilibrium model with three different types of agents as in Chen and Zhang (2011), multiple varieties, and strategic technology adoption choices.[2]

The rest of the paper is structured as follows: in section 2, the sector-level empirical analysis is presented, while in section 3, we build the theoretical model. In section 4, we calibrate the model and estimate the general equilibrium dampening factor allowing us to interpret our empirical results accounting for substitution across sectors and other general equilibrium effects. In section 5, using United States demographic data, we estimate the contribution of the age demand channel on production growth in the United States in the last decades. Finally, section 6 concludes. All proofs and mathematical details are in the appendix.

2 Empirical analysis

In this section, we present the empirical evidence on the effect of a change in the age composition of consumers on prices and production output considering three different age categories (young, middle-aged, and old). To identify the effect coming from the change in the age of consumers, we use a shift-share IV approach and instrument the change in the age com-

[2]More recent works on the macroeconomic consequences of search frictions on the goods market include Kaplan and Menzio (2016), Bai et al. (2024), Albrecht et al. (2023), Kryvtsov and Vincent (2021) Sara-Zaror (2021) among others.

position of consumers with foreign demographics weighted by the exposure of the domestic economy to foreign demand.

We document that an increase in the share of young and old consumers is associated with lower prices and higher production output. In contrast, the opposite results for middle-aged consumers suggest that young and old consumers increase the market competition while middle-aged consumers reduce it. We verify this hypothesis showing that an increase in the share of young and old consumers is associated with lower profits while the opposite holds for middle-aged consumers.

In what follows, we present the data and the empirical strategy used in the analysis, discuss the results, and present several robustness checks using different age definitions and instruments.

2.1 Data

To recover a measure of the exposure of the domestic economy to foreign demand, we use the World Input-Output Database (Timmer et al., 2015) which provides sector-level statistics on value-added, hours worked, price deflator, and input-output tables with information on trade links at the country-sector level. The WIOD covers the 27 European Union countries, 13 other major economies in the world for the period 1995-2009, and estimates for the rest of the world.[3] The dataset provides information over 35 sectors. The structure of the input-output tables is represented in Figure (1). Rows represent the country-sector supplying the input, while the columns the country-sector buying the inputs to be used in the production process. Each cell represents the amount traded in terms of value-added. The columns "Final use" and "Total use" represent the amount produced by each country-sector which is consumed by each country and the total output of the country-sector respectively.[4] Using the input-output tables allows us to capture the interdependence coming from the integrated production structure of the world's economies.

To recover the demographic variables, we use the United Nations (2022) World Population Prospects (WPP, 1996, 2006, and 2019 revisions) providing estimates and projections in 1996,

[3]Besides the 27 European Union countries, the WIOD dataset contains information on Australia, Brazil, Canada, China, Indonesia, India, Japan, South Korea, Mexico, Russia, Turkey, Taiwan, and the United States.

[4]Several variables compose the "Final use" columns (i.e. "Final consumption expenditure by households", "Final consumption expenditure by non-profit organizations serving households (NPISH)", "Final consumption expenditure by the government", "Gross fixed capital formation", "Changes in inventories and valuables"). Coherently with the scope of our analysis, we consider only the "Final consumption expenditure by households" variable.

Figure (1)   The structure of a world input-output table

			Input use & value added							Final use			Total use
			Country 1			$\cdots$	Country J			Country 1	$\cdots$	Country J	
			Industry 1	$\cdots$	Industry S	$\cdots$	Industry 1	$\cdots$	Industry S				
Intermediate	Country 1	Industry 1	Z^{11}_{11}	$\cdots$	Z^{1S}_{11}	$\cdots$	Z^{11}_{1J}	$\cdots$	Z^{1S}_{1J}	F^{1}_{11}	$\cdots$	F^{1}_{1J}	Y^{1}_{1}
		$\cdots$	$\cdots$	Z^{rs}_{11}	$\cdots$	$\cdots$	$\cdots$	Z^{rs}_{1J}	$\cdots$	$\cdots$	$\cdots$	$\cdots$	$\cdots$
		Industry S	Z^{S1}_{11}	$\cdots$	Z^{SS}_{11}	$\cdots$	Z^{S1}_{1J}	$\cdots$	Z^{SS}_{1J}	F^{S}_{11}	$\cdots$	F^{S}_{1J}	Y^{S}_{1}
inputs	$\cdots$	$\cdots$	$\cdots$	$\cdots$	$\cdots$	Z^{rs}_{ij}	$\cdots$	$\cdots$	$\cdots$	$\cdots$	F^{r}_{ij}	$\cdots$	Y^{r}_{i}
supplied	Country J	Industry 1	Z^{11}_{J1}	$\cdots$	Z^{1S}_{J1}	$\cdots$	Z^{11}_{JJ}	$\cdots$	Z^{1S}_{JJ}	F^{1}_{J1}	$\cdots$	F^{1}_{JJ}	Y^{1}_{J}
		$\cdots$	$\cdots$	Z^{rs}_{J1}	$\cdots$	$\cdots$	$\cdots$	Z^{rs}_{JJ}	$\cdots$	$\cdots$	$\cdots$	$\cdots$	$\cdots$
		Industry S	Z^{S1}_{J1}	$\cdots$	Z^{SS}_{J1}	$\cdots$	Z^{S1}_{JJ}	$\cdots$	Z^{SS}_{JJ}	F^{S}_{J1}	$\cdots$	F^{S}_{JJ}	Y^{S}_{J}
Value added			VA^{1}_{1}	$\cdots$	VA^{S}_{1}	VA^{s}_{j}	VA^{1}_{J}	$\cdots$	VA^{S}_{J}				
Gross output			Y^{1}_{1}	$\cdots$	Y^{S}_{1}	Y^{s}_{j}	Y^{1}_{J}	$\cdots$	Y^{S}_{J}	$\cdots$			

Source: World Input-Output Database

2006, and 2019 of the age composition of the population in the past, current, and future years. We use these datasets to recover measures of the actual demographic change (WPP 2019), and of the unexpected demographic changes (WPP 1996 and 2006).

The aggregate nature of our dataset limits our analysis as we can only estimate average effects at the sector level. The dataset also lacks information on each sector's actual age composition of the demand. However, by weighing our demographic variables by the exposure of each country-sector to the different countries, we obtain sector-level measures of demand.

2.2 Empirical strategy

In this section, we present the OLS baseline model and highlight the caveats of this approach. We then present the shift-share IV identification approach addressing these caveats.

2.2.1 OLS

To estimate the effect of a change in the age composition of consumers on sector aggregate price and production output, we use the following long-difference fixed-effect model specification similar to Acemoglu and Restrepo (2022):

$$\Delta log Y_i^s = \beta_0 + \beta_1 \cdot \Delta AgeDemand_i^s + \beta_2 \cdot ForeignExposure_i^s + \gamma_i + \gamma_s + \epsilon_i^s, \qquad (1)$$

The left-hand side variables are, in turn, the log difference in prices and production output between 1996 and 2006 in sector s, country i.[5] We use the sector-specific value-added price deflator as a proxy for the average price which measures prices from the producers' side and, thus, contrary to the consumer price index (CPI), does not depend on the basket of goods and services purchased by consumers. As a proxy for production output, we use real value-added.

The regressor of interest is the change in the age composition of demand at the country-sector level and it is defined as the change between 1996 and 2006 of the country-level demographic measure weighted by the exposure of each country-sector to each country's demand:

$$\Delta AgeDemand_i^s = \sum_j \xi_{i,j,2006}^s \cdot age_{j,2006} - \sum_j \xi_{i,j,1996}^s \cdot age_{j,1996}, \tag{2}$$

where $\xi_{i,j,t}^s$ is a measure of the exposure of sector s in country i to the demand of country j in period t. We define the exposure share as in Ferrari (2023):

$$\xi_{i,j}^s \equiv \frac{F_{i,j}^s \ + \ \sum_r \sum_k \ a_{i,k}^{s,r} \ F_{k,j}^r \ + \ \sum_r \sum_k \sum_g \sum_m \ a_{i,k}^{s,r} \ a_{k,m}^{r,g} \ F_{m,j}^g + ...}{Y_i^s} \ , \tag{3}$$

The first term in the numerator, $F_{i,j}^s$, represents the output produced by sector s in country i which is directly sold for consumption in country j; the second term represents the fraction of output produced by sector s in country i sold to any producer r in any country k which is then consumed in country j. The same logic applies to higher-order terms.[6]

This definition of exposure shares captures the interconnection of global trade allowing us to track down all the intermediate trades occurring from the initial producer to the final consumer, considering both the direct and the indirect sales. Consider, for example, a German car producer using tires produced in Italy. Assume that the German producer sells its cars in France. By only considering the direct sale, we would not capture the exposure of the Italian tire producer to French demand. This simple example shows, particularly for very

[5] We consider the longest available period in the WIOD 2013 release excluding the recession years from 2007 on; we consider 1996 instead of 1995 (the first year available in the WIOD 2013 release) to consistently define the dependent variables across the different models as the UN WPP was published in 1996 but not in 1995.

[6] We compute the exposure of each sector s in country i to country j making use of the Leontief inverse matrix $(I - A)^{-1}$. We retrieve the Leontief inverse matrix from the Leontief input-output model relating production (Y) with final demand $(F \equiv [\sum_j F_{i,j}^s])$: $Y = AY + F$, where $A \equiv [a_{i,j}^{s,r}] \equiv [Z_{i,j}^{s,r}/Y_i^s]$ is the input-output matrix. The Leontief inverse matrix relates the exposure share matrix $[\xi_{i,j}^s]$ to the final demand matrix $[f_{i,j}^s] \equiv [F_{i,j}^s/Y_i^s]$ that shows the amount of output produced by sector s in country i consumed or invested in country j as a share of the total output produced by sector s in country i. We, therefore, estimate the exposure share matrix as $[\xi_{i,j}^s] = (I - A)^{-1} \cdot [f_{i,j}^s]$.

interconnected countries, the necessity of taking into account also indirect sales to retrieve the correct measure of final demand exposure.

Regarding the demographic variables, we consider three different age categories, i.e., $age_j \in \{young_j, middle\text{-}aged_j, old_j\}$. We define $young_j$ as the share of the population between 25 and 44, relative to the total population between 25 and 79 in country j. Similarly, we define $middle\text{-}aged_j$ as the share of the population between 45 and 64, and old_j as the share of the population between 65 and 79. We exclude younger and older consumers (<25 and 80+) as we focus on independent consumers.[7] The three different age categories are defined to capture the salient differences in the purchasing behavior of agents across age categories. As Bornstein et al. (2018) shows, indeed, young consumers have significantly lower consumer inertia (an inverse measure of the probability to re-optimize over the consumption basket) than middle-aged and old consumers. Further, older consumers dispose of significantly more time to devote to search for goods which determines a different purchasing price relative to young and middle-aged consumers Aguiar and Hurst (2005).

