Health Sector Structural Change
(Supplemental Appendix for Online Publication Only)

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B Data Appendix

This appendix describes the data series used in our both our descriptive and structural analyses. We consider the shares of GDP for both direct health spending and spending on indirect governmental administrative matters. We describe how we construct our relative health-services price index. We also discuss the sources of our accidental and non-accidental mortality data, where we consider the inverse of latter to be a direct function of health spending at the cohort-level.

B.1 Aggregate Health Shares

Nominal consumption expenditure data are taken from the BEA's NIPA Table 2.5.5. We focus on the PCE data directly. For those who are unfamiliar with the NIPA PCE data, see Chapter 5 of the BEA's NIPA handbook (*Concepts and Methods of the U.S. National Income and Product Accounts* 2022). PCE data, including health services expenditure, includes new purchases of all goods and services made by households, non-profits acting in service of households, and purchases abroad by U.S. residents while traveling. It also includes expenditure made by third-party payers but the services from which are ultimately utilized by households. This means that "Health" expenditure as it is presented in NIPA Table 2.5.5. is the value of all out-of-pocket expenditures made by households plus the value of all health expenditures financed by either employer-paid or personal health insurance plus the value of health expenditures financed via various government programs, including Medicaid and Medicare.

While the price indices in NIPA Table 2.5.4 and the expenditure series in NIPA Table 2.5.5 account for the value of *final* health services ultimately utilized/consumed by households, regardless of their funding source, these tables *do not* account for public administrative costs associated

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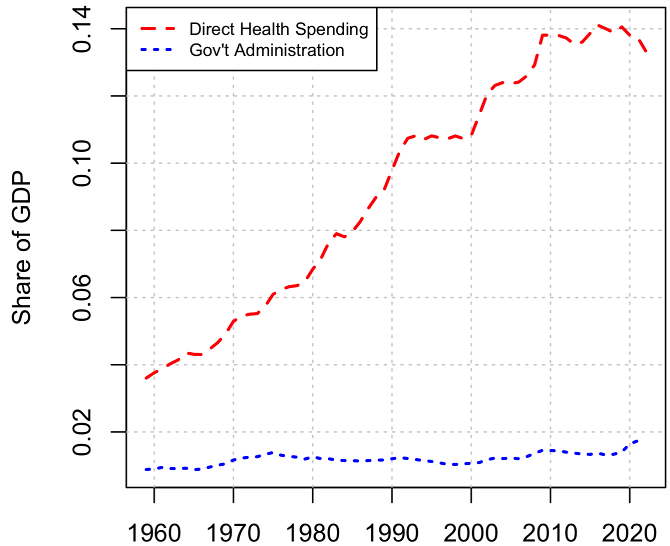


Figure B.1: Direct expenditure on health services as a percentage of GDP grew from less than 5% to just over 13% from 1959-2022 (red line), while the value of governmental administrative costs associated with Medicaid, Medicare, and other health services (blue line) rose from 0.9% to 1.8% over this same period.

with the Medicaid and Medicare programs. We do not have an explicit governmental administrative sector in our model, but rather the government simply functions as an intermediary facilitating transfers of pension payments from young to old, where such payments implicitly finance both health-care spending and other consumption. Failure to consider the role of Medicaid and Medicare at driving up total costs would be important if we observed that administrative costs associated with Medicaid and Medicare as a fraction of GDP were themselves growing over time, perhaps as a consequence of population aging. Figure B.1 presents a time series breakdown of the shares of GDP for "Direct Health Spending" and "Gov't Administration." The line associated with "Direct Health Spending" contains the PCE value of health outlay from NIPA Table 2.5.5 divided by GDP estimates from NIPA Table 1.5.5. The "Gov't Administration" line contains the value of governmental administrative costs associated with providing health-financing services to households, but it *does not* contain the actual value of governmental outlay paid toward the direct provision of those services, which can be noted by referring to Chapter 9 of *Concepts and Methods of the U.S. National Income and Product Accounts* (2022). Notice that direct spending's share of GDP more than doubled from 1959-2022, while the governmental administrative share remained flat and stagnant, so that administrative costs did not significantly grow over this period. Since governmental administrative costs have not appeared to grow over the 1959-2022 period, we believe our conclusions are robust to abstracting more directly from the government's role in facilitating the provision of health services.

B.2 Relative Health-services Prices

Note that PCE price indices in NIPA Table 2.5.4 are chain-weighted, unlike the Consumer Price Index from the Bureau of Labor Statistics. Chain-weighting is an attempt at accounting for composition effects possibly biasing intertemporal price comparisons. However, to reconstruct price sub-indices for narrower categorizations from chain-weighted ones, we must first unwind the chain-weighted price indices and then rewind them back up according to the alternative consumption categorizations we desire.

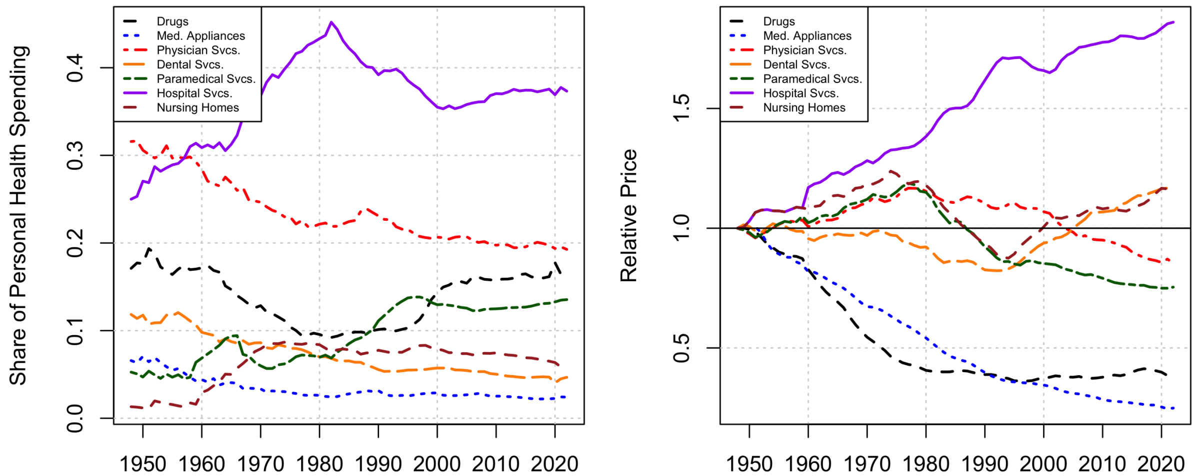
For example, NIPA Table 2.5.4 contains one price index for all "Personal consumption expenditures," which itself is comprised of 13 expenditure categories for domestic consumption: 1) "Food and beverages purchased for off-premises consumption," 2) "Clothing, footwear, and related services," 3) "Housing, utilities, and fuels," 4) "Furnishings, household equipment, and routine household maintenance," 5) "Health," 6) "Transportation," 7) "Communication," 8) "Recreation," 9) "Education," 10) "Food services and accommodations," 11) "Financial services and insurance," 12) "Other goods and services," 13) "Final consumption expenditures of nonprofit institutions serving households." Note that we require one price index for "Health" and another index for "Non-health" consumption. While we could, crudely, use the PCE's aggregate index to stand-in for non-health consumption, ideally we need to build a new price index that excludes health's contribution to aggregate PCE in order to arrive at a true estimate of the relative price of health services to non-health-services consumption.

To do this we take the various sub-categories of PCE that are *not* health services and then recombine them all into a new chain-weighted index. We follow procedures described in Whelan (2000) and Whelan (2002) and the appendices of Herrendorf, Rogerson, and Valentinyi (2013) and Bednar and Pretnar (2024). Specifically, non-health-consumption major sub-categories of PCE from NIPA Tables 2.5.4 and 2.5.5 are as follows: 1) "Food and beverages purchased for off-premises consumption," 2) "Clothing, footwear, and related services," 3) "Housing, utilities, and fuels," 4) "Furnishings, household equipment, and routine household maintenance," 5) "Transportation," 6) "Communication," 7) "Recreation," 8) "Education," 9) "Food services and accommodations," 10) "Financial services and insurance," 11) "Other goods and services," 12) "Final consumption expenditures of nonprofit institutions serving households." We let the base year of all prices be 1959, the first year of modern NIPA PCE consumption-category classifications.

B.3 Components of Health-services Prices

For illustration only we include in this appendix breakdowns of the components of health-services from NIPA Table 2.5.5 to understand which sub-sectors may be most contributing to rising sectoral shares and prices. Figure B.2 features both the shares of nominal outlay by function in panel (a), and the prices of each function of outlay relative to the health-sector aggregate price are in (b).

Looking at panel (a) notice that hospital services and paramedical services (i.e., ambulances, urgent care, and other emergency services) have been increasing in share since the 1950s. Mean-



(a) Contributors to Health PCE (b) Relative Within-sector Prices

Figure B.2: Panel (a) plots the shares of personal health spending associated with the various sub-categories by function from NIPA Table 2.5.5, while panel (b) plots the relative price of the different components of health services to the PCE aggregate health-services price level from NIPA Table 2.5.4. with all prices normalized to unity in 1948.

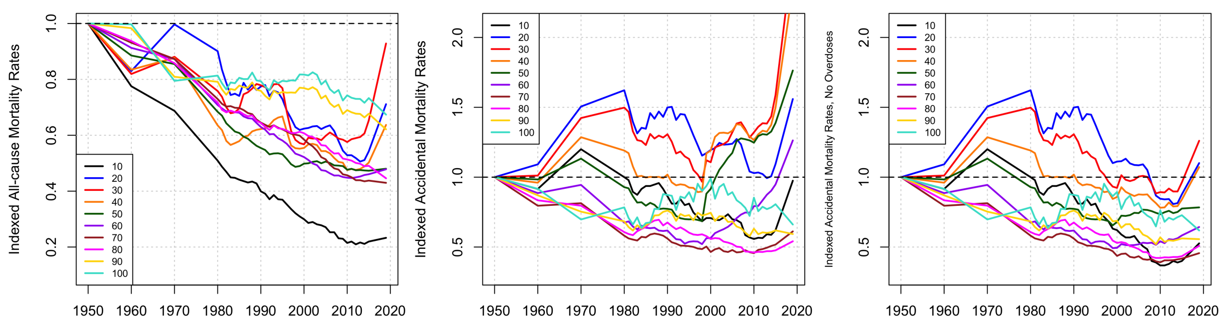
while, all other series are either decreasing or flat, with the exception of drugs' share of health-services spending, which declines from 1950-1990 before rising again to achieve its 1950 share by 2020.

Turning to panel (b) it becomes apparent, as well, that increasing prices of hospital services are likely the chief driver of increasing relative health-services prices. Note that because the composition of the expenditure basket within the health-services sector is changing and these indices are chain-weighted, we cannot directly attribute increasing relative health-services prices to increasing hospital-services prices. But, given it is the only sub-component that is increasing relative to the basket's aggregate, *and* given that its share has risen the most as it has come to dominate the basket, the empirical evidence suggests that whatever may be driving up shares and prices in the hospital-services sub-sector is likely important for rising aggregate health-services shares and relative prices — hence, our focus on markups.

B.4 Mortality Data

Sources and implications for the rise in life expectancy and decline in mortality rates since mid-century are thoroughly explored in Murphy and Topel (2006). As in Hall and Jones (2007) our health investment formulation allows the choice of health spending to affect only non-accidental mortality rates, so that accidental mortality is exogenous. In this appendix we briefly show how both accidental and non-accidental mortality rates have changed over time for different age groups. Up to 2010 accidental mortality had declined for all age groups, coinciding with increased safety regulations both in consumers' personal lives and at the workplace.[1] However, recent data suggest that there has been a reversal in the trend-decline in accidental mortality for some age groups. This has dampened, and for same age groups even reversed, the decline in all-cause mortality since 1950.

For both accidental and non-accidental mortality rates we turn to the CDC's *Health, United States 2017* mortality tables.[2] We classify accidental deaths as those corresponding to drug overdoses, car accidents, homicides, and suicides. All other deaths are indirectly classified as non-accidental and, for our modeling purposes, are considered functions of a living agents' health level which s/he can control via health investment.



(a) All Cause Mortality Growth (b) Accidental Mortality Growth (c) Accidental Growth, No Drugs

Figure B.3: All time series are normalized to unity in 1950. Panel (a) features all-cause mortality rates. Panel (b) features accidental mortality rates, including drug overdoses. To show that the recent increase in accidental mortality rates is mostly attributable to increases in overdoses, we show accidental mortality rates, excluding overdoses, in panel (c).

Specifically, we use Table 21 for all cause mortality, Table 27 for drug overdoses (since 1999), Table 28 for car accidents (since 1950), Table 29 for homicides (since 1950), and Table 30 for suicides (since 1950). Since drug-overdose deaths are only available since 1999, we interpolate back to 1950 by age using the trend from 1999 to 2017. Since the CDC reports death rates by age group for broad, 10-year age groups, except those between 1 and 4 years old, we assume that the reported age is the mid-point of the age-range (i.e., if the age range is 35-44, the age associated with the datapoint is 40) and we interpolate (linearly) across ages within a period. Then, since data is available only every 10 years until 1980, we interpolate the age-specific mortality rates over years. After interpolating drug overdoses and all non-drug accidental mortality rates across cohorts within a period and within cohorts over time, we arrive at data for accidental mortality rates by age. Finally, for non-accidental mortality rates we use all-cause mortality from Table 21 and interpolate it first within a period over cohorts and then within cohorts over time. We then subtract the accidental mortality rates from the all-cause mortality rate to get the non-accidental mortality

[1]Safety improvements to automobiles come to mind, as well as both a decline in the number of jobs requiring strenuous physical labor with dangerous machines and increased regulation regarding safety procedures associated with using such machines.

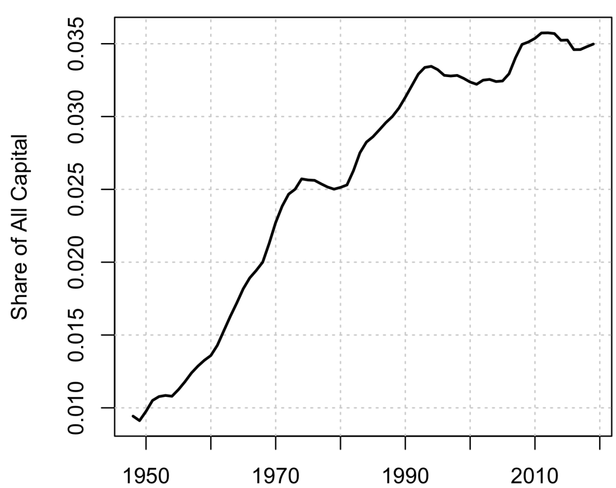
[2]The dataset can be accessed here: https://www.cdc.gov/nchs/hus/contents2017.htm.

rate. For years after 2017, we use linear extrapolation.

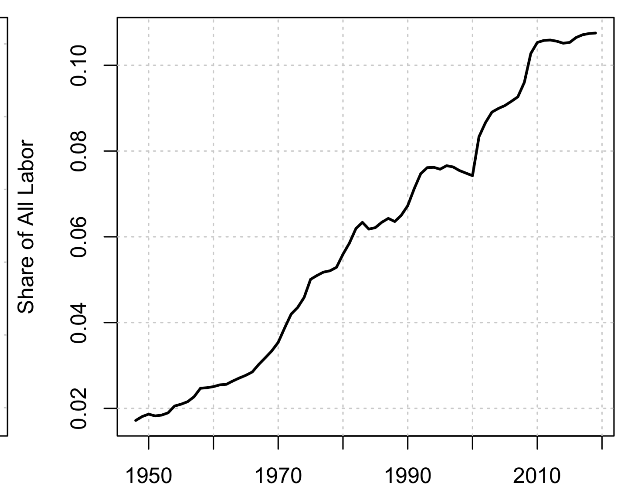
Figure B.3 shows how age-specific mortality rates have changed since 1950.[3] All cause mortality rates have declined since 1950 for all age groups, though rates have seen a recent uptick relative to long-run trends for adults aged 30 to 50. Panels (b) and (c) suggest that the uptick may be almost entirely due to recent increases in accidental mortality rates, driven by increased drug overdoses. While we take no direct stand on reasons for the rise of non-accidental mortality rates, concerns over the role of drug overdoses in driving this phenomenon have inspired an emergent new literature in economics, best punctuated by a recent working paper by Greenwood, Guner, and Kopecky (2022).

B.5 Sectoral Capital and Labor Data

We must compute sectoral capital and labor shares to assess how our model predicts general equilibrium outcomes. Specifically, we want data for the share of all capital in the economy which is used in health-services production, along with the same statistic for labor. For capital by sector we turn to the BEA's Fixed Assets Table 3.1ESI, "Current-cost Net Stock of Private Fixed Assets by Industry." This table accounts for the value of all equipment, structures, and intellectual property used in production. Capital used in the production of health services is taken to be that under the category "Health and social assistance." Total, economy-wide capital is taken to be "Private fixed assets." For the growth-accounting exercise we must deflate the nominal capital stock. To do this we use the quantity indices from the BEA's Fixed Assets Table 3.2ESI.



(a) Share of All Capital in Health



(b) Share of All Labor in Health

Figure B.4: Panel (a) presents the share of total, economy-wide capital that is used in the production of health services. Panel (b) shows the share of total, economy-wide labor, in units of full-time equivalent employees, used in the production of health services.

[3]Note that all rates are normalized to unity in 1950.

For labor by sector we turn to BEA NIPA Tables 6.5B, 6.5C, and 6.5D, which record "Full-time Equivalent Employees by Industry." Table 6.5B is used to compute the industrial composition of labor from 1948-1987, Table 6.5C is used for 1988-2000, and Table 6.5D is used for 2001 and after. In Table 6.5B and 6.5C the relevant category for health services labor is simply listed as "Health services," while for Table 6.5D we must add labor records from "Ambulatory health care services," "Hospitals," and "Nursing and residential care facilities."

Figure B.4 shows the shares of all capital and all labor used in the production of health services. These values are $K_{ht}/(K_{ht}+K_{ct})$ and $L_{ht}/(L_{ht}+L_{ct})$, respectively. Notice that the share of capital in health-services rose by approximately 2.55 percentage points from 1948 to 2019. For labor the share rose by approximately 9.03 percentage points over this period.

Finally, as a secondary assessment of our model performance, we engage in a decomposition in Section 2 and a calibration in Section 4 where we allow the labor share of the non-health sector to vary over time. The time-varying labor share time series we use is presented in Figure B.5.

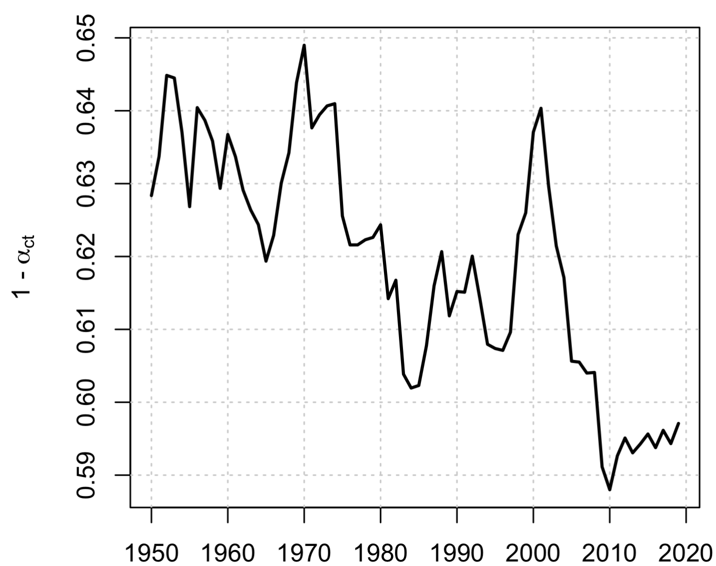


Figure B.5: We plot the labor share, $1-\alpha_{ct}$, from Feenstra, Inklaar, and Timmer (2015) that we use in our secondary decomposition and calibration exercises.

B.6 Health-sector Wages

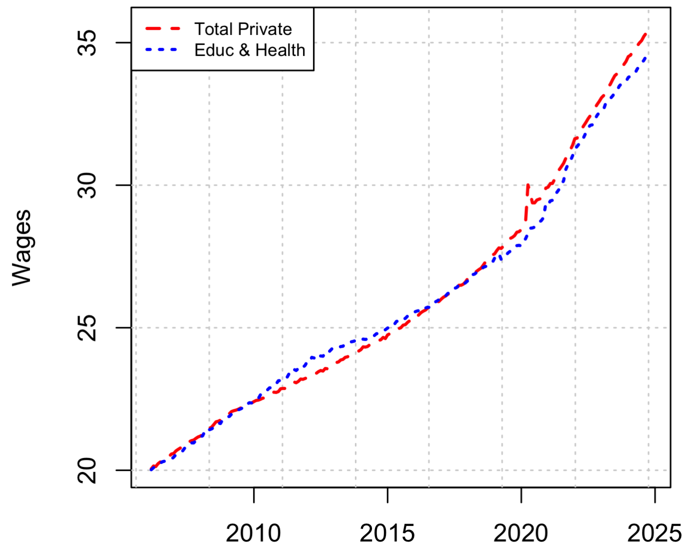


Figure B.6: Average hourly wages for the private-education plus health-services sector track exactly with average hourly wages for all private-sector workers.

As a robustness check, we turn to data from the BLS' Current Employment Statistics (Establishment Survey), Table B-3 to examine wages by sector. The goal is to provide evidence that supports the assumption that the wage rate is constant across the health and non-health sectors. Table B-3 in this survey contains sector-level average hourly wage data at a monthly frequency going back to 2006. While data for the health sector is not available on its own, Table B-3 does provide data for the sector comprising private education and health. In Figure B.6 we compare the evolution of hourly wages from March of 2006 through November of 2024 for all private-sector workers and those in the private education and health-services sectors. Note that the series track with each other almost exactly, and we conclude that the assumption that w_t is constant across the two sectors is innocuous.