To control for the heterogeneous exposure of sectors to foreign demand, we include in the regression the exposure to foreign demand ($ForeignExposure_i^s$) at the initial period (1996) defined as the sum of the exposure of each country-sector relative to foreign countries, i.e., $\sum_{j \neq i} \xi_{i,j,1996}^s$. Furthermore, to control for sector-specific and country-specific trends, we include country and sector dummies (γ_i and γ_s respectively). In this context, it is relevant to control for sector-specific trends as young, middle-aged, and old consumers might differ in their consumption basket due to heterogeneity in preference for goods. Think, for instance, of elderly consumers who on average consume more health services than young and middle-aged consumers. In the case in which the growth rates of prices and production in this sector differ relative to the growth rates in other sectors, a higher share of old consumers would affect the price and production growth rates through a change in the sector composition of demand. Controlling for sector-fixed effects, we account for the changes in consumption patterns across age categories affecting the allocation of demand across sectors.

Regression (2) suffers from two major caveats: 1) the correlation between changes in the age composition of demand and changes in the age composition of workers and 2) the predictability of demographic changes. In the next paragraphs, a shift-share IV regression model addresses these caveats.

[7] Younger consumers (<25) might still have no income and depend on their parents regarding their consumption decisions; older consumers (80+) might delegate their consumption decision choices to someone else (think, for instance, of the older in nursing homes).

2.2.2 Shift-share IV

Since changes in the age composition of consumers are correlated with the change in the age composition of workers which is likely to be a strong predictor of technology adoption affecting the sectors' aggregates of interest (price and production output), we implement a shift-share IV identification approach and instrument the change in the age composition of demand with foreign demographics weighted by the exposure of the domestic economy to foreign demand. We, therefore, exploit the wedge between the age composition of consumers (which depends on both the domestic and the foreign age composition of consumers) and the age composition of the domestic population. This allows us to disentangle the effect coming from the demand side of the economy (i.e., the change in the age composition of consumers) from other direct effects going through the labor market such as changes in the age composition of workers, and other domestic channels.

We follow the methodology described in Borusyak et al. (2022), Adão et al. (2019), and Goldsmith-Pinkham et al. (2020) which requires either exogenous shares (the exposure to foreign demand) or exogenous shifts (the change in foreign demographics). Since the exposure to foreign demand is potentially endogenous as firms choose the sectors and the countries to trade with, we identify exogenous shifts. Finally, to control for the simultaneity between firms' exposure and the shifts, we fix exposure shares at the initial period of our panel. We, therefore, estimate the following first-stage model:

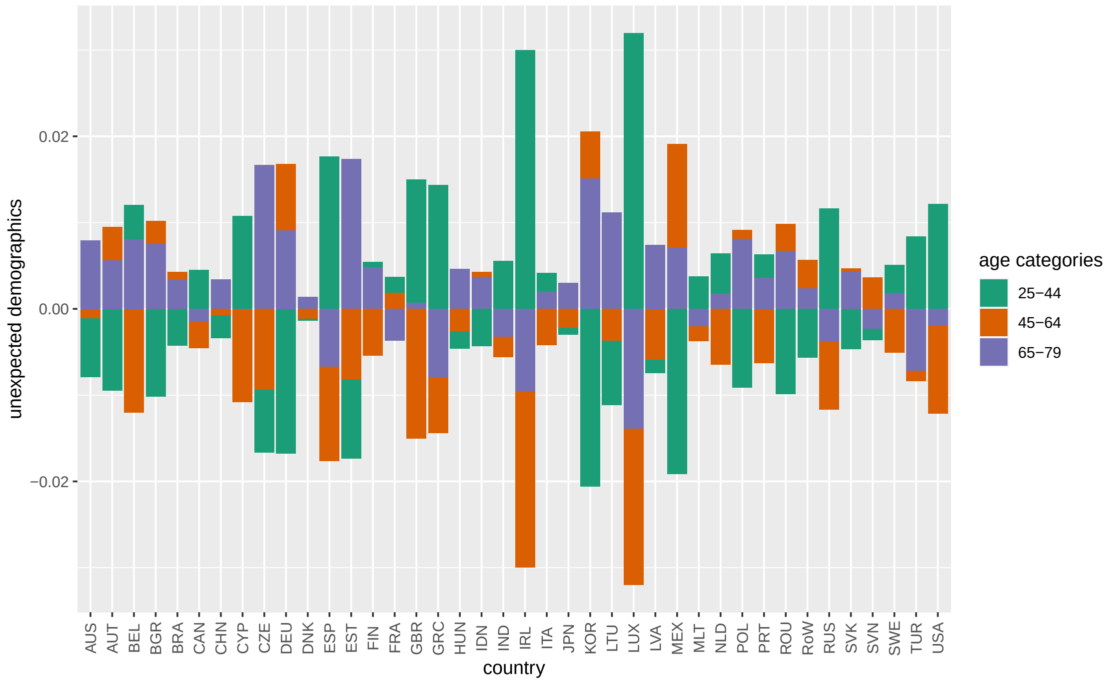
$$\Delta AgeDemand_i^s = \alpha_0 + \alpha_1 \cdot \Delta ForeignAgeDemand_i^s + \alpha_2 \cdot ForeignExposure_i^s + \gamma_i + \gamma_s + \nu_i^s, \quad (4)$$

where $\Delta ForeignAgeDemand_i^s$ is the shift-share instrument defined as a measure of demographic change (shift) weighted by the exposure of each country-sector to foreign demand (share):

$$\Delta ForeignAgeDemand_i^s \equiv \sum_{j \neq i} \xi_{i,j,1996}^s \cdot DemographicShift_{j,1996}. \quad (5)$$

To ensure the exogeneity of the instrument relative to the dependent variables in this framework, we require the exogeneity of the shifts relative to the dependent variables (which in our framework means the exogeneity of foreign demographics relative to domestic price and domestic production) and the independence of the shifts relative to the shares. Exogeneity of the shifts with respect to the dependent variables means that foreign demographics is independent relative to domestic price and domestic production which is a plausible assumption.

Figure (2) Unexpected demographic changes aggregated in three age categories.



Note: this figure shows the prediction revisions for the year 2006 between 1996 and 2006. For each age category we compute its share in the total population between 25 and 79 years old. The prediction revisions are computed according to equation (6) from different vintages of the UN World Population Prospects.

To ensure that the shifts and the shares are independent one another, as it is standard in the shift-share literature, we use lagged values of the shares shielding the results from contemporaneous co-movements of the shifts and the shares. However, in our framework, this strategy might not be enough to guarantee the independence between the shifts and the shares as demographic changes are highly predictable. Demographic expectations, indeed, could still affect the lagged exposure shares. We, therefore, build a measure of unexpected demographic change using the error in forecasts in 1996 regarding the 2006 demographic composition of countries:

$$DemographicShift_{j,1996} \equiv age_{j,2006} - \mathbb{E}_{1996}\left(age_{j,2006}\right). \tag{6}$$

By fixing exposure shares at the initial period and considering the error in expectations in 1996 regarding demographics in 2006, we ensure that the demographic shifts are unexpected and, therefore, uncorrelated with the exposure shares. Figure (2) shows that there are large variations in prediction errors in demographics across countries and age categories guaranteeing enough variation to perform the empirical estimation.

Finally, since sectors selling to the same foreign countries are exposed to the same shocks, we cluster standard errors by the main exposure country (i.e. the country's final demand to which each country-sector sells the highest share of its value-added). Our clustering partly mitigates concerns related to this correlation.

2.3 Results

Table (1) summarizes the main results of our empirical analysis. In Panel A the OLS model specification estimates are presented, while the results of the shift-share IV model are shown in Panel B. Columns (1)-(3) report the results for the regression on prices, while columns (4)-(6) show the results for the production output. For each model specification, we run three separate regressions alternating the age category regressor considered, i.e., young (25-44), middle-aged (45-64), and old (65-79).

Our results suggest that while young and old consumers are generally associated with lower prices and higher production, middle-aged consumers are associated with higher prices and lower production. Focusing on middle-aged consumers for whom the coefficient estimates are the most significant, the shift-share IV model estimates imply that, in the period between 1996 and 2006, a standard deviation increase in middle-aged (2.21%) leads to an increase in prices of 2.28% and a reduction in production output of 1.82% per year.[8]

While standard demand shocks usually lead to a positive co-movement between prices and production output, we observe a negative co-movement between price and production output as the share of consumers in each age category changes suggesting that the change in the age composition of consumers leads to a supply-side response by firms. We hypothesize that, since consumers across different age categories have different purchasing behaviors due to heterogeneity in preferences and search costs, a change in the age composition of consumers, by affecting the market structure, leads to changes in the pricing and investment strategies of firms affecting, in turn, the production output. We can, therefore, interpret the increase in prices and the reduction in production output driven by the increase in middle-aged consumers as a reduction in the competition in the economy, while the reduction in prices and increase in production driven by the increase in young and old consumers as an increase in competition.

[8]The average annual changes are computed as follows: $100 \times \left(1 + \frac{\%\Delta y}{100}\right)^{\frac{1}{2006-1996}} - 100$, where $\%\Delta y$ is the cumulative percentage change in price (over the period 1996-2006), i.e., $\%\Delta y = 100 \cdot (e^{\hat{\beta}_1 \cdot \Delta x} - 1)$, and $\hat{\beta}_1$ is the coefficient estimates for the IV model specification for prices and production in Table (1), and Δx is set to be equal to one standard deviation in the domestic change between 1996 and 2006 of the share of the age category analyzed.

Table (1) Effect of the age composition of consumers on prices, production output, and profits.