C Decomposition Appendix

C.1 Decomposing Price Growth with Time-varying α_{ct}

In this appendix we show how to decompose the contributors to $\widetilde{g}_{p,t}$ while relaxing the assumption that the labor share in the broader $C + I$ sector is constant. Denote the labor share of income by $1 - \alpha_{ct}$. Assume that $1 - \alpha_{ct}$ follows the economy-wide evolution of the labor share as featured in the Penn World Tables (Feenstra, Inklaar, and Timmer 2015).[4] Assume $\alpha_h = 0.26$ is fixed,

[4] This is also series id 'LABSHPUSA156NRUG' from FRED: https://fred.stlouisfed.org.

following Donahoe (2000). Expression (5) in the main text now has additional time-varying terms:

$$\sigma_{H,t} = \mu_t \left(\frac{r_t}{w_t}\right)^{\alpha_h - \alpha_{ct}} \left(\frac{A_{ct}\alpha_{ct}^{\alpha_{ct}}(1-\alpha_{ct})^{1-\alpha_{ct}}}{A_{ht}\alpha_h^{\alpha_h}(1-\alpha_h)^{1-\alpha_h}}\right)\frac{H_t}{X_t}. \tag{C.1}$$

Its log-decomposition can be written

$$\begin{aligned}\widetilde{g}_{\sigma_H,t} = {} & \widetilde{g}_{\mu,t} + \alpha_h\left(\widetilde{g}_{r,t} - \widetilde{g}_{w,t}\right) + \widetilde{g}_{A_c,t} - \widetilde{g}_{A_h,t} + \widetilde{g}_{H,t} - \widetilde{g}_{X,t} \\ & - \alpha_{ct}\ln(r_t/w_t) + \alpha_{c,t-1}\ln(r_{t-1}/w_{t-1}) + \alpha_{ct}\ln\alpha_{ct} - \alpha_{c,t-1}\ln\alpha_{c,t-1} \\ & + (1-\alpha_{ct})\ln(1-\alpha_{ct}) - (1-\alpha_{c,t-1})\ln(1-\alpha_{c,t-1}).\end{aligned} \tag{C.2}$$

Notice that this expression is not as clean as (5). Let $\widetilde{g}_{\alpha_c,t} = \alpha_{ct}\ln\alpha_{ct} - \alpha_{c,t-1}\ln\alpha_{c,t-1}$ and $\widetilde{g}_{(1-\alpha_c),t} = (1-\alpha_{ct})\ln(1-\alpha_{ct}) - (1-\alpha_{c,t-1})\ln(1-\alpha_{c,t-1})$. Substituting out $\frac{r_t}{w_t} = \frac{\alpha_h L_{ht}}{(1-\alpha_h)K_{ht}}$ and $\widetilde{g}_{r,t} - \widetilde{g}_{w,t} = \widetilde{g}_{L_h,t} - \widetilde{g}_{K_h,t}$ from (C.2), we can write

$$\begin{aligned}\widetilde{g}_{\sigma_H,t} = {} & \widetilde{g}_{\mu,t} + \alpha_h\widetilde{g}_{L_h,t} - \alpha_h\widetilde{g}_{K_h,t} + \widetilde{g}_{A_c,t} - \widetilde{g}_{A_h,t} + \widetilde{g}_{H,t} - \widetilde{g}_{X,t} \\ & - \Delta\alpha_{ct}\ln\left(\frac{\alpha_h}{1-\alpha_h}\right) - \widetilde{g}_{\alpha_c\ln(L_h/K_h),t} + \widetilde{g}_{\alpha_c,t} + \widetilde{g}_{(1-\alpha_c),t},\end{aligned} \tag{C.3}$$

where $\Delta\alpha_{ct} = \alpha_{ct} - \alpha_{c,t-1}$ and $\widetilde{g}_{\alpha_c\ln(L_h/K_h),t} = \alpha_{ct}\ln(L_{ht}/K_{ht}) - \alpha_{c,t-1}\ln(L_{ht}/K_{ht})$. Now substitute out $\widetilde{g}_{H,t} = \widetilde{g}_{A_h,t} + \alpha_h\widetilde{g}_{K_h,t} + (1-\alpha_h)\widetilde{g}_{L_h,t}$ to get

$$\widetilde{g}_{\sigma_H,t} = \widetilde{g}_{\mu,t} + \widetilde{g}_{L_h,t} + \widetilde{g}_{A_c,t} - \widetilde{g}_{X,t} - \Delta\alpha_{ct}\ln\left(\frac{\alpha_h}{1-\alpha_h}\right) - \widetilde{g}_{\alpha_c\ln(L_h/K_h),t} + \widetilde{g}_{\alpha_c,t} + \widetilde{g}_{(1-\alpha_c),t}. \tag{C.4}$$

Just like in the main text, we can identify $\widetilde{g}_{\mu,t}$ from (C.4). Unlike in the main text, however, (C.4) depends on α_h, while (7) does not. Thus, if α_{ct} (labor share in the non-health sector) is time-varying then we must make an assumption regarding the value of α_h (labor share in the health sector) in order to identify the growth rate of relative markups. Still, though, the growth rate of relative markups can be identified in (C.4) independent of knowledge regarding $\widetilde{g}_{A_h,t}$. To get the health-sector TFP growth rate we can simply return to a version of (8) where the non-health-sector labor share is time dependent:

$$\widetilde{g}_{p,t} = \widetilde{g}_{\mu,t} + (\alpha_h - \alpha_{ct})\left(\widetilde{g}_{L_h,t} - \widetilde{g}_{K_h,t}\right) + \widetilde{g}_{A_c,t} - \widetilde{g}_{A_h,t}. \tag{C.5}$$

To summarize, given an assumption regarding α_h (Donahoe 2000), data on $1-\alpha_{ct}$ and $\widetilde{g}_{A_c,t}$ (Penn World Tables), $\widetilde{g}_{\sigma_H,t}$ (NIPA PCE), $\widetilde{g}_{K_h,t}$ (BEA Fixed Asset Tables 3.1 and 3.2; see Appendix B.5), $\widetilde{g}_{L_h,t}$ (NIPA Tables 6.5B, 6.5C, and 6.5D; see Appendix B.5), and $\widetilde{g}_{X,t}$ (NIPA PCE), we can back out $\widetilde{g}_{\mu,t}$ from (C.4). The growth in relative markups is thus identified independent of knowledge of $\widetilde{g}_{A_h,t}$ but *not* independent of α_h when α_{ct} is time-varying. Then, given $\widetilde{g}_{\mu,t}$ from (C.4) we can identify $\widetilde{g}_{A_h,t}$ from (C.5). With all growth-accounting objects in hand, we can then engage in the same decomposition as in the baseline exercise.

C.2 Robustness — Estimating α_h Given $\widetilde{g}_{A_h,t}$

Our baseline estimate of $\widetilde{g}_{A_h,t}$ in the main text, under the assumption that α_c is constant, gives us an average-annual growth rate of 0.3% from 1955 to 2019, compared to an average-annual growth rate of 0.6% for $\widetilde{g}_{A_c,t}$. This estimate is actually on the higher end of estimates for health-sector TFP growth from the literature, which roughly posits a sector-wide range between -0.3% and 0.4%, annually. How much is our assumption regarding α_h helping drive the sectoral TFP estimates?[5] As a robustness check we now assume various annualized values for $\widetilde{g}_{A_h,t} = \widetilde{g}_{A_h}$ over a range from the literature and estimate α_h given $\widetilde{g}_{\mu,t}$ using the expression in (8) as follows:

$$\widetilde{g}_{p,t} - \widetilde{g}_{\mu,t} + \alpha_c \left(\widetilde{g}_{L_h,t} - \widetilde{g}_{K_h,t}\right) - \widetilde{g}_{A_c,t} + \widetilde{g}_{A_h} = \alpha_h \left(\widetilde{g}_{L_h,t} - \widetilde{g}_{K_h,t}\right) + \epsilon_t. \tag{C.6}$$

This is a linear regression without an intercept, where the left-hand-side values are taken as data, and the regression operates on the right-hand-side variable $\widetilde{g}_{L_h,t} - \widetilde{g}_{K_h,t}$. Since this is a GE model using aggregate data, all variables are endogenous. The error term, ϵ_t, will thus be biased. Therefore, we let one-period lagged values of $\widetilde{g}_{p,t}$, $\widetilde{g}_{\mu,t}$ (taken as identified from (7)), $\widetilde{g}_{L_h,t} - \widetilde{g}_{K_h,t}$, and $\widetilde{g}_{A_c,t}$ stand as instrumental variables in a 2SLS regression of (C.6) to identify α_h conditional on assumptions regarding $\widetilde{g}_{A_h}$.

Table C.1: 2SLS Regressions of (C.6) with One-period Lagged IV's

$\widetilde{g}_{A_h}$	0.000	0.001	0.004	-0.003	-0.006	0.010
$\widehat{\alpha}_h$	0.328	0.340	0.376	0.292	0.256	0.448
	(0.049)	(0.048)	(0.047)	(0.052)	(0.056)	(0.047)
R^2	0.404	0.430	0.499	0.321	0.238	0.588

The results of this regression for each of the assumptions on $\widetilde{g}_{A_h}$ are presented in Table C.1. Recall that the literature discussing the value of α_h is sparse relative to the literature estimating values for $\widetilde{g}_{A_h}$. The literature provides strong support for TFP growth-rates such that, $-0.003 \leq \widetilde{g}_{A_h} \leq 0.001 << \widetilde{g}_{A_c}$. Given estimates of α_h from Donahoe (2000), we should expect our estimates of α_h to fall between 0.25 and approximately $0.35 < \alpha_c$, as the health sector is considered to be more labor-intensive than the broader economy. In our regression this holds for reasonable values of $\widetilde{g}_{A_h}$.

D Quantitative Model Appendix

D.1 Solving the Household's Problem

All exogenous processes are assumed to evolve deterministically, since this model features a representative agent and is primarily about long-run growth, not short-run fluctuations. In this section we drop time (t) subscripts. For a given set of prices $\{r, w, q, b, \{T_j, \pi_j\}\}$, where b and $\{T_j, \pi_j\}$

[5] In this robustness exercise we always assume α_c is constant.

are endogenous to the general equilibrium but exogenous from the perspective of the household, we solve the household's problem using the Carroll (2006) modification of Krueger and Ludwig (2007) as follows:

i. Set a fixed grid for assets, $\mathscr{A}$, and endogenous, age-dependent grid for cash-on-hand, $\mathscr{C}_j$, where $\mathscr{C}_J$ (the grid for the agent in its last period of life) is fixed.

ii. For age J agents, set the consumption policy $c_J = \mathscr{C}_J$ at every point along the grid and compute $\mathcal{V}(c_J) = \chi + \xi\, c_J^{1-\gamma}/(1-\gamma)$. Set $h_J = a'_J = s_J = 0$, where a'_J are assets at age $J+1$, which of course is zero because the agent would be dead.

iii. Iterate back from $j = J-1$ to $j = 1$ doing the following:

   a. Let $\underline{\mathscr{C}}$ denote the smallest cash-on-hand grid point which is fixed for all ages. Set the minimum consumption level (first grid point in c_j) to $c_j = \underline{\mathscr{C}}$ and make the corresponding grid points $h_j = a'_j = s_j = 0$.

   b. Now iterate forward on the elements of $\mathscr{A}$, which should be a strictly increasing grid, setting $cash_{j+1} = w\eta_{j+1}(1-\tau) + (1+r-\delta)(\mathscr{A}+b) + T_{j+1} + \pi_j$ for each element of $\mathscr{A}$. Note that $T_j = 0$ if $j < J_R$, $T_j = T$ (constant) if $j \geq J_R$, and $\eta_j = 0$ for $j \geq J_R$. This is the value of cash an age-j agent today will have at age $j+1$ if they survive and also choose the particular element of $\mathscr{A}$. Thus, there should be as many $cash_{j+1}$ as there are elements on $\mathscr{A}$.

   c. Compute c'_j (future c) and $\mathcal{V}'_j$ (future $\mathcal{V}$) by interpolating each point $cash_{j+1}$ on the endogenous grid $\mathscr{C}_{j+1}$.

   d. With c'_j and $\mathcal{V}'_j$ in hand, calculate $h_j(\mathscr{A})$ and $c_j(\mathscr{A})$ by solving the first-order condition:

$$\frac{\partial s_j}{\partial h_j}\mathcal{V}'_j = p\, s_j(h_j)\,(1+r-\delta)\,(c'_j)^{-\gamma}$$

   This is the health choice as a function of the asset grid points. Again, there should be as many elements of h_j as there are elements of $\mathscr{A}$ (one for each point).

   e. Given $h_j(\mathscr{A})$ compute $s_j(\mathscr{A})$ and $c_j(\mathscr{A})$, where s_j is given directly by the survival function, and c_j solves the first-order condition:

$$q\, c_j^{-\gamma} = \beta\, \frac{\partial s_j}{\partial h_j}\mathcal{V}'_j$$

   f. Update the endogenous cash grid and a'_j:

$$\mathscr{C}_j = \mathscr{A} + c_j + q\, h_j$$
$$a'_j = \mathscr{A}$$

   g. Send j to $j-1$ and repeat until all policy functions are in hand.