Panel A OLS	*Dependent variable:*								
	Δ log Price			Δ log Production			Δ log Profit		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
ΔYoung (25-44)	1.034			0.029			1.171		
	(0.670)			(0.804)			(3.046)		
ΔMiddle-aged (45-64)		3.162***			−3.143***			18.744***	
		(0.750)			(0.901)			(3.181)	
ΔOld (65-79)			−4.437***			0.838			−31.190***
			(0.939)			(1.135)			(3.984)
Initial Foreign Exposure	✓	✓	✓	✓	✓	✓	✓	✓	✓
Country-fixed effects	✓	✓	✓	✓	✓	✓	✓	✓	✓
Sector-fixed effects	✓	✓	✓	✓	✓	✓	✓	✓	✓
Observations	1,353	1,353	1,353	1,353	1,353	1,353	917	917	917
R^2	0.884	0.885	0.885	0.578	0.582	0.578	0.269	0.297	0.318

Panel B Shift-share IV	*Dependent variable:*								
	Δ log Price			Δ log Production			Δ log Profit		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
ΔYoung (25-44)	−12.859			12.395*			−109.172		
	(14.195)			(6.920)			(181.879)		
ΔMiddle-aged (45-64)		10.212**			−8.308***			46.099**	
		(4.440)			(2.878)			(21.020)	
ΔOld (65-79)			−14.597*			19.627			−49.142***
			(8.571)			(20.029)			(8.965)
Initial Foreign Exposure	✓	✓	✓	✓	✓	✓	✓	✓	✓
Country-fixed effects	✓	✓	✓	✓	✓	✓	✓	✓	✓
Sector-fixed effects	✓	✓	✓	✓	✓	✓	✓	✓	✓
Observations	1,353	1,353	1,353	1,353	1,353	1,353	917	917	917
R^2	0.845	0.877	0.875	0.500	0.571	0.487	−0.870	0.236	0.302

Note: *p<0.1; **p<0.05; ***p<0.01

To test for this hypothesis, we analyze the effect of a change in the age composition of consumers on the profit shares using a similar identification approach for the price and the production output analysis. We estimate the sector-level profit shares as in Van Vlokhoven (2024). Columns (7)-(9) in Table (1) show that middle-aged consumers are associated with higher profit shares relative to both young and old verifying our hypothesis.

These results are in line with Bornstein et al. (2018) showing that, compared to young consumers, middle-aged consumers re-optimize their consumption basket less often making it more difficult for entrants to establish a customer base and, therefore, reducing competition in the market. Differently from Bornstein et al. (2018), our results reject the prediction that an aging society necessarily leads to lower competition. Indeed, we find evidence that old consumers are associated with lower prices and higher production suggesting an increase in competition. This result is consistent with the findings in Aguiar and Hurst (2007) showing that elderly consumers tend to face lower prices as they have a lower opportunity cost and, therefore, lower search costs.

Our findings are, therefore, the results of distinct mechanisms. Relative to middle-aged consumers, young consumers (who quickly update their consumption basket and are less loyal to brands) tend to increase competition in the market (Bornstein et al., 2018). Old consumers, as well, tend to increase competition in the market because of their lower opportunity cost of time (Aguiar and Hurst, 2007). Middle-aged consumers who, instead, are more loyal to the brand compared to young consumers and have a higher opportunity cost of time compared to old consumers, tend to reduce competition. This results in higher prices, lower production output, and higher profit shares as the share of middle-aged consumers increases.

2.4 Robustness

In this section, we perform a series of robustness checks focusing on the middle-aged category.[9] We consider alternative definitions of the middle-aged category by changing the thresholds considered. We, therefore, alternatively define middle-aged as the share of the population aged 45-59, 40-64, and 40-59 (45-64 in the baseline model). Table (2) rows (2)-(4) shows that results are fully consistent across the different definitions of middle-aged consumers and quantitatively similar to the baseline results (row 1).

We also consider a change in expectations between 1996 and 2006 regarding demography in year $t \in \{2010, 2015, 2020\}$ ($t = 2006$ in the baseline model). We, therefore, define the

[9]Tables for other age categories can be found in the appendix.

Table (2) Robustness checks for middle-aged consumers. Row (1) is the baseline model. In rows (2)-(4), the age thresholds differ relative to the baseline model; in rows (5)-(7) the expectation error is considered with respect to demography in year $t \in \{2010, 2015, 2020\}$ respectively ($t = 2006$ in the baseline model) according to equation (7); in row (8) actual demographics change is considered according to equation (8); in row (9) lagged fertility rates (20-, 25-, 30-, 35-, 40-, 45-, 50-, 55-year lags) are considered according to equation (9). All model specifications include the same controls as in the baseline model.

		Dependent variable:		
		Δ log Price	Δ log Production	Δ log Profit
(1)	ΔMiddle-aged (45-64) $t = 2006$ Unexpected Demographics	10.212** (4.440)	−8.308*** (2.878)	46.099** (21.020)
(2)	ΔMiddle-aged (45-59) $t = 2006$ Unexpected Demographics	12.668*** (4.053)	−9.952** (4.355)	50.313*** (13.554)
(3)	ΔMiddle-aged (40-64) $t = 2006$ Unexpected Demographics	12.790*** (3.029)	−8.805* (4.718)	52.913*** (11.077)
(4)	ΔMiddle-aged (40-59) $t = 2006$ Unexpected Demographics	12.636*** (2.484)	−7.706 (5.629	46.273*** (3.944)
(5)	ΔMiddle-aged (45-64) $t = 2010$ Unexpected Demographics	9.279** (4.095)	−7.849*** (2.252)	43.359** (19.434)
(6)	ΔMiddle-aged (45-64) $t = 2015$ Unexpected Demographics	9.615** (4.056)	−7.249*** (2.096)	47.258** (19.613)
(7)	ΔMiddle-aged (45-64) $t = 2020$ Unexpected Demographics	7.511** (3.096)	−5.340*** (1.496)	42.963*** (13.481)
(8)	ΔMiddle-aged (45-64) $t = 2006$ Actual Demographics	4.247 (2.895)	−3.647 (2.545)	21.105* (12.123)
(9)	ΔMiddle-aged (45-64) $t = 2006$ Fertility	2.335** (0.923)	−2.122 (1.381)	20.401*** (6.386)
Note:				*p<0.1; **p<0.05; ***p<0.01

instrumental variable as:

$$\Delta ForeignAgeDemand_i^s \equiv \sum_{j \neq i} \xi_{i,j,1996}^s \cdot \left[\mathbb{E}_{2006}\left(age_{j,t}\right) - \mathbb{E}_{1996}\left(age_{j,t}\right)\right]. \tag{7}$$

Table (2) rows (5)-(7) shows that the results obtained considering the change in expectations with respect to future demographics are qualitatively and quantitatively consistent with the results of the baseline shift-share IV model.

A potential concern of our baseline model is that the demographic variable can be affected by immigration. Since economic reasons are often at the base of the decision to migrate, the age variable might be partially endogenous in the context of our baseline model specification.

Moreover, in the case in which immigrants have different purchasing behaviors with respect to the native population, our results might partially capture the effect of immigration rather than age. While in the baseline model, we do not directly account for these issues, we can analyze the relevance of these potential effects by comparing the model estimates of a model in which we control for immigration and a model in which we do not control for it. We consider the actual demographic change between 1996 and 2006 as a proxy of the demographic shift that captures both the effect of native demographic change and immigration. We, therefore, define the instrumental variable as:

$$\Delta ForeignAgeDemand_i^s \equiv \sum_{j \neq i} \xi^s_{i,j,1996} \cdot \left[age_{j,2006} - age_{j,1996}\right]. \tag{8}$$

To control for the effect of immigration on age, we use lagged fertility rates weighted by the exposure shares which allows us to identify the native demographic component that explains the demographic shift. We, therefore, estimate the following first-stage model:

$$\Delta AgeDemand_i^s = \alpha_0 + \sum_x \alpha_x \sum_{j \neq i} \xi^s_{i,j,1996} \cdot fert_{j,2006-x} + \Gamma_i^s + \nu_i^s, \tag{9}$$

where $fert_{j,2006-x}$ is the fertility rate in country j in year $2006-x$, with $x \in \{20, 25, 30, 35, 40, 45, 50, 55\}$ and Γ_i^s are the same controls as in the baseline model. Table (2) shows that the point estimates between the model using actual demographic change (row 8) and the model controlling for immigration (row 9) are not significantly different suggesting that the effect of immigration is marginal.

3 Theoretical model

To highlight the mechanisms driving the empirical results, we build a multi-sector general equilibrium model with search on the goods' market. We consider three types of agents (young, middle-aged, and old) which are heterogeneous in their preferences (elasticity of substitution across goods) and search costs. Firms compete through prices and (cost-reducing or productivity-enhancing) technology adoption. Competition occurs within and between sectors since agents have a positive, although finite, elasticity of substitution across goods produced in different sectors. Consumers are active in every market since goods produced in different sectors are not perfect substitutes. Depending on the observed prices, consumers decide on the quantity purchased of every good. Besides the different goods produced, sectors are assumed to be identical.

To describe the search behavior of the agents and the within-sector competition between firms, we initially present the sector model. Then, we nest the sector model into the general equilibrium framework with multiple sectors capturing substitution across sectors and other general equilibrium effects. Finally, we analyze the mechanisms through which demographic shifts affect demand allocation and firms' price and technology adoption strategies.

3.1 Sector model

In this section, we focus our analysis on a single sector. A sector is defined as a market in which a finite number of firms produce a homogeneous good. Initially, we proceed by analyzing the search behavior of the agents, then we consider the optimal pricing and technology adoption strategy of firms. Firm strategies, and therefore the price and technology adoption distributions, depend on the expectations over the demand faced which, in turn, depends on the age composition of consumers. To simplify notation, we abstract from the sector subscripts when not required.[10]

3.1.1 Consumer search

The economy is populated by young (Y), middle-aged (M), and old (O) consumers such that $\sum_i \lambda^i = 1$, where λ^i is the fraction of consumers in the age category $i \in \{Y, M, O\}$. Agents observe prices sequentially. We assume that all consumers observe the first price for free. Agents face age-specific search costs when observing other prices. To capture the lower opportunity cost of time of old relative to working-age consumers, we assume that old consumers face zero search costs, while young and middle-aged consumers pay $\nu > 0$ to observe one more price. Consumers with positive search costs find it profitable to continue searching if the expected benefits from searching exceed the costs. Given the lowest previously observed price z, we define the consumer surplus of observing a price $p < z$ for a

[10]a) Given that each sector has a mass zero, the price realization in one sector, and the subsequent consumption decision, does not affect aggregate expenditures, and, therefore, consumption decisions in other sectors. This also implies independence between the reservation price in one sector and the realization of prices in the other sectors. Finally, since sectors are symmetrical, reservation prices are identical in all sectors.
b) We assume that agents observe the first price in every market at the same time. Given that agents consume a positive mass of goods in symmetrical markets, the reservation price in a given market depends only on the distribution of prices but not on the price realization in this market.

consumer of type $j \in \{Y, M\}$ as:

$$CS^j(p;z) \equiv \int_p^z D^j(x)\ dx, \tag{10}$$

where the sector-level demand function $D^j(x)$ is age-specific as it depends on age-specific preferences, and is decreasing in the price.[11] The expected consumer surplus for a young and a middle-aged consumer of randomly observing another price is:

$$ECS^j(z) \equiv \int_b^z CS^j(p;z)\ dF(p), \tag{11}$$

where b is the minimum value in the price distribution $F(p)$.