D.2 Solving the General Equilibrium

After solving the household's problem given the price vector, we follow Krueger and Ludwig (2007) and iterate on the price vector $\{r, w, p, b, \{T_j, \pi_j\}\}$ to solve the GE. Some innovations are required to pin down the allocation of capital and labor to the two sectors. Further, we must ensure the monopolistically competitive markup over marginal cost is satisfied.

We start by solving an artificial steady state in period $t = 1$ which corresponds to the year 1950. We then iterate forward by setting the prices for period $t-1$ to be the starting values for period t and moving the growth objects forward one period. Recall, the objects that grow/change over time are $\{N_{1t}, z_t, A_{ct}, A_{ht}, \mu_t, \{\zeta_{jt}\}_j\}_t$, where the population of newborns, economy-wide health-investment productivity, sectoral TFP's, and age-specific health-investment productivities grow at constant rates, while the time series for $\{\mu_t\}_t$ is directly calibrated. Next, we iterate on the household problem under these prices to solve for the policies. We then aggregate the household problem and use a root-solver (Broyden's method) to find the price vector which solves a system of equations that correspond to the equilibrium allocations of capital and labor across sectors in the given period t.

The following algorithm solves the GE along the transition path:

i. For a given set of prices $\{r, w, p, b, \{T_j, \pi_j\}\}$, solve for household policy functions as described in Technical Appendix D.1.

ii. To aggregate household decisions we start by assuming that in every period the first generation enters the economy with $a_1 = 0$, though they may have bequests, b. Given this assumption we can use the endogenous grids, $\mathscr{C}_j$, to iterate over the age distribution within the period from $j = 2$ to J to solve for the optimal decision paths for a', c, h, and s. This step involves interpolation over equilibrium available cash-on-hand, which is given by $cash_j = w\eta_j(1-\tau) + (1 + r - \delta)(a_j + b) + T_j + \pi_j$. In this first period's steady state a_j is the optimal decision made by the age $j-1$ agent in the same period. Along the transition path $a_j = a'_{j-1,t-1}$, so that the optimal asset allocation decision made by an age $j-1$ agent in period $t-1$ is taken to be the asset level of a living age j agent in period t. This ensures that the aggregate capital used in t is equal to that which the surviving agents from period $t-1$ carried forward into the future plus $b \sum_j N_j$, which is the total capital bequeathed by those who died at the end of $t-1$.

iii. To complete aggregation we also need the population levels by age. Note that $N_{1,1} = 0$ in the initial period's steady state. Thereafter, we compute the population by cohort as $N_{jt} = s_{j-1,t-1} N_{j-1,t-1}$, where we re-introduce time subscripts here to show that, along the transition path, the population of cohort j in period t is simply those age $j-1$ agents from period $t-1$ who survived to live another year.

iv. Aggregate the household decisions: $L = \sum_j N_j \eta_j$, $K = \sum_j N_j(a_j + b)$, $K' = \sum_j N_j a'_j$, $H = \sum_j N_j h_j$, $C = \sum_j N_j c_j$. Also, $I = K' - (1-\delta)K$.

v. Now, use the fact that under Cobb-Douglas production marginal costs can be written as functions of input prices as in (3). Use the marginal cost condition from (3) to compute the fractions of capital and labor going to each sector as:

$$
\begin{aligned}
K_c &= \left(\frac{mc^c(w,r\,;\, A_c)\,\alpha_c\,(C+I)}{mc^c(w,r\,;\, A_c)\,\alpha_c\,(C+I) + mc^h(w,r\,;\, A_h)\,\alpha_h\,H} \right) K \\
K_h &= \left(\frac{mc^h(w,r\,;\, A_h)\,\alpha_h\,H}{mc^c(w,r\,;\, A_c)\,\alpha_c\,(C+I) + m^h(w,r\,;\, A_h)\,\alpha_h\,H} \right) K \\
L_c &= \left(\frac{mc^c(w,r\,;\, A_c)\,(1-\alpha_c)\,(C+I)}{mc^c(w,r\,;\, A_c)\,(1-\alpha_c)\,(C+I) + mc^h(w,r\,;\, A_h)\,(1-\alpha_h)\,H} \right) L \\
L_h &= \left(\frac{mc^h(w,r\,;\, A_h)\,(1-\alpha_h)\,H}{mc^c(w,r\,;\, A_c)\,(1-\alpha_c)\,(C+I) + mc^h(w,r\,;\, A_h)\,(1-\alpha_h)\,H} \right) L
\end{aligned}
$$

vi. Compute the pricing relationships between aggregates, including health sector profits:

$$
\begin{aligned}
r &= A_c\,\alpha_c \left(\frac{K_c}{L_c} \right)^{\alpha_c - 1} \\
w &= A_c(1-\alpha_c) \left(\frac{K_c}{L_c} \right)^{\alpha_c} \\
p &= \mu \left(\frac{mc^h(w,r\,;\, A_h)}{mc^c(w,r\,;\, A_c)} \right) \\
b &= \frac{\sum_j (1-s_j) N_j a_j'}{\sum_j N_j} \\
T_j &= \begin{cases} 0, & j < J_R \\ \frac{\sum_j N_j\, w\, \eta_j\, \tau}{\sum_j N_j}, & j \geq J_R \end{cases} \\
\pi_j &= \left(\frac{a_j + b}{K} \right) \Pi
\end{aligned}
\tag{D.1}
$$

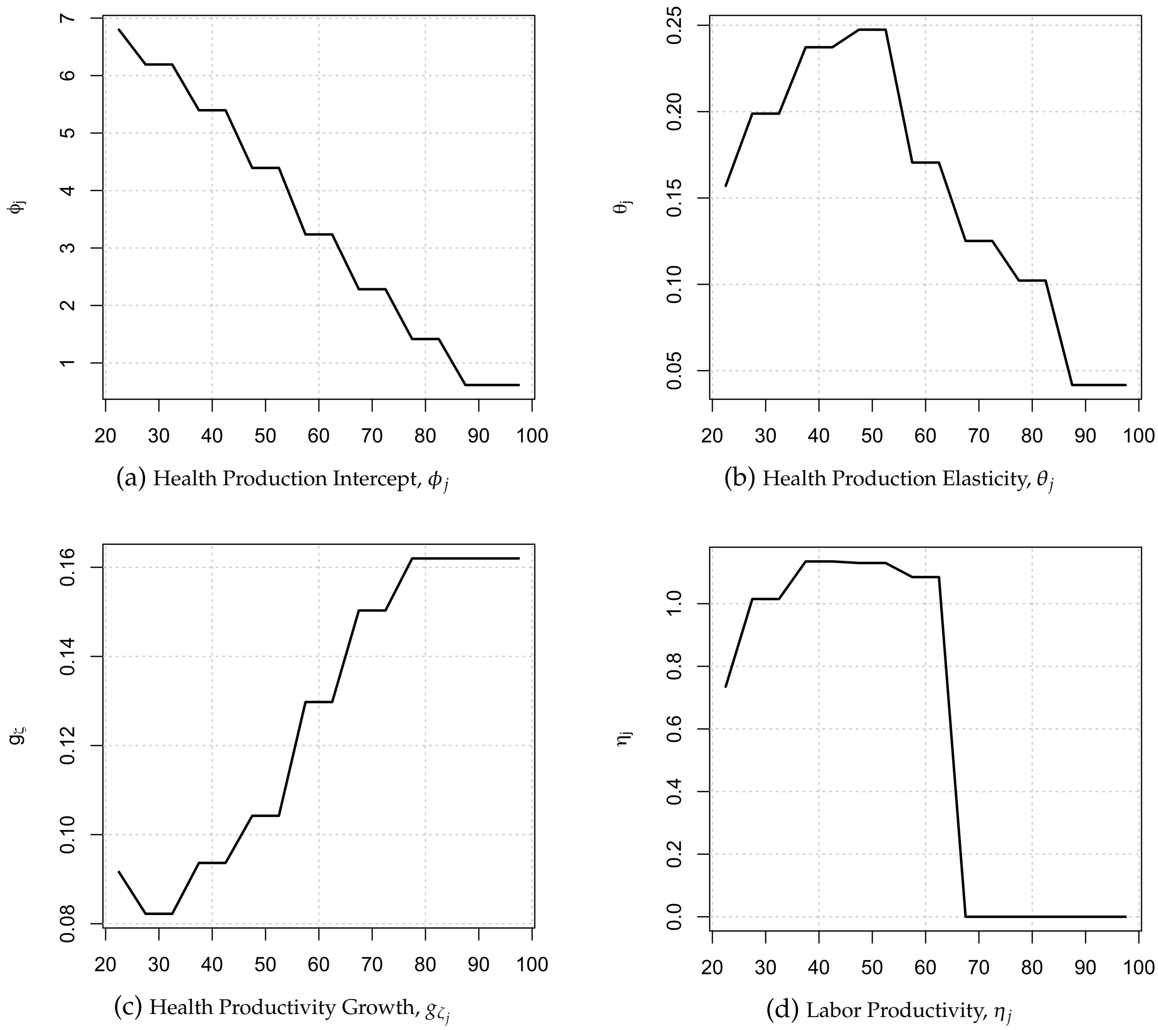
vii. Note that (D.1) forms a self-map on the price vector, as in Krueger and Ludwig (2007). Let $\mathscr{P}$ be the collapsed price vector $\{r, w, p, b, \{T_j, \pi_j\}\}$. Further, let $\boldsymbol{f}(\mathscr{P})$ describe the self-map in (D.1) which is a $J+6$-dimensional, vector-valued function.[6] The root-finder seeks to solve for the price set such that $\mathscr{P} = \boldsymbol{f}(\mathscr{P})$.

viii. When the root has been found, set $\mathscr{P}_{t+1} = \mathscr{P}_t$ as an initial value, iterate the growth parameters forward, and solve for the next period's prices, returning to part (i).