We define r^j as the reservation price for the consumer of type j such that $ECS^j(r^j) = \nu$ if $ECS^j(p)$ has a root, $r^j = +\infty$ otherwise. This implies the following search rule for consumers of type j: if $p \leqslant r^j$, the consumer purchases at price p; if $p > r^j$, the consumer continues to search; if $p > r^j$ for all firms, the consumers pick the lowest observed price.

Differently from young and middle-aged consumers who have positive search costs, since old consumers pay a zero search cost, they observe all prices and purchase at $p = b$.[12]

3.1.2 Firms

Production In each sector, a finite number $N \geqslant 2$ of ex-ante identical firms produce a homogeneous good and compete through prices. Each firm produces goods using only labor according to the following production function:

$$y^{sup.}(a) = (\bar{a} - a)^{-1} \cdot \ell, \tag{12}$$

where $y^{sup.}$ is the quantity of goods produced (*supplied*) by each firm; ℓ is the amount of labor used in production, and $(\bar{a} - a)^{-1}$ is the productivity of labor depending on the technology parameter $\bar{a}$ and the technology adoption choice of the firm $a \in [0, \bar{a})$. By investing in technology, firms can therefore increase labor productivity and reduce the marginal cost of

[11] We micro-found the sector-level age-specific demands when discussing the multi-sector general equilibrium.

[12] In particular, we rule out the monopolistic price equilibrium in which all firms set the price equal to the monopolistic price by assuming that old consumers stop searching only once they observe twice the lowest price b. Otherwise, firms could all charge the monopolistic price, and the old consumers would stop at the first observation since the lowest price is the monopolistic price. Assuming that the old consumers stop searching only once they face the lowest price twice, the monopolist price equilibrium cannot be sustained since firms have a profitable deviation in marginally lowering the price to attract all the old buyers.

production, $m(a) \equiv w \cdot (\bar{a} - a)$, where w is the wage paid for one unit of labor.[13] We assume quadratic technology adoption cost, $z(a) = a^2/\bar{z}$, where $\bar{z}$ is a technology cost parameter.

Expected demand We consider the following symmetric Nash Equilibria definition (Chen and Zhang, 2011):

A symmetric Nash Equilibrium is a vector $\{F(p), G(a), r^Y, r^M\}$, where $F(p)$ and $G(a)$ are the distribution functions of prices and technology adoption respectively. Given the reservation prices of young and middle-aged, r^Y and r^M, and that other firms adopt $F(p)$ and $G(a)$, it is optimal for every firm to choose $F(p)$ and $G(a)$. Given $F(p)$ and $G(a)$, young and middle-aged consumers optimally search sequentially with reservation price r^Y and r^M respectively.

The game does not have any pure-strategy equilibria and the price distribution is atomless in its support, i.e., the distribution is continuous and there are no individual values in the support with significant probability mass, hence the probability of any single value occurring is zero. Intuitively, if a measure of firms set the same price, a firm can increase profits by marginally lowering the price to attract those consumers with zero search costs who observe all prices. Therefore, a price distribution with mass points cannot be optimal.

Lemma 3.1. *Given the NE-distribution of prices F and the following condition:*

$$\begin{cases} \mathbb{E}\{\pi(p,F)\} > \frac{\lambda^M}{N} R^M(\hat{p}) - z\left(a(\hat{p})\right) & \text{if } r^Y \leqslant r^M \\ \mathbb{E}\{\pi(p,F)\} > \frac{\lambda^Y}{N} R^Y(\hat{p}) - z\left(a(\hat{p})\right) & \text{if } r^Y > r^M, \end{cases} \tag{13}$$

where $\mathbb{E}\{\pi(p,F)\}$ are the expected profits, $\hat{p} \in (min\{r^Y, r^M\}, max\{r^Y, r^M\}]$, and $R^j(p) \equiv D^j(p)(p - m(a))$, then the support of the price distribution is bounded above by $\bar{r} \equiv min\{r^Y, r^M, p^{mon.}\}$, where $p^{mon.}$ is the monopolistic price.

Lemma 3.1 sets the limit of the upper bound of the equilibrium distribution of prices which cannot be greater than the *monopolistic* price and it needs to be equal to the smallest between the reservation prices if $min\{r^Y, r^M\} < p^{mon.}$. Inequalities (13) set the condition under which targeting a particular type of consumer does not represent a profitable deviation relative to setting a price $\hat{p} \in (min\{r^Y, r^M\}, max\{r^Y, r^M\}]$, i.e., a firm has no incentive

[13] To recover the marginal cost, we rewrite labor as $\ell = y^{sup.}(\bar{a} - a)$. Given the cost of one unit of labor w, the total cost of production is $w \cdot y^{sup.}(\bar{a} - a)$. Taking the first derivative with respect to $y^{sup.}$, we obtain the marginal cost $m(a) \equiv w \cdot (\bar{a} - a)$.

in only targeting agents with the highest reservation price as it would make lower profits than setting a price below or equal to $min\{r^Y, r^M\}$. Given the condition (13) and that $min\{r^Y, r^M\} < p^{mon.}$, then the upper bound of the distribution is given by $min\{r^Y, r^M\}$ since a firm setting a price $\bar{r} < min\{r^Y, r^M\}$ would be able to sell to the same number of consumers by setting the price to $min\{r^Y, r^M\}$ which is closer to the monopolistic price that maximizes the profits. A similar condition can be found in Chen and Zhang (2011). We assume condition (13) to hold and verify numerically our conjecture ex-post.

Given Lemma 3.1, for a given price $p < p^{mon.}$, each producer faces the following expected quantity *demanded*:

$$\mathbb{E}\{y^{dem.}(p)\} = \frac{\lambda^Y}{N} \cdot D^Y(p) + \frac{\lambda^M}{N} \cdot D^M(p) + \lambda^O \left[1 - F(p)\right]^{N-1} \cdot D^O(p). \tag{14}$$

The expected demand function is composed of three terms: the first two are the demands coming from young and middle-aged consumers, while the last one is the demand coming from older consumers. Since the upper limit of the equilibrium price distribution is $\bar{r} = min\{r^Y, r^M\}$, young and middle-aged consumers randomly observe only one price and never find it optimal to pay the search cost to observe a further price. This implies that each firm expects λ^Y/N young and λ^M/N middle-aged buyers. Old consumers, instead, have zero search costs, observe all the prices, and purchase at the lowest pricing firm in each sector. $[1 - F(p)]^{N-1}$ is, indeed, the probability that a firm setting price p is the lowest pricing firm in the sector.

Profit maximization The producers choose the price and the technology adoption level to maximize profits. Expected profits are, therefore, given by:

$$\mathbb{E}\{\pi(p, F)\} \equiv \left\{ \max_{\{a,p\}} \; y \cdot (p - m(a)) - z(a) \right\}, \tag{15}$$

such that the production of the firm equals the expected demand, $y^{sup.}(a) = \mathbb{E}\{y^{dem.}(p)\} \equiv y$, and the expected profits are the same for any price in the support of the price distribution, $\mathbb{E}\{\pi(p, F)\} = \pi, \forall \; p \in [b, \bar{r}]$. The optimality condition for problem (15) imply the following:

Proposition 3.2. *The equilibrium technology adoption,*

$$a^*(p) = \left[\left(\frac{p}{w} - \bar{a} \right)^2 + \bar{z}\pi \right]^{\frac{1}{2}} - \left(\frac{p}{w} - \bar{a} \right) > 0, \tag{16}$$

is negatively related to the price.

This proposition allows a first characterization of firms. Since technology adoption increases productivity, the proposition implies a negative relationship between price and productivity and a positive relationship between firm size (in terms of production) and productivity which is a common feature observed in the data.

Price distribution At price $\bar{r}$, $F(\bar{r}) = 1$, i.e., a firm is the highest pricing firm in the sector does not attract any old consumers as older buyers observe all prices and purchase at the lowest pricing firm. Therefore:

$$\mathbb{E}\{\pi(\bar{r}, F)\} = \frac{\lambda^Y}{N} \cdot R^Y(\bar{r}) + \frac{\lambda^M}{N} \cdot R^M(\bar{r}) - z(a(\bar{r})). \tag{17}$$

Since in equilibrium, all prices in the support of F give the same expected profits, it must hold that $\mathbb{E}\{\pi(\bar{r}, F)\} = \mathbb{E}\{\pi(p, F)\} = \pi$ from which we get the equilibrium cumulative distribution of prices:

$$F(p) = 1 - \left[\frac{\lambda^Y \left(R^Y(\bar{r}) - R^Y(p) \right) + \lambda^M \left(R^M(\bar{r}) - R^M(\bar{p}) \right)}{N \cdot \lambda^O R^O(p)} - \frac{z(a(\bar{r})) - z(a(p))}{\lambda^O R^O(p)} \right]^{\frac{1}{N-1}}. \tag{18}$$

To complete the characterization of $F(p)$, we pin down the lower bound of the price distribution, b, using the fact that $F(b) = 0$.

As in Stahl (1989), the equilibrium price distribution of strategies is U-shaped and presents two larger density areas of strategies. The first one, an almost mass point at the upper bound of the price distribution, includes all the strategies focused on buyers who randomly observe only one price. Firms that set the price close to the upper bound of the distribution attract few buyers, sell few products per buyer, and have a low level of technology adoption. The second density area, close to the minimum price, includes the strategies focused on buyers that observe all prices and, therefore, purchase at the lowest price in the sector. These firms compete to attract more buyers and adopt more productivity-enhancing technology as they can spread technology costs over a larger production.

3.2 Multi-sector general equilibrium

We now embed the sector model into a multi-sector general equilibrium framework to capture the effect of demographic shifts taking into account substitution across sectors and other general equilibrium effects. We first derive the consumers' demands for each sector solving the household utility maximization problem. Aggregating the sector-level demands, we then recover the aggregate demand and the aggregate labor demand. Finally, imposing the labor market clearing conditions, we complete the model.

Consumer demand The economy is composed of a unit measure of sectors, $s \in [0,1]$. Each consumer $i \in \{Y, M, O\}$ gets utility by consuming an aggregate consumption good, $U(C^i) = C^i$, composed by aggregating goods produced in the different sectors through a CES consumption aggregator. We assume age-specific elasticity of substitution between goods across different sectors, σ_i. Therefore, an agent of type i faces the following utility maximization problem:

$$max_{\{c_s^i\}}\ C^i \equiv \left[\int_s (c_s^i)^{\frac{\sigma_i - 1}{\sigma_i}} ds\right]^{\frac{\sigma_i}{\sigma_i - 1}} \tag{19}$$

$$\text{s.t.} \qquad I^i = \widetilde{P}^i \cdot C^i, \tag{20}$$

where $I^i \equiv \phi^i \cdot W$, is the income of agent i defined as the share (ϕ^i) of the total wealth (W, given by the sum of total labor cost, technology cost, and profits) held on average by each agent i. $\widetilde{P}^i \equiv \left[\int_s (\widetilde{p}_s^i)^{1-\sigma_i} ds\right]^{\frac{1}{1-\sigma_i}}$ is the normalized price aggregator obtained by setting the average price in the economy as the numeraire (Ghironi and Melitz, 2005).[14]

The price aggregators are age-specific as agents differ in terms of both their search costs and their elasticity of substitution. From the maximization problem (19), we obtain the consumption of good s for agent of type i:

$$c_s^i = C^i \left(\frac{\widetilde{p}_s^i}{\widetilde{P}^i}\right)^{-\sigma_i}, \tag{21}$$

which defines the sector-specific demand of agent i for a given price p, i.e., $D_s^i(p) \equiv c_s^i$.

Aggregate production The production in each sector fulfills the market clearing conditions. Therefore, given the aggregate demand in each sector, $\sum_i \lambda^i c_s^i$, the aggregate output in the economy is:

$$Q = \int_s \sum_i \lambda^i c_s^i \, ds = \sum_i \lambda^i \left(\frac{C^i}{\widetilde{P}^{i^{-\sigma_i}}} \int_s (\widetilde{p}_s^i)^{-\sigma_i} ds\right). \tag{22}$$

[14]In particular, it holds that $\widetilde{p}_s^i \equiv p_s^i / P_{AVR}$ and $\widetilde{P}^i \equiv P^i / P_{AVR}$, where p_s^i is the price in sector s faced by agent of type i, $P^i \equiv \left[\int_s (p_s^i)^{1-\sigma_i} ds\right]^{\frac{1}{1-\sigma_i}}$, and $P_{AVR} \equiv \sum_i \lambda^i P^i$.

Since we assume that, besides the good variety produced, all the sectors are identical, the expected price by a consumer of type i in each sector is the same. We can therefore rewrite the aggregate output as:

$$Q = \sum_i \lambda^i \frac{C^i}{\widetilde{P}^{i^{-\sigma_i}}} \mathbb{E}[(\widetilde{p}^i)^{-\sigma_i}], \tag{23}$$

Moreover, since young and middle-aged consumers randomly observe a price, they face the same price distribution as the price strategy distribution of firms, i.e., $F^Y(p) = F^M(p) = F(p)$. Old consumers, instead, observe all prices and buy in each market s at the lowest price. Since in each sector, there is the same number of firms, N, the price distribution faced by old consumers in each sector is given by the distribution of the minimum when N independent draws from $F(p)$ occur, i.e.:

$$F^O(p) = 1 - (1 - F(p))^N . \tag{24}$$

Labor market clearing The labor demand in each sector s is given by $\sum_i \lambda^i c_s^i(\bar{a} - a^*)$, which implies that we can write the aggregate labor demand as:

$$ALD = \int_s \sum_i \lambda^i c_s^i(\bar{a} - a^*)\ ds = \sum_i \lambda^i \left(\frac{C^i}{\widetilde{P}^{i^{-\sigma_i}}} \int_s (\widetilde{p}_s^i)^{-\sigma_i} \cdot (\bar{a} - a^*)\ ds \right) di, \tag{25}$$

and, since sectors are assumed to be identical:

$$ALD = \sum_i \lambda^i \frac{C^i}{\widetilde{P}^{i^{-\sigma_i}}} \mathbb{E}\left[(\widetilde{p}_s^i)^{-\sigma_i} \cdot (\bar{a} - a^*)\right]. \tag{26}$$

Finally, to highlight the effect of a demographic change on the market structure through the demand channel, we fix the labor supply, i.e., $ALS = 1$. In equilibrium, the wage adjusts such that $ALD = ALS$.

4 Quantitative analysis

In this section, we calibrate the theoretical model using our empirical evidence. In particular, since the empirical analysis is at the sector level, we keep fixed general equilibrium adjustments to calibrate the model.

4.1 Calibration

The model has 12 parameters: the search cost parameter, ν, the technology parameter, $\bar{a}$, the technology cost parameter, $\bar{z}$, two elasticity of substitution parameters $\{\underline{\sigma}, \bar{\sigma}\}$, the number of firms in each sector, N, three budget constraint parameters, ϕ^i, and three demographic parameters, λ^i for $i \in \{Y, M, O\}$.

We externally calibrate the budget constraint parameters on United States wealth data so that the income of agent i is equal to the average wealth of a consumer in the i age category in 1995 (Survey of Consumer Finances). The demographic parameters come from the UN World Population Prospect (1996), while the remaining six parameters, $\{\nu, \bar{a}, \bar{z}, \underline{\sigma}, \bar{\sigma}, N\}$, are internally calibrated targeting six of our empirical results. In particular, we target the effect of young, middle-aged, and old on prices and output estimated through our IV model specification. Since our empirical results are sector-level estimates, we use the sector model to target such relations, i.e., we keep fixed general equilibrium objects such as aggregate production, aggregate labor demand, and wages.

Table (3) Calibrated parameters

	Externally calibrated parameters	Value
ϕ^Y	share of wealth held on average by young	0.22
ϕ^M	share of wealth held on average by middle-aged	0.46
ϕ^O	share of wealth held on average by old	0.32
λ^Y	demographic share of young	0.48
λ^M	demographic share of middle-aged	0.30
λ^O	demographic share of old	0.22
	Internally calibrated parameters	
$\bar{a}$	technology parameter	0.75
$\bar{z}$	technology cost parameter	1.14
ν	search cost parameter	0.61
$\bar{\sigma}$	elasticity of substitution (young)	1.37
$\underline{\sigma}$	elasticity of substitution (middle-aged and old)	0.82
N	number of firms in each sector	4.00

Table (4) Model fit

	Targeted moments	Data	Model
$\frac{dp}{d\lambda^Y}$	effect of young on prices	-2.76	-1.36
$\frac{dp}{d\lambda^M}$	effect of middle-aged on prices	$+2.28$	$+2.45$
$\frac{dp}{d\lambda^O}$	effect of old on prices	-2.10	-0.76
$\frac{dQ}{d\lambda^Y}$	effect of young on ouput	$+2.74$	$+1.66$
$\frac{dQ}{d\lambda^M}$	effect of middle-aged on output	-1.82	-2.82
$\frac{dQ}{d\lambda^O}$	effect of old on output	$+2.89$	$+0.84$

Model results require cautious interpretation as calibration does not perfectly match the data (Table 4). Two key reasons explain this. First, we target the rate of change rather than absolute levels. This prioritizes capturing the effects of different age groups on prices and output, not replicating specific data points. Second, the model's simplicity is deliberate to isolate age group effects. Adding more features might improve the fit, but it would introduce unnecessary complexity, potentially obscuring the core mechanisms we are interested in.

This calibration strategy helps bridge the gap between our empirical findings and the model's theoretical framework by estimating substitution across sectors not captured in the empirical analysis. Indeed, by comparing the calibrated sector model results with the results of the general equilibrium model in which general equilibrium variables are allowed to adjust, we recover estimates of the effect of a demographic change accounting for substitution across sectors and other general equilibrium effects.[15]

4.2 Demographic analysis

We now analyze the different channels linking the age composition of consumers to the allocation of demand across firms, firms' strategies, and productivity. In what follows, we assume that young consumers have a higher elasticity of substitution across different goods relative to middle-aged and old consumers: $\bar{\sigma} \equiv \sigma^Y$ and $\underline{\sigma} \equiv \sigma^M = \sigma^O$ such that $\bar{\sigma} > \underline{\sigma}$.[16] We also assume that middle-aged consumers have a lower reservation price so that the upper bound of the price distribution is equal to the reservation price of middle-aged consumers, i.e., $\bar{r} = r^M$. Intuitively, since middle-aged consumers have a lower elasticity of substitution across varieties relative to young consumers, once they observe a high price, they are more willing (relative to young consumers) to pay the search costs to observe another price, i.e., $r^M < r^Y$ which implies that $\bar{r} \equiv \min\{r^Y, r^M\} = r^M$. Young consumers, indeed, would find instead optimal to reduce the consumption of the good with a high price and purchase more of another good without having to pay search costs. We verify numerically ex-post that reservation prices fulfil this order. Finally, to simplify the analysis and highlight the mechanisms going through the search cost and elasticity of substitution heterogeneity, we abstract from effects going through changes in the age-specific budget constraint.[17] We

[15] Further details on the calibration are in the appendix.

[16] This is in line with the evidence in Bornstein et al. (2018) showing that middle-aged and old consumers have similar consumption inertia which is significantly higher than the one of young consumers, and the evidence in Lambert-Pandraud et al. (2005) showing that middle-aged and old consumers show higher brand loyalty with respect to young consumers.

[17] The budget constraint is not relevant to explain the mechanisms driving the results of the empirical analysis since the model features a continuum of sectors so that the fraction of wealth that is allocated to

calibrate age-specific budget constraints in the quantitative exercise.

To identify the channels through which demographic shifts affect the economy, we keep, in turn, the share of different age categories constant and consider three different scenarios: a first aging phase in which part of young consumers becomes middle-aged (keeping the share of old constant); a second aging phase in which a share of middle-aged consumers becomes old (keeping the share of young constant); and a combined reduction in fertility rates and increase in longevity scenario in which the share of young declines and the share of old increase (keeping the share of middle-aged constant). Demographic changes generally affect the shares of all the age categories meaning that the actual effect of population aging is a combination of the effects we depict in this analysis.