[6] There are J values of π_j, two T_j though one is trivial, and four other prices.

D.3 Exogenously Calibrated Sets of Parameters

In this appendix we show the following age-dependent, health-production parameters which are taken from Hall and Jones (2007) and Hansen (1993) — $\{\phi_j\}_j$, $\{\theta_j\}_j$, $\{g_{\zeta_j}\}_j$, and $\{\eta_j\}_j$. Note that growth rates for ζ_{jt} are age-dependent but constant over time. For the labor productivity parameters we take the average of the male/female productivity estimates from Hansen (1993). All of the age-dependent parameter values are in Figure D.1.



(a) Health Production Intercept, ϕ_j

(b) Health Production Elasticity, θ_j

(c) Health Productivity Growth, g_{ζ_j}

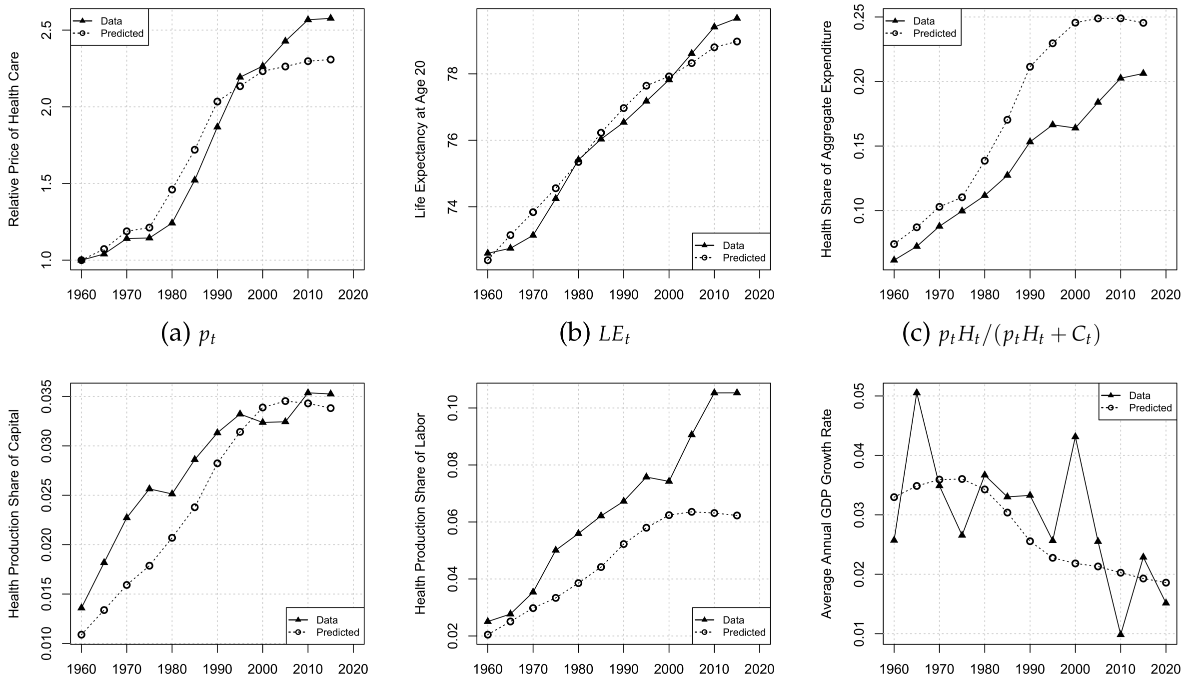
(d) Labor Productivity, η_j

Figure D.1: Panels (a) through (d) contain plots of the exogenously calibrated age-dependent parameters, ϕ_j, θ_j, g_{ζ_j}, and η_j, respectively.

D.4 Model Fitness for Alternative Calibrations

This appendix presents analogous plots to those in Figure 5 for the non-baseline calibrations. In order we show model fits against data for the constant α_c model with relative markup growth stopping in 2015 (calibration (2) in Figure D.2), time-varying α_{ct} model (calibration (3) in Figure D.3), the model with markups extracted directly from Horenstein and Santos (2019) (calibration (4) in Figure D.4), and the model where relative markup growth is assumed to be zero (calibration (5) in Figure D.5).

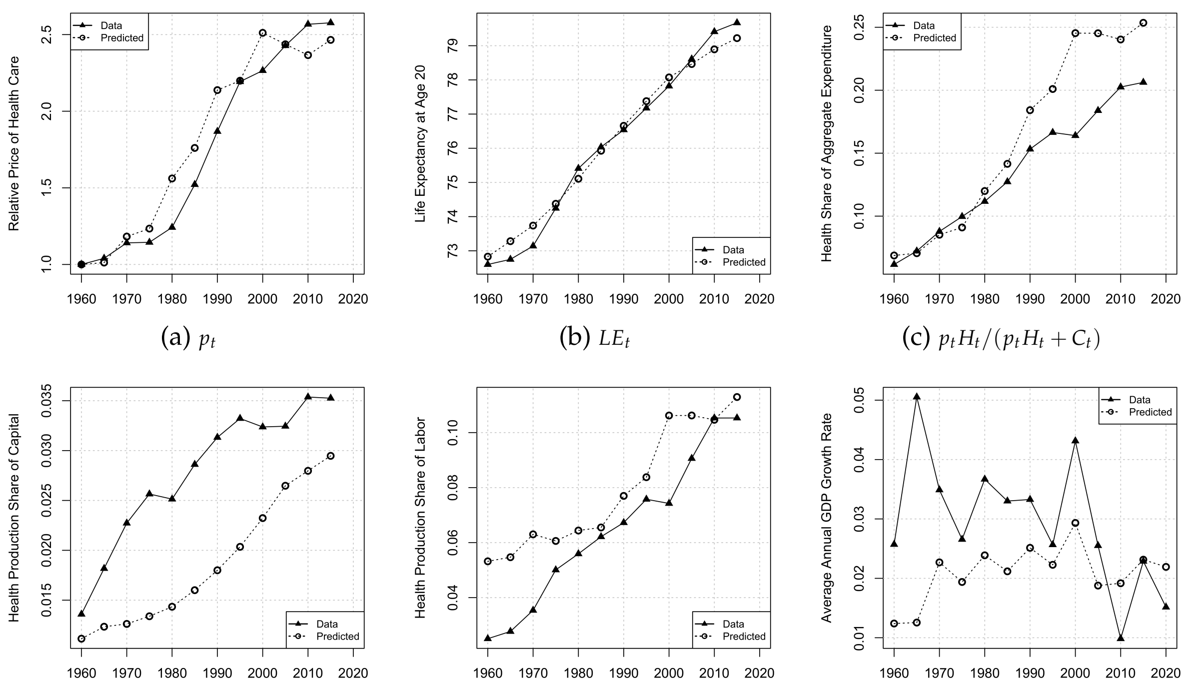
Note that all models fit the growth in life expectancy well: this is because life-expectancy variation is almost entirely driven by z_t, estimates of which are similar across different calibrations. The time-varying α_{ct} model is also the apparently best predictor of relative price growth, though this comes at the expense of poor performance predicting the factor-input shares (see Figures **??** and D.3e), while also undershooting GDP growth rates (see Figure D.3f). Horenstein and Santos (2019) markups undershoot price growth (see Figure D.4a), while overshooting expenditure-share growth (see Figure **??**). On average the Horenstein and Santos (2019) model performs closest to the baseline calibration, though performs relatively worse with regards to factor-input share growth. Without allowing for markup growth, unbalanced technical change does most of the work in driving up relative prices but, as we see in Figure D.5a, it fails to adequately explain the relative price growth. Indeed, Figure D.5 can accurately match all but p_t and the capital share in health production, showing that more than just unbalanced technical change and the changing composition of demand is needed to explain health-sector structural change.



(a) p_t (b) LE_t (c) $p_t H_t/(p_t H_t + C_t)$

(d) K_{ht}/K_t (e) L_{ht}/L_t (f) $g_{Y,t}$

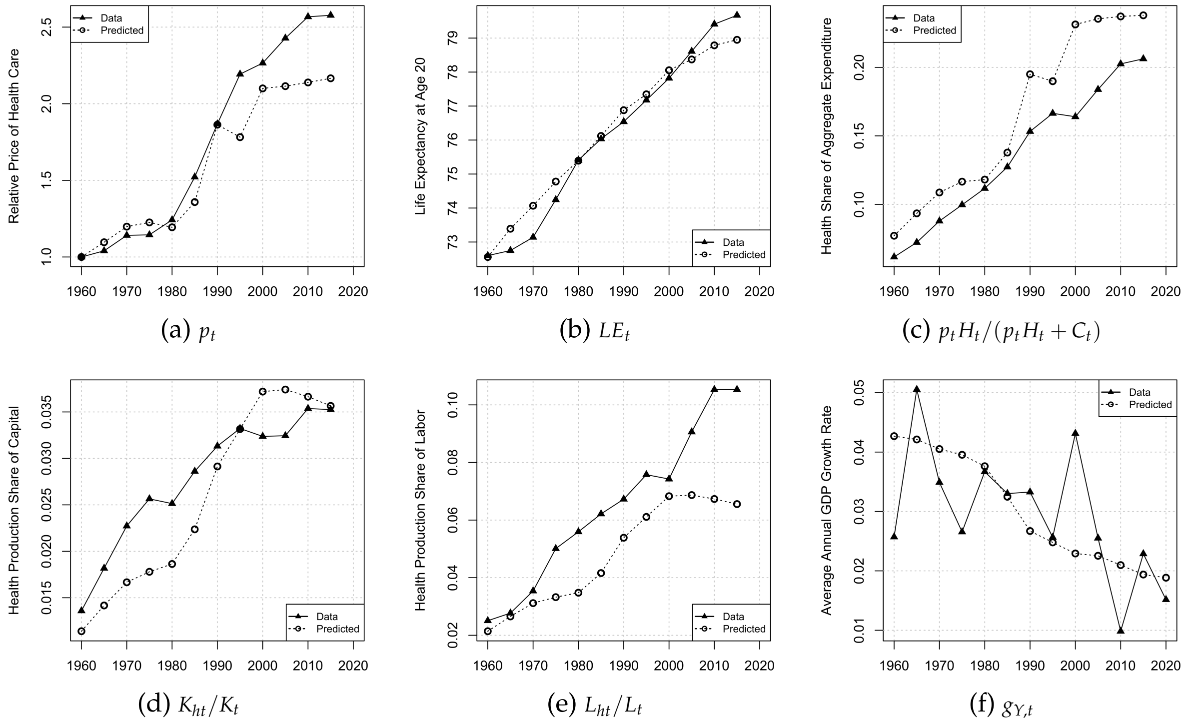
Figure D.2: This figure shows model fit for calibration (2).