Aging (1) - Young become Middle-aged We now consider a first aging scenario in which the young become middle-aged keeping the share of old constant. This can be mapped into the increase in the share of middle-aged consumers due to the aging of the baby-boomer generation in the period between 1990 and 2010 in the United States.

An increase in the share of middle-aged consumers keeping the share of old consumers constant means that the share of young consumers reduces to fully compensate for the increase in middle-aged ($-\Delta\lambda^Y = \Delta\lambda^M > 0$). This implies that the share of consumers with relatively high search costs stays constant ($\lambda^Y + \lambda^M + \Delta\lambda^Y + \Delta\lambda^M = \lambda^Y + \lambda^M$), while the share of consumers with low elasticity of substitution increases ($\lambda^M + \lambda^O + \Delta\lambda^M > \lambda^M + \lambda^O$). The effect on the economy coming from this demographic process is, therefore, determined only by the increase in the share of consumers with low elasticity of substitution which reduces the between-sector competition. In this case, we observe the *strategy channel* at play: as firms observe an increase in the share of consumers with low elasticity of substitution, they will exploit the lower between-sectors competition favoring higher prices and lower technology adoption strategies leading to an average increase in prices, and a reduction in output and productivity.

Aging (2) - Middle-aged become Old We now consider the following demographic shift: part of middle-aged becomes old ($-\Delta\lambda^M = \Delta\lambda^O > 0$) while the share of young stays constant. This can be interpreted as a second phase in the aging process; a situation in which, for instance, the middle-aged baby-boomer generation ages and becomes old as in the United States in the period following 2010. In this case, the share of consumers with

each sector is infinitesimal.

relatively high search costs declines ($\lambda^Y + \lambda^M + \Delta\lambda^M < \lambda^Y + \lambda^M$) while the share of consumers with low elasticity of substitution ($\lambda^M + \lambda^O + \Delta\lambda^M + \Delta\lambda^O = \lambda^M + \lambda^O$) stays constant.

A reduction in the share of consumers with relatively high search costs implies higher within-sector competition and affects the economy in two ways. First, it changes the allocation of demand across firms as a larger share of consumers observe all the prices. This *allocation channel* mechanically reduces the demand faced by firms choosing high-price and low-technology adoption strategies leading to an average reduction in prices, and an average increase in output and productivity. Second, the higher within-sector competition implies an update in firm strategies favoring low-price and high-technology adoption. This *strategy channel*, therefore, leads to lower average prices, and higher output and productivity. Since these effects go in the same direction, this demographic shift leads to an average reduction in prices and an increase in output and productivity.

Aging (3) - Fertility reduction / Longevity increase We now consider the case in which the share of young declines, the share of middle-aged stays constant, and the share of old increases such that $-\Delta\lambda^Y = \Delta\lambda^O > 0$. This can be interpreted as a combined reduction in fertility reducing the share of the young and an increase in longevity increasing the share of old which is a common phenomenon in all advanced economies in the last decades.

A reduction in the share of young and an increase in the share of old implies a reduction in the share of agents with relatively high search costs ($\lambda^Y + \lambda^M + \Delta\lambda^Y < \lambda^Y + \lambda^M$) determining higher within-sector competition, and an increase in the share of agents with low elasticity of substitution ($\lambda^M + \lambda^O + \Delta\lambda^O > \lambda^M + \lambda^O$) determining a lower between-sector competition. Since firms react oppositely to the higher within-sector and the lower between-sector competition, the effect on price, production, and productivity is uncertain.

5 Relating the empirical results to the model

Comparing the sector model results with the general model results, we estimate a *general equilibrium dampening factor* capturing the substitution across sectors and general equilibrium effects. This allows us to reinterpret our empirical results accounting for these effects.

5.1 General equilibrium dampening factor estimation

We now link our empirical results regarding the effect of the age composition of consumers on production output to the model accounting for substitution across sectors and other general

Table (5) Sector-level (SL) and multi-sector general equilibrium (GE) effect of a demographic shift (one standard deviation change in one age category compensated by the change in another age category) on production output measured in percentage points (p.p.).

Demographic shift		SL	GE	$\left(1 - \frac{GE}{SL}\right)$
Aging (1)	$-\Delta\lambda^Y = \Delta\lambda^M > 0$	-3.37 p.p.	-0.52 p.p.	84%
Aging (2)	$-\Delta\lambda^M = \Delta\lambda^O > 0$	$+4.05$ p.p.	$+0.54$ p.p.	87%
Aging (3)	$-\Delta\lambda^Y = \Delta\lambda^O > 0$	$+0.79$ p.p.	-0.04 p.p.	105%

equilibrium results. We define the general equilibrium dampening factor as $1 - \frac{GE}{SL}$, where $\frac{GE}{SL}$ is the ratio of the effects in the general equilibrium model and the sector-level model. This dampening factor provides a measure of the dampening effect on the sector-level model when accounting for substitution across sectors and other general equilibrium effects.

Table (5) shows the effect of different demographic shifts on production output in the sector-level and general equilibrium model. Considering an increase in one standard deviation in the share of middle-aged consumers ($2.21\% \times \lambda^M$) compensated by a proportional reduction in young consumers, the sector model predicts a reduction in GDP growth of 3.37 percentage points, while the general equilibrium model predicts a reduction of 0.52 percentage points dampening the effect by 84%. Similarly, for a reduction in one standard deviation in the share of middle-aged compensated by an equivalent increase in old consumers, the general equilibrium model dampens the positive effect on GDP growth by 87%. Finally, when we consider a one standard deviation increase in the share of old consumers ($1.45\% \times \lambda^O$) compensated by an equivalent reduction in young consumers, we find that the positive effect on production estimated in the sector-level model completely vanishes in the general equilibrium, i.e., the general equilibrium dampening factor is larger than one. In this case, the positive effect on production growth driven by the increase in the within-sector competition is dominated by the negative effect determined by the reduction in the between-sector competition captured when considering the general equilibrium model.

5.2 Empirical results accounting for general equilibrium effects

We can now reinterpret our empirical results accounting for substitution across sectors and other general equilibrium effects. To do so, we pass our empirical sector-level estimates through the general equilibrium dampening factors capturing the dampening effect of the general equilibrium.

In the empirical analysis, the underlying assumption was to analyze the effect of an increase in one of the age categories keeping the share of the other age categories constant.

This means that the increase in one of the age categories was at the expense of both the others in such a way as to keep their ratio constant. To remain consistent with this assumption, we decompose the demographic change into two *clean* demographic shifts weighting the effect of the change in one age category by its relative initial share. Focusing on the middle-aged category, we estimate the effect of an increase in the share of the middle-aged on output (β^M_{GE}) taking into account substitution across sectors and other general equilibrium effects as follows:

$$\beta^M_{GE} = \beta^M_{SL} \cdot \left[\frac{\lambda^Y}{\lambda^Y + \lambda^O} \left(1 - \frac{GE}{SL}\right)^M_Y + \frac{\lambda^O}{\lambda^Y + \lambda^O} \left(1 - \frac{GE}{SL}\right)^M_O \right], \tag{27}$$

where β^M_{SL} is the sector-level coefficient estimate capturing the effect of an increase in the share of middle-aged on output estimated in our empirical analysis, and $\left(1 - \frac{GE}{SL}\right)^M_Y$ and $\left(1 - \frac{GE}{SL}\right)^M_O$ are the general equilibrium dampening factors resulting from an increase in middle-aged compensated by a reduction in young and old respectively as estimated in Table (5).[18]

We find that $\beta^M_{GE} = -1.27$ which implies a cumulative reduction in GDP growth following one standard deviation increase (2.21%) in the middle-aged of around 2.76 percentage points (dropping from the 16.7 percentage points reduction estimated through the sector-level empirical model) in the period 1996-2006 or, equivalently, a per year reduction in GDP growth of 0.28 percentage points (dropping from the 1.81 percentage points reduction estimated through the sector-level empirical model).

6 Aging consumers in the United States

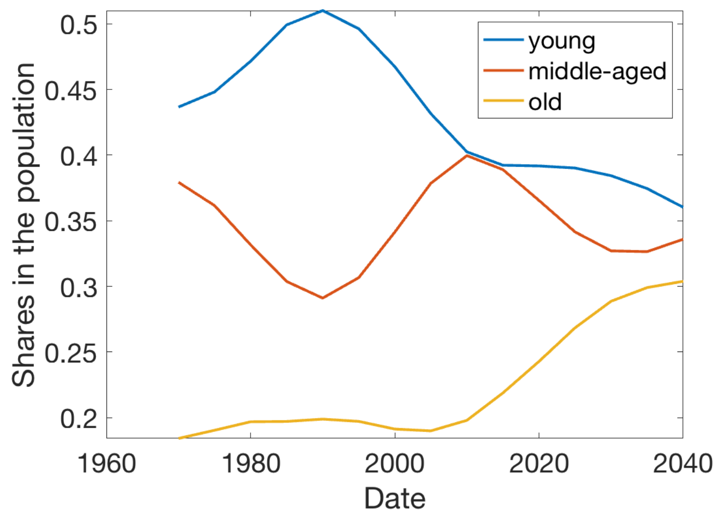
In this section, we look more precisely at the case of the United States. Using our estimated general equilibrium model and demographic data about the age composition of the population, we compute the contribution of the age demand channel to the GDP growth trend in the United States in the last decades.

6.1 United States demographics

The United States demographic evolution has been largely determined by the baby-boomer generation (those born between 1946 and 1965) who have represented by far the largest

[18] We set $\beta^M_{SL} = -8.308$ as estimated in the IV model specification, and we use United States demographic data in 1995 to compute the weights $\left(\frac{\lambda^Y}{\lambda^Y + \lambda^O} = 0.77 \text{ and } \frac{\lambda^O}{\lambda^Y + \lambda^O} = 0.23\right)$.

Figure (3) Demographic trends in the United States



Note: age decomposition of the demography in the United States, we define young as 25-44, middle-aged as 45-64, and old as 64-79 years old. Shares are computed using total population between 25 and 79 as the denominator. Source: UN WPP 2019.