(a) p_t (b) LE_t (c) $p_t H_t/(p_t H_t + C_t)$

(d) K_{ht}/K_t (e) L_{ht}/L_t (f) $g_{Y,t}$

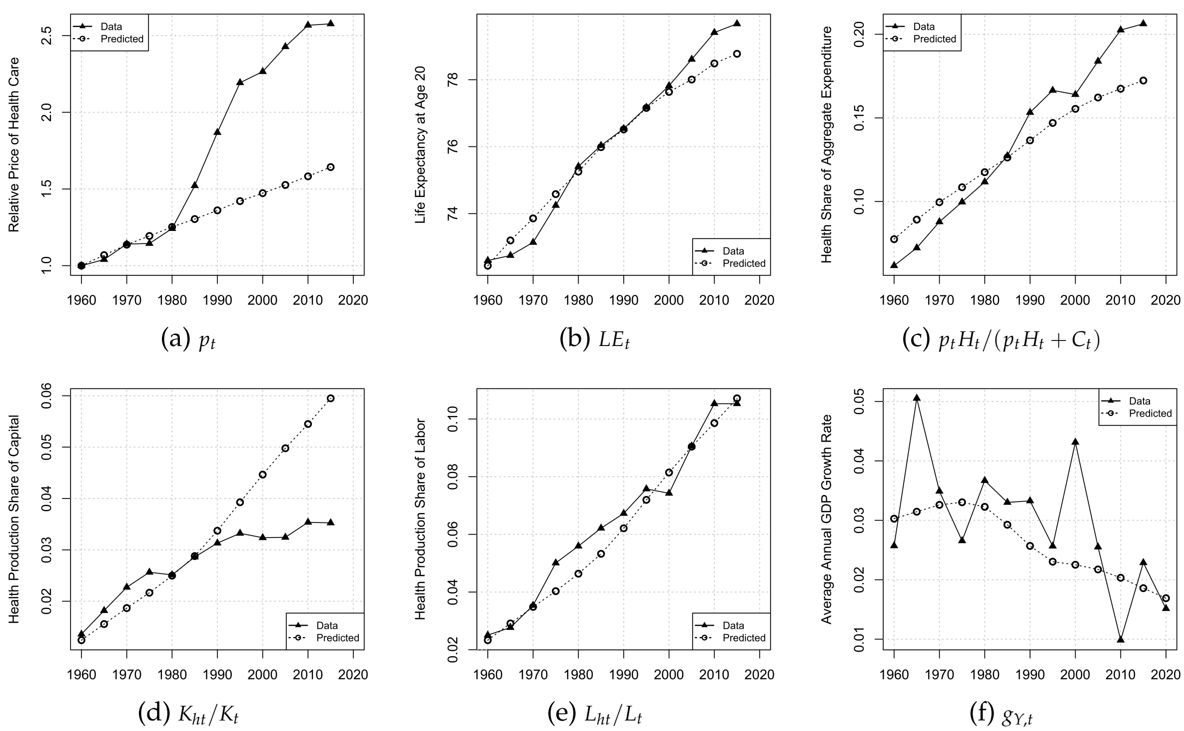
Figure D.3: This figure shows model fit for calibration (3).



(a) p_t (b) LE_t (c) $p_t H_t/(p_t H_t + C_t)$

(d) K_{ht}/K_t (e) L_{ht}/L_t (f) $g_{Y,t}$

Figure D.4: This figure shows fitness for the calibration (4).



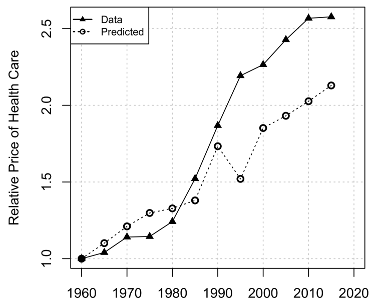
(a) p_t (b) LE_t (c) $p_t H_t/(p_t H_t + C_t)$

(d) K_{ht}/K_t (e) L_{ht}/L_t (f) $g_{Y,t}$

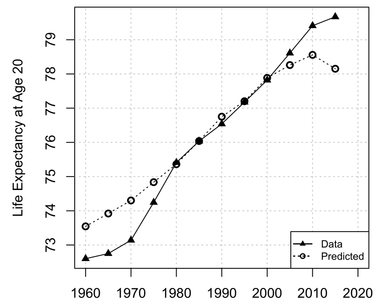
Figure D.5: This figure shows fitness for calibration (5).

D.5 Robustness — Baseline Calibration with H-S Markups

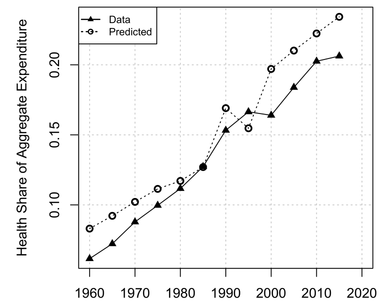
In this appendix we re-simulate calibration (2) after replacing markups with those from Horenstein and Santos (2019). This increases RMSE by over 97%, which is mostly a result of failing to accurately predict relative prices.



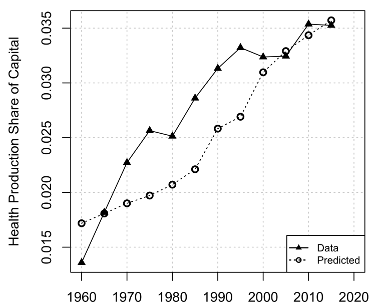
(a) p_t



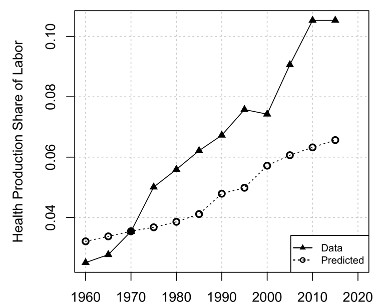
(b) LE_t



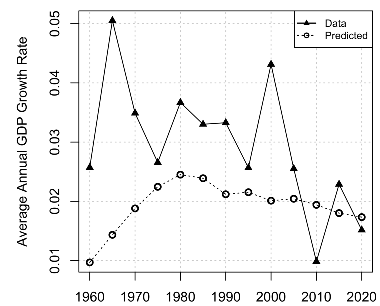
(c) $p_t H_t / (p_t H_t + C_t)$



(d) K_{ht}/K_t



(e) L_{ht}/L_t

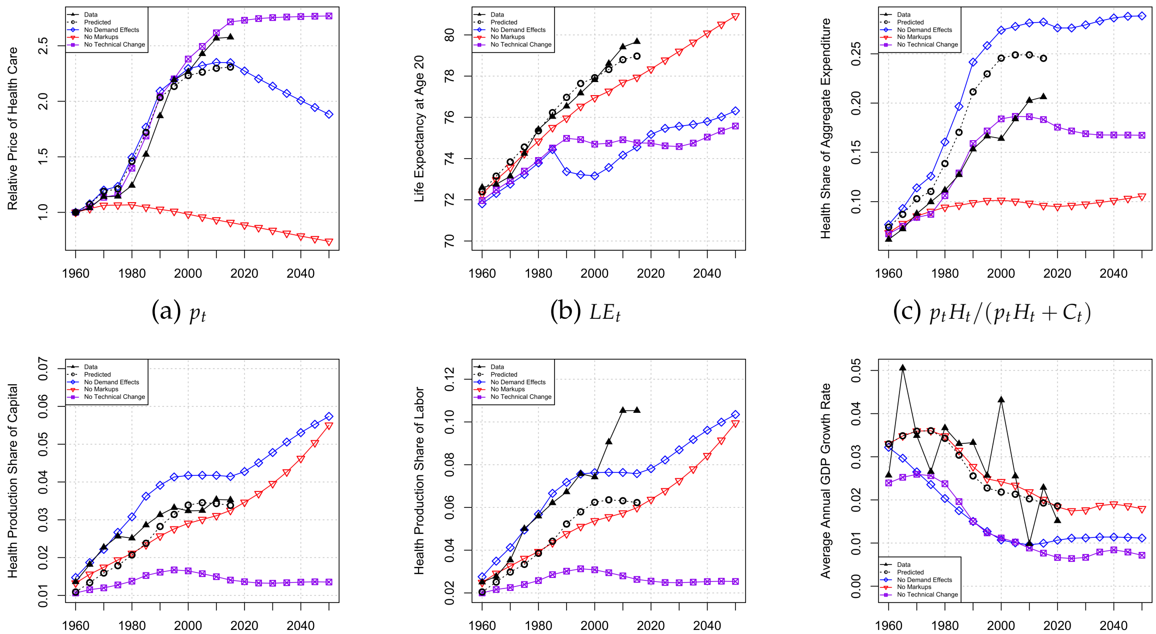


(f) $g_{Y,t}$

Figure D.6: This figure shows predicted values (round dots and dashed line) from the baseline model where only markup growth rates are replaced with Horenstein and Santos (2019) markups against data (solid triangles and solid line).

D.6 Counterfactuals Under Alternative Calibrations

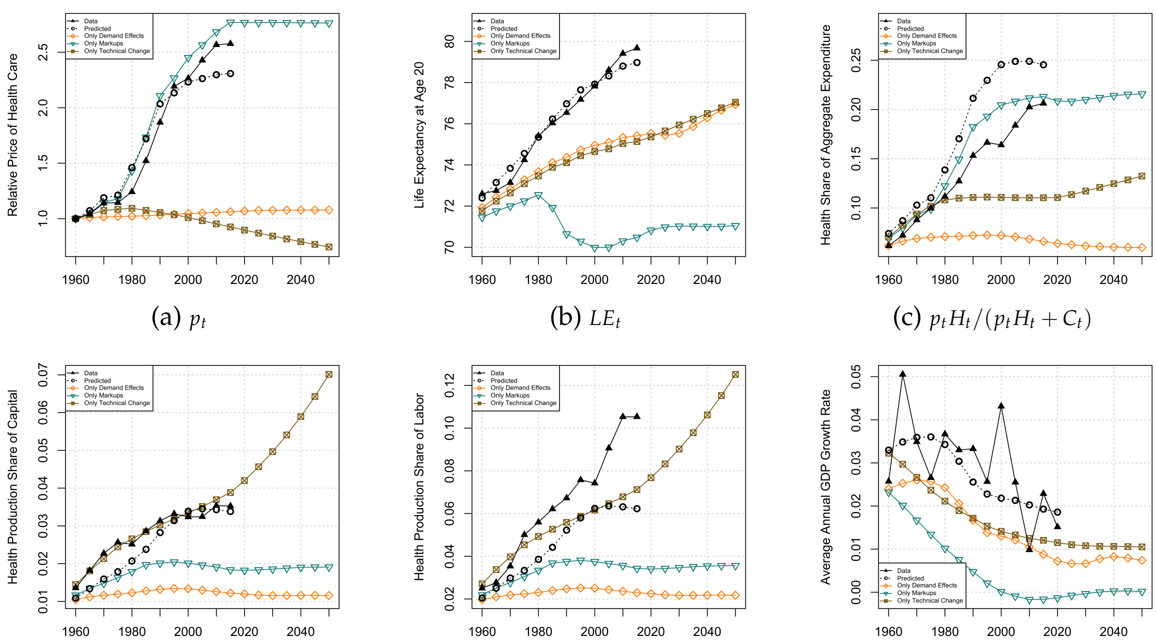
The figures in this appendix mirror those in Figures 7 and 8 from the main text. While the model with time-varying α_{ct} (yields results that slightly deviate from the main text counterfactuals, using slower markup growth rates as in Horenstein and Santos (2019) does not qualitatively alter our results. In order Figures D.7 and D.8 show the constant α_c counterfactuals with no markup growth after 2015, Figures D.9 and D.10 show the time-varying α_{ct} counterfactuals, Figures D.11 and D.12 show the counterfactuals with Horenstein and Santos (2019) markups, and Figures D.13 and D.14 show counterfactuals with zero markup growth.