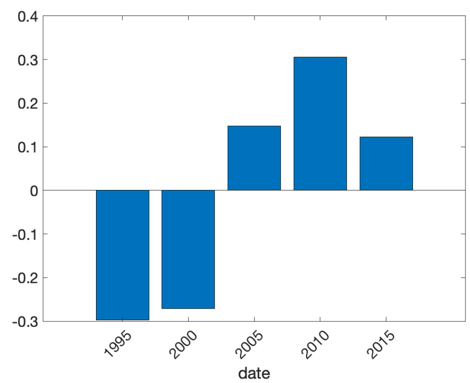
generational cohort in the twentieth century, and still today represent the second largest living cohort. Figure (3) shows how the shares of the young, middle-aged, and old population have evolved from the 1970s. As the baby-boomers entered the young age (25-44), the share of young started to increase. The increase continued up to the early 1990s when the baby-boomers became middle-aged determining a sharp reduction in the share of the young population and an equivalent increase in the share of the middle-aged. The share of middle-aged people increased until the early 2010s and then started to decline as the baby-boomers grew older. In the last decade, indeed, we observed a clear increase in the share of the older population which had remained constant in the previous decades.

6.2 Effects on GDP growth

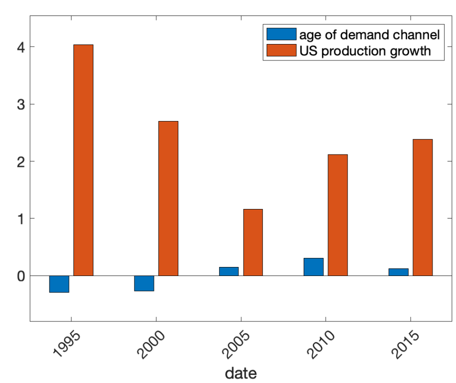
Figure (4) shows the the 5-year average effect of the age demand channel on GDP growth (panel a) and it relates this effect to the average GDP growth rate of the United States (panel b) in the period 1995-2019. We observe that the contribution of the age demand channel has been negative in the period 1995-2004 contributing to a reduction in GDP growth of around 8.7% (around 0.29 percentage points per year with an average GDP growth rate of 3.35% in the period). Instead, in the period 2005-2019, the effect of the age demand channel has been positive contributing to an increase in GDP growth of around 10.3% (around 0.19 percentage points per year with an average GDP growth rate of 1.87% in the period).

The initial negative effect of the age demand channel is due to the aging of the baby-boomers that in the period 1995-2004 became middle-aged leading to a reduction in competition with negative effects on GDP growth. In the period following 2005, instead, as the share of the middle-aged declined and the share of the old kept increasing, i.e., as the baby-boomers went from being middle-aged to old, the effect of the age demand channel reversed, positively affecting GDP growth.

Figure (4) Age demand channel relevance on United States GDP growth (1995-2015)



(a) Age demand channel



(b) Age demand and GDP growth

Note: Age demand channel compared with the United States GDP growth in the period 1995-2019. Each bar represents the per year average effect of the age demand channel (5-years average) and the United States 5-years average GDP growth measured in percentage points.

7 Conclusion

Population aging is a complex phenomenon that affects society and the economy in numerous dimensions. While most previous literature has analyzed the macroeconomic implications of population aging focusing on its effect on the labor market, adoption of automated technologies, innovation, and public spending, we highlight a complementary channel: the effect of aging consumers on competition and firms' strategies. Since consumers have age-specific characteristics affecting demand, firms react to demographic shifts by updating their strategies, with potentially relevant macroeconomic effects.

In this paper, we provide novel evidence of these effects suggesting that the aging of consumers does not have a monotonic effect on the competition level and GDP growth. We observe, indeed, that while middle-aged consumers are associated with lower competition and production growth, young and old consumers have the opposite effect. Based on micro evidence from the literature, we rationalize these findings into a heterogeneous agent model with competition over two margins: within and between markets. The model accounts for substitution across sectors and other general equilibrium effects not accounted for in the empirical analysis.

We estimate a significant contribution of aging consumers to the United States GDP growth. In particular, we observe how the aging of the baby-boomer generation determines the initial negative (pre-2005) and then positive (post-2005) effect of the age demand channel on the GDP growth highlighting the relevance of considering the aging process as a shift in the entire age distribution rather than a simple increase in the average/median age or in the share of old population. Abstracting from this characterization of the aging process might lead to severely misleading results not accounting for the non-linear and eventually non-monotonic effects of population aging on the economy.

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A Empirical Appendix

A.1 Summary statistics

Table (6) Summary statistics

Statistic	N	Mean	St. Dev.	Min	Pctl(25)	Pctl(75)	Max
Δlog Price	1,319	0.563	0.848	−1.661	0.109	0.670	3.776
Δlog Output	1,319	0.346	0.489	−2.885	0.091	0.566	3.177
Δlog Productivity	1,319	0.298	0.474	−2.318	0.026	0.530	3.841
Initial Foreign Exposure	1,319	0.390	0.260	0.0001	0.174	0.574	1.000
ΔYoung	1,319	0.033	0.022	−0.015	0.015	0.051	0.079
ΔMiddle-aged	1,319	−0.025	0.022	−0.078	−0.040	−0.007	0.026
ΔOld	1,319	−0.008	0.015	−0.044	−0.019	0.001	0.020
$\Delta\,\mathbb{E}$ Young	1,319	0.001	0.011	−0.021	−0.007	0.006	0.032
$\Delta\,\mathbb{E}$ Middle-aged	1,319	−0.004	0.007	−0.020	−0.008	0.001	0.012
$\Delta\,\mathbb{E}$ Old	1,319	0.003	0.007	−0.014	−0.002	0.007	0.017
ΔYoung Demand OLS	1,319	−0.030	0.018	−0.104	−0.041	−0.016	0.077
ΔMiddle-aged Demand OLS	1,319	0.024	0.018	−0.026	0.013	0.034	0.078
ΔOld Demand OLS	1,319	0.007	0.011	−0.046	−0.0003	0.014	0.051
ΔYoung Demand IV(1)	1,319	0.014	0.010	0.0000	0.006	0.020	0.059
ΔMiddle-aged Demand IV(1)	1,319	−0.010	0.008	−0.059	−0.015	−0.004	0.0000
ΔOld Demand IV(1)	1,319	−0.004	0.003	−0.024	−0.005	−0.001	0.006
ΔYoung Demand IV(2)	1,319	−0.0001	0.001	−0.013	−0.001	0.0003	0.008
ΔMiddle-aged Demand IV(2)	1,319	−0.001	0.001	−0.007	−0.001	−0.0001	0.003
ΔOld Demand IV(2)	1,319	0.001	0.001	−0.001	0.0003	0.001	0.010

Table (7) Robustness check; the expectation error is considered with respect to demography in years 2010 (Panel A), 2015 (Panel B), 2020 (Panel C), and 2025 (Panel D) respectively (2006 in the baseline model) in accordance with equation (7). All model specifications include the same controls as in the baseline model.

Panel A t = 2010	*Dependent variable:*								
	Δ log Price			Δ log Production			Δ log Profit		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
ΔYoung (25-44)	−12.110 (13.658)			12.069* (6.748)			−114.061 (198.104)		
ΔMiddle-aged (45-64)		9.279** (4.095)			−7.849*** (2.252)			43.359** (19.434)	
ΔOld(65-79)			−14.041* (7.770)			17.847 (18.286)			−51.003*** (10.096)
Observations	1,353	1,353	1,353	1,353	1,353	1,353	917	917	917
Panel B t = 2015	*Dependent variable:*								
	Δ log Price			Δ log Production			Δ log Profit		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
ΔYoung (25-44)	−11.340 (13.157)			11.483* (6.442)			−130.753 (239.670)		
ΔMiddle-aged (45-64)		9.615** (4.056)			−7.249*** (2.096)			47.258** (19.613)	
ΔOld (65-79)			−13.001* (7.342)			19.134 (20.468)			−58.211*** (11.263)
Observations	1,353	1,353	1,353	1,353	1,353	1,353	917	917	917
Panel C t = 2020	*Dependent variable:*								
	Δ log Price			Δ log Production			Δ log Profit		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
ΔYoung (25-44)	−10.553 (12.649)			11.771* (6.549)			−148.216 (276.836)		
ΔMiddle-aged (45-64)		7.511** (3.096)			−5.340*** (1.496)			42.963*** (13.481)	
ΔOld(65-79)			−13.960** (6.400)			18.880 (19.576)			−60.765*** (9.722)
Observations	1,353	1,353	1,353	1,353	1,353	1,353	917	917	917
Pane D t = 2025	*Dependent variable:*								
	Δ log Price			Δ log Production			Δ log Profit		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
ΔYoung (25-44)	−9.492 (11.176)			13.674* (7.017)			−99.608 (152.398)		
ΔMiddle-aged (45-64)		8.632 (6.283)			−14.698** (7.022)			42.973*** (11.501)	
ΔOld(65-79)			−15.847** (7.054)			21.962 (22.839)			−64.263*** (9.024)
Observations	1,353	1,353	1,353	1,353	1,353	1,353	917	917	917
Note:							*p<0.1; **p<0.05; ***p<0.01		

Table (8) Robustness check; differently from the baseline mode, the actual demographics change is considered in accordance with equation (8). All model specifications include the same controls as in the baseline model.

Shift: *Actual Demographics*	*Dependent variable:*								
	Δ log Price			Δ log Production			Δ log Profit		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
ΔYoung (25-44)	−9.946			10.339			−8.512		
	(8.959)			(7.483)			(16.443)		
ΔMiddle-aged (45-64)		4.247			−3.647			21.105*	
		(2.895)			(2.545)			(12.123)	
ΔOld(65-79)			−4.843**			2.685			−51.785***
			(2.110)			(4.131)			(7.967)
Observations	1,353	1,353	1,353	1,353	1,353	1,353	917	917	917
Note:							*p<0.1; **p<0.05; ***p<0.01		

Table (9) Robustness check; differently from the baseline mode, lagged fertility rates (20, 25, 30, 35, 40, 45, 50, 55 year lags) are considered in accordance with equation (9). All model specifications include the same controls as in the baseline model.