(a) p_t (b) LE_t (c) $p_t H_t/(p_t H_t + C_t)$

(d) K_{ht}/K_t (e) L_{ht}/L_t (f) GDP Growth Rates

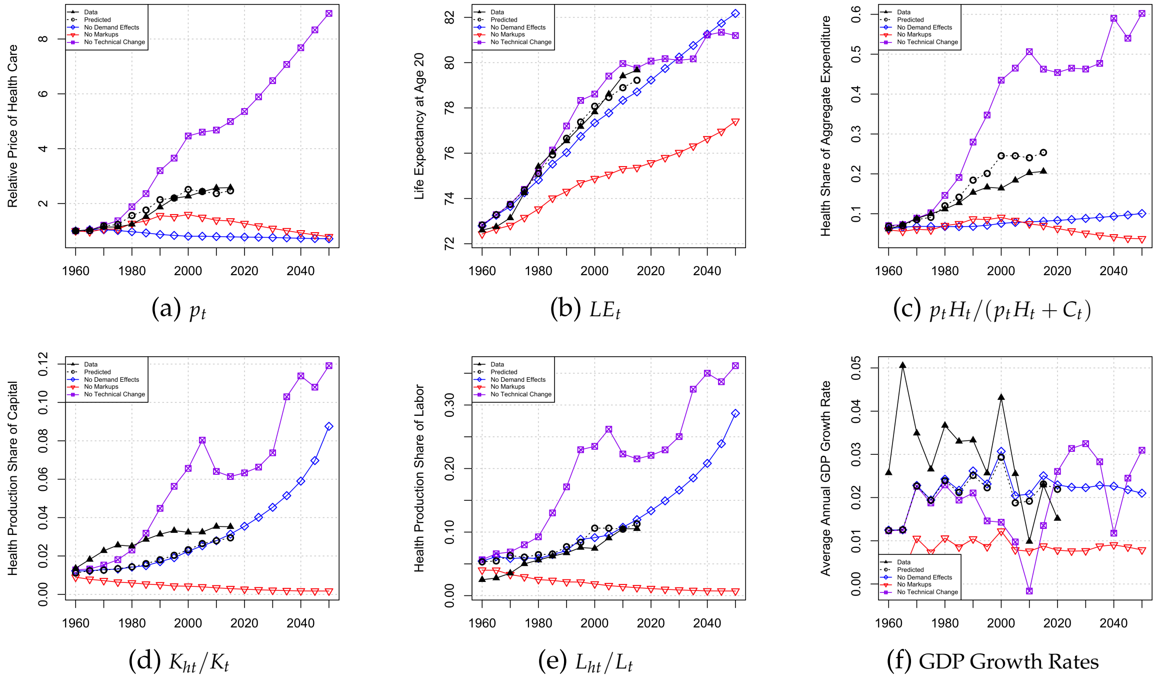
Figure D.7: This figure shows counterfactual values (round dots and dashed line) from the constant α_c model with no markup growth after 2015, turning off growth channels one at a time.



(a) p_t (b) LE_t (c) $p_t H_t/(p_t H_t + C_t)$

(d) K_{ht}/K_t (e) L_{ht}/L_t (f) GDP Growth Rates

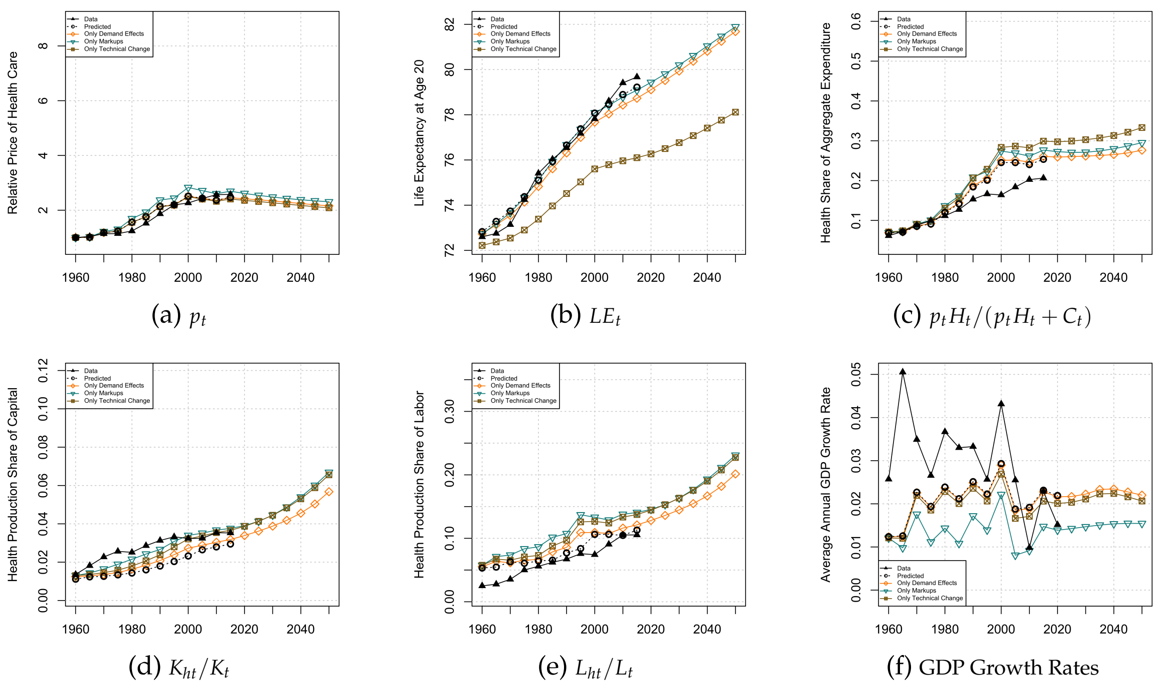
Figure D.8: This figure shows counterfactual values (round dots and dashed line) from the constant α_c model with no markup growth after 2015, leaving on only one growth channel at a time.



(a) p_t (b) LE_t (c) $p_tH_t/(p_tH_t + C_t)$

(d) K_{ht}/K_t (e) L_{ht}/L_t (f) GDP Growth Rates

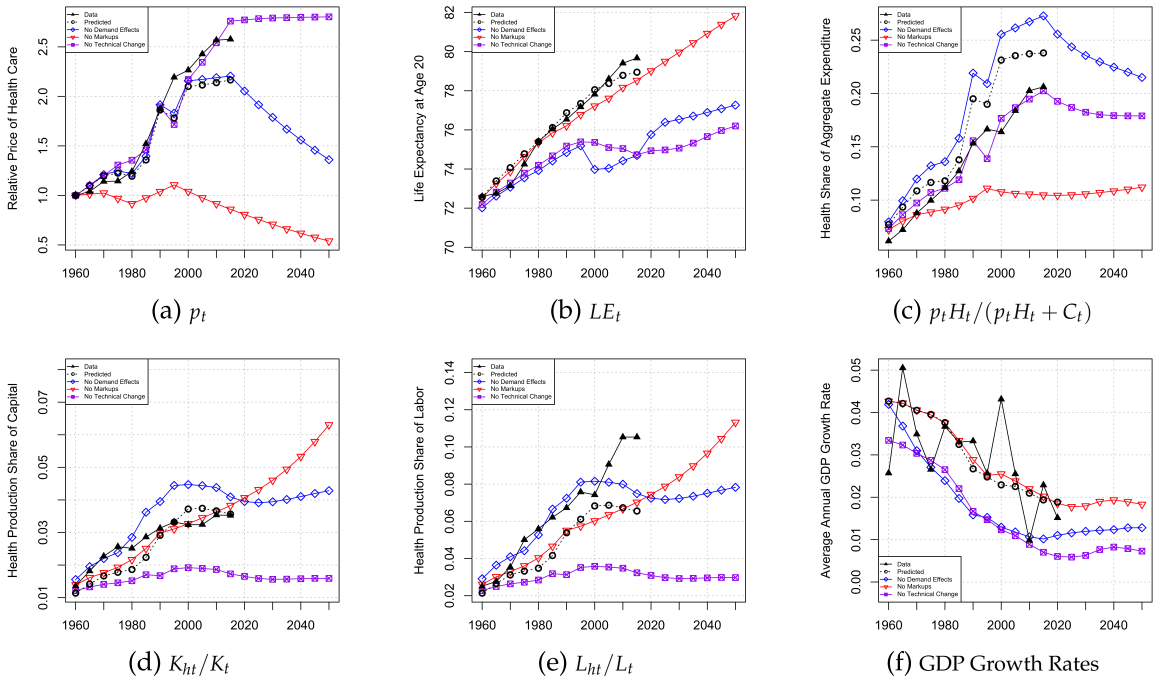
Figure D.9: This figure shows counterfactual values (round dots and dashed line) from the time-varying α_{ct} model, turning off growth channels one at a time.



(a) p_t (b) LE_t (c) $p_tH_t/(p_tH_t + C_t)$

(d) K_{ht}/K_t (e) L_{ht}/L_t (f) GDP Growth Rates

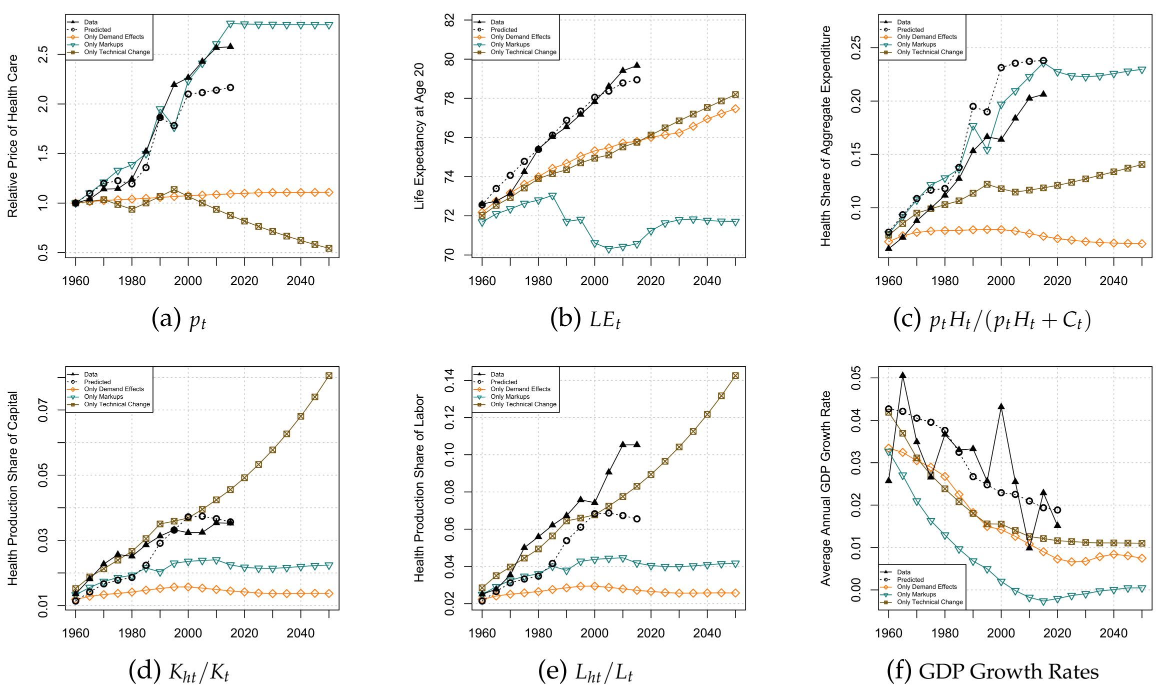
Figure D.10: This figure shows counterfactual values (round dots and dashed line) from the time-varying α_{ct} model, leaving on only one growth channel at a time.