	Dependent variable:								
	Δ log Price			Δ log Production			Δ log Profit		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
ΔYoung (25-44)	−1.062			−0.518			−11.495		
	(2.143)			(2.404)			(7.306)		
ΔMiddle-aged (45-64)		2.335**			−2.122			20.401***	
		(0.923)			(1.381)			(6.386)	
ΔOld(65-79)			−5.885***			2.711			−38.042***
			(1.802)			(4.360)			(5.326)
Observations	1,353	1,353	1,353	1,353	1,353	1,353	917	917	917
Note:							*p<0.1; **p<0.05; ***p<0.01		

B Model Appendix

B.1 Proof of Lemma 3.1

Given $F(p)$ defined in $[b, \bar{r} \equiv min\{r^Y, r^M, p^{mon.}\}]$, to show that the proposed is an equilibrium, we need to show that, given the reservation prices and the monopolistic price, and given that other firms choose $F(p)$, there is not a profitable deviation in setting a price above $\bar{r}$. For any $p \in [b, \hat{r}]$, the firm's expected profits are:

$$\mathbb{E}\{\pi(p,F)\} = \frac{\lambda^Y}{N} R^Y(p) + \frac{\lambda^M}{N} R^M(p) + \lambda^O \left(1 - F(p)\right)^{N-1} R^O(p) - z(a(p)). \tag{28}$$

Since in equilibrium, it must hold that $\mathbb{E}\{\pi(p,F)\} = \mathbb{E}\{\pi(\bar{r},F)\}$, we can rewrite:

$$\mathbb{E}\{\pi(p,F)\} = \frac{\lambda^Y}{N} R^Y(\bar{r}) + \frac{\lambda^M}{N} R^M(\bar{r}) - z(a(\bar{r})). \tag{29}$$

A firm setting a price above $max\{r^Y, r^O\}$ would make zero profits. But a firm setting a price $\hat{p} \in (\bar{r}, max\{r^Y, r^O\}]$ would still attract consumers with the highest reservation price, with expected profit:

$$\begin{cases} \mathbb{E}\{\pi(\hat{p},F)\} = \frac{\lambda^M}{N} R^M(\hat{p}) - z(a(\hat{p})) & \text{if } \; r^Y \leqslant r^M \\ \mathbb{E}\{\pi(\hat{p},F)\} = \frac{\lambda^Y}{N} R^Y(\hat{p}) - z(a(\hat{p})) & \text{if } \; r^Y > r^M. \end{cases} \tag{30}$$

Imposing $\mathbb{E}\{\pi(p,F)\} > \mathbb{E}\{\pi(\hat{p},F)\}$, we obtain:

$$\begin{cases} \mathbb{E}\{\pi(p,F)\} = \frac{\lambda^Y}{N} R^Y(r^Y) + \frac{\lambda^M}{N} R^M(r^Y) - z\left(a(r^Y)\right) > \frac{\lambda^M}{N} R^M(\hat{p}) - z\left(a(\hat{p})\right) & \text{if } r^Y \leqslant r^M \\ \mathbb{E}\{\pi(p,F)\} = \frac{\lambda^Y}{N} R^Y(r^M) + \frac{\lambda^M}{N} R^M(r^M) - z\left(a(r^M)\right) > \frac{\lambda^Y}{N} R^Y(\hat{p}) - z\left(a(\hat{p})\right) & \text{if } r^Y > r^M. \end{cases} \tag{31}$$

Now, we want to show that under condition (31), $\bar{r} = min\{r^Y, r^M, p^{mon.}\}$.

- $\bar{r} \leqslant max\{r^Y, r^M\}$ since a firm setting a price above $max\{r^Y, r^M\}$ earns zero profits;
- given that $p^{mon.} > min\{r^Y, r^M\}$, then $\bar{r} \geqslant min\{r^Y, r^M\}$ since a firm setting a price $\bar{r} < min\{r^Y, r^M\}$ would be able to sell to the same number of consumers by setting the price to $min\{r^Y, r^M\}$ which is closer to the monopolistic price that maximizes the profits which implies that $\bar{r} \in [min\{r^Y, r^M\}, max\{r^Y, r^M\}]$;
- finally, under condition (31), it is not profitable to only focus on the consumer type

with the highest reservation price and set a price in between the two reservation prices is not a profitable deviation.

In particular, in the case in which $p^{mon.} > max\{r^Y, r^M\}$ then the most profitable deviation in $(min\{r^Y, r^M\}, max\{r^Y, r^M\}]$ is $max\{r^Y, r^M\}$ as it brings the price closer to the monopolistic price keeping the same share of consumers (i.e., the ones with the highest reservation price). In this case, condition (31) is fulfilled either if the share of consumers with the highest reservation price is low enough or if the difference between the reservation prices is small which in turn depends on the demand functions of the agents. In particular, since we assume that agents have different elasticity of substitution, given the share of consumer types with the highest reservation price, condition (31) is fulfilled if the elasticity of substitution of young and middle-aged are not too different.

B.2 Proof of proposition 3.2

Using the FOC from problem (15), we obtain an expression for output:

$$y = \frac{2a}{w\bar{z}}. \tag{32}$$

Substituting equation (32) into the equilibrium profit condition, $\mathbb{E}\{\pi(p, F)\} = \pi$, we obtain the following quadratic polynomial:

$$a^2 + 2a\left(\frac{p}{w} - \bar{a}\right) - \bar{z}\pi = 0, \tag{33}$$

which has two solutions:

$$a_1 = \left[\left(\frac{p}{w} - \bar{a}\right)^2 + \bar{z}\pi\right]^{1/2} - \left(\frac{p}{w} - \bar{a}\right),$$
$$a_2 = -\left[\left(\frac{p}{w} - \bar{a}\right)^2 + \bar{z}\pi\right]^{1/2} - \left(\frac{p}{w} - \bar{a}\right).$$

Since $a_2 < 0$, the unique solution for the investment is $a^*(p) = a_1$ which is decreasing in prices:

$$\frac{\partial a^*}{\partial p} = \frac{1}{w}\left[\frac{\frac{p}{w} - \bar{a}}{\sqrt{\left(\frac{p}{w} - \bar{a}\right)^2 + \bar{z}\pi}} - 1\right] < 0 \tag{34}$$

B.3 Equilibrium Profits

Since in equilibrium all prices in the support of F give the same expected profits π, it holds that $\mathbb{E}\{\pi(\bar{r}, F)\} = \pi$. A firm setting the reservation price $\bar{r}$ is the highest pricing firm in the sector and $F(\bar{r}) = 1$. Therefore, it holds that:

$$\mathbb{E}\{\pi(\bar{r}, F)\} = \frac{\lambda^Y}{N} \cdot R^Y(\bar{r}) + \frac{\lambda^M}{N} \cdot R^M(\bar{r}) - z(a(\bar{r})). \tag{35}$$

Substituting the optimal technology adoption (equation (16)) in equation (35), we obtain the following polynomial in π:

$$0 = -\pi + \frac{\lambda^Y}{N} R^Y(\bar{r}) + \frac{\lambda^M}{N} R^M(\bar{r}) - z(a(\bar{r})). \tag{36}$$

The polynomial has three solutions:

$$\begin{aligned}
\pi_1 &= -\frac{(\bar{r} - \bar{a}w)^2}{w^2 \bar{z}}; \\
\pi_2 &= \frac{\left[\lambda^Y D^Y(\bar{r}) + \lambda^M D^M(\bar{r})\right] \cdot \left[4N \cdot (\bar{r} - \bar{a}w) + w^2 \bar{z} \cdot \left(\lambda^Y D^Y(\bar{r}) + \lambda^M D^M(\bar{r})\right)\right]}{4N^2}; \\
\pi_3 &= -\frac{\left[\lambda^Y D^Y(\bar{r}) + \lambda^M D^M(\bar{r})\right] \cdot \left[4N \cdot (\bar{r} - \bar{a}w) + w^2 \bar{z} \cdot \left(\lambda^Y D^Y(\bar{r}) + \lambda^M D^M(\bar{r})\right)\right]}{4N^2}.
\end{aligned}$$

Under the condition that $\bar{r} - \bar{a}w > 0$, π_1 and π_3 are negative. $\bar{r} - \bar{a}w > 0$ means that the reservation price is larger than the marginal costs of a firm which does not invest in the labor saving technology. Let's assume that $\bar{r} - \bar{a}w \leqslant 0$, then a firm setting its price at $\bar{r}$ would make zero or negative profits, which implies that $\bar{r}$ is not in the equilibrium support of F, a contradiction. This implies that the unique solution for profits is: $\pi = \pi_2$.

B.4 Derivation of the sector-specific demand

The consumer's problem is to maximize utility subject to the budget constraint:

$$\max_{c_s^i} \left[\int_s c_s^{i\,\frac{\sigma_i - 1}{\sigma_i}} \, ds\right]^{\frac{\sigma_i}{\sigma_i - 1}} \tag{37}$$

$$\text{s.t. } \widetilde{P}^i C^i \equiv \int_s \widetilde{p}^i(s) \cdot c_s^i \; ds = I^i \tag{38}$$

The first order conditions for a good i:

$$\left[\int_s c_s^{i\,\frac{\sigma_i-1}{\sigma_i}} ds\right]^{\frac{1}{\sigma_i-1}} c_s^{i\,-\frac{1}{\sigma_i}} - \theta \cdot \widetilde{p}^i(s) = 0, \tag{39}$$

where θ is the Lagrangian multiplier linked to the constraint (38). We combine the FOCs for two distinct products s and t:

$$c_s^i = \left(\frac{\widetilde{p}^i(s)}{\widetilde{p}^i(t)}\right)^{-\sigma_i} \cdot c_t^i \tag{40}$$

Replacing c_s^i in the budget constraint, we obtain the expenditure in a given market t:

$$\widetilde{p}^i(t) \cdot c_t^i = I^i \cdot \left(\frac{\widetilde{p}^i(t)}{\widetilde{P}^i}\right)^{1-\sigma} \tag{41}$$

Using the condition $I^i = \widetilde{P}^i C^i$, we then obtain the demand from each product:

$$c_t^i = D(\widetilde{p}^i(t)) = C^i \left(\frac{\widetilde{p}^i(t)}{\widetilde{P}^i}\right)^{-\sigma}. \tag{42}$$

C Calibration and estimation

The model is calibrated to the United States economy in 1995. The share of each demographic group λ_i in the population between 25 and 79 years old comes from the UN World Population Prospect of 1996. We calibrate the shares of total wealth for each consumer in the age category i in the United States using the wealth data in the Survey of Consumer Finances (1995). We define:

$$\phi^i \equiv \frac{\lambda_i wealth_i}{\sum_i \lambda_i wealth_i} \tag{43}$$

with $wealth_i$ the average wealth of age-category i in the data.. Parameters are estimated targeting the point estimate of average price and total output responses to an increase in the share of young, middle-aged, and old. These 6 moments allow us to estimate 6 parameters of the model. We assume that an increase in the share of an age category i, δ_{λ_i}, comes from each of the two other age categories in proportion to their share in the economy, i.e.:

$$\delta_{\lambda_j} \equiv -\frac{\lambda_j}{1-\lambda_i}\delta_{\lambda_i} \text{ , with } \quad j \neq i \tag{44}$$

Our target function is the root mean square error between the model-implied moments and the data.

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