(a) p_t (b) LE_t (c) $p_t H_t/(p_t H_t + C_t)$

(d) K_{ht}/K_t (e) L_{ht}/L_t (f) GDP Growth Rates

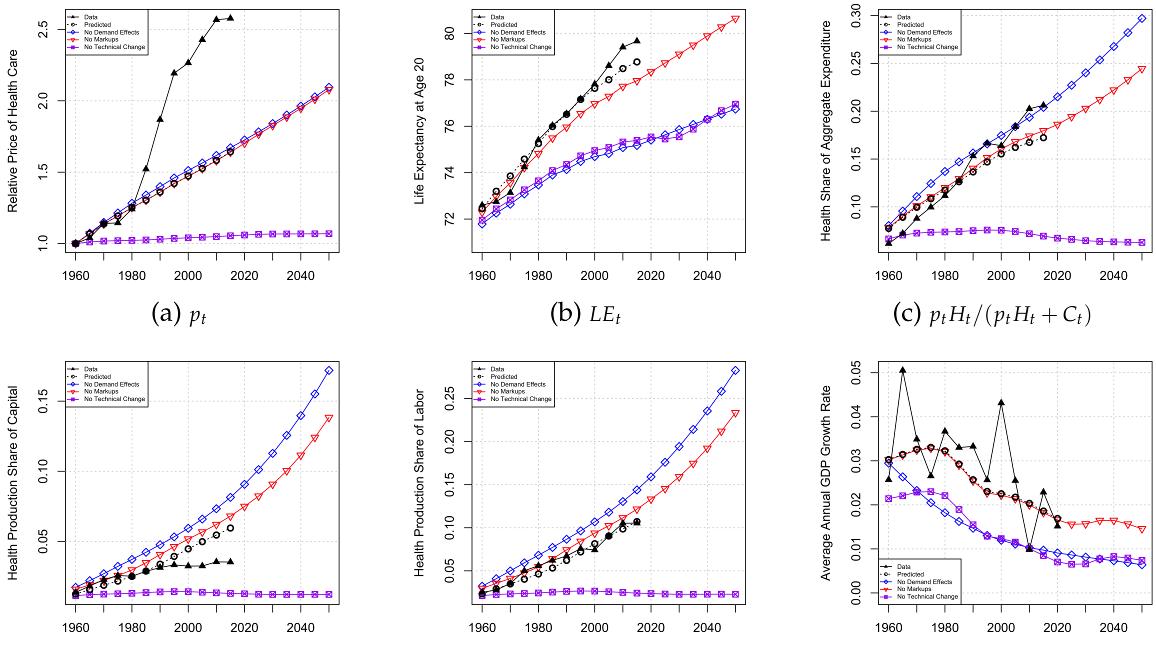
Figure D.11: This figure shows counterfactual values (round dots and dashed line) from the Horenstein and Santos (2019) model, turning off growth channels one at a time.



(a) p_t (b) LE_t (c) $p_t H_t/(p_t H_t + C_t)$

(d) K_{ht}/K_t (e) L_{ht}/L_t (f) GDP Growth Rates

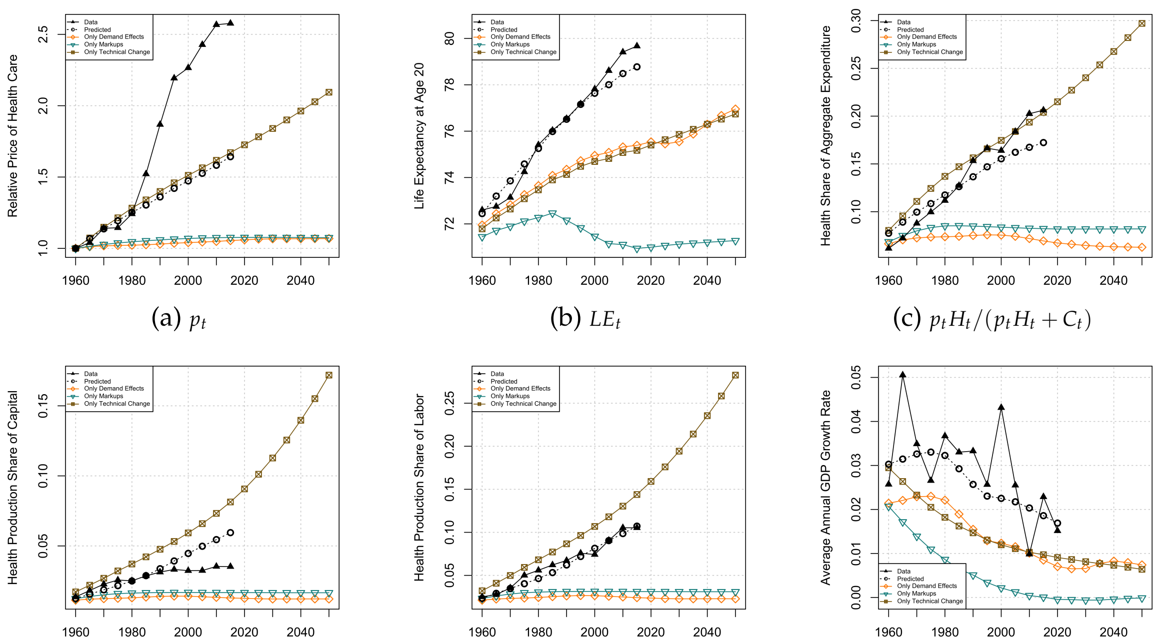
Figure D.12: This figure shows counterfactual values (round dots and dashed line) from the Horenstein and Santos (2019) model, leaving on only one growth channel at a time.



(a) p_t (b) LE_t (c) $p_tH_t/(p_tH_t + C_t)$

(d) K_{ht}/K_t (e) L_{ht}/L_t (f) GDP Growth Rates

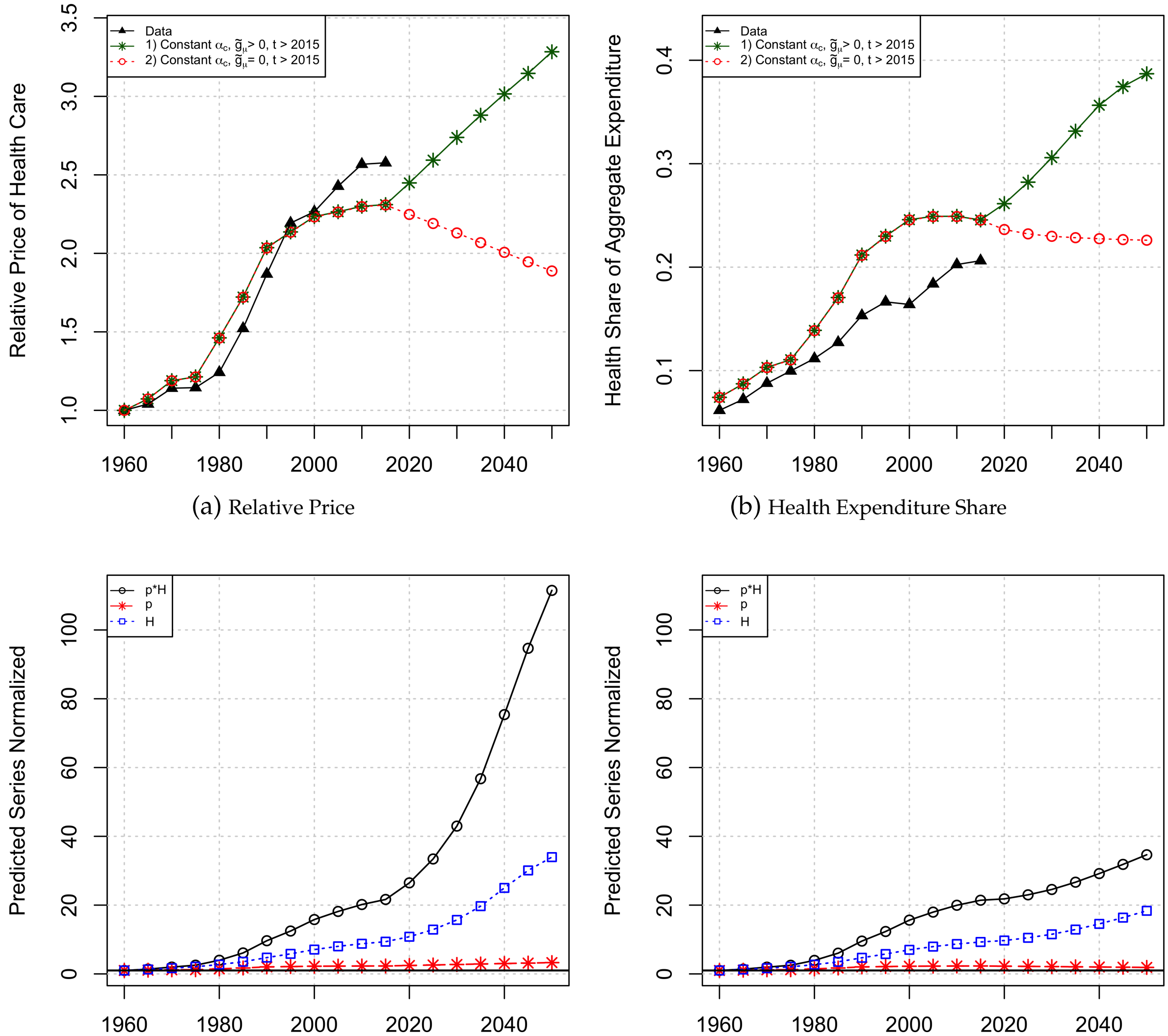
Figure D.13: This figure shows counterfactual values (round dots and dashed line) from the $\widetilde{g}_{\mu,t} = 0$ model, turning off growth channels one at a time.



(a) p_t (b) LE_t (c) $p_tH_t/(p_tH_t + C_t)$

(d) K_{ht}/K_t (e) L_{ht}/L_t (f) GDP Growth Rates

Figure D.14: This figure shows counterfactual values (round dots and dashed line) from the $\widetilde{g}_{\mu,t} = 0$ model, leaving on only one growth channel at a time.



(a) Relative Price

(b) Health Expenditure Share

(c) Decomposition, Calibration (1)

(d) Decomposition, Calibration (2)

Figure D.15: This figure presents predictions for the evolution of relative prices and expenditure shares in panels (a) and (b), along with decomposition of the drivers of expenditure evolution in panels (c) and (d). In panels (c) and (d) all series are normalized to unity in 1960.

D.7 Predictive Implications for Future Health Services Expenditure

How will the health-services sector evolve in the twenty-first century, according to our model? We now look at the predictions for future prices, quantities, and expenditure shares, focusing on calibrations (1) and (2), so that we can compare how the health sector will evolve under different assumptions regarding relative markup growth. Recall, in our baseline calibration we assume that relative markups grow at the 1955-2015 average annual rate of 1.7% out to 2100, while in calibration (2) we completely shut down relative markup growth after 2015 (the last of the five-year intervals for which we have the complete data moments untainted by the COVID-19 recession).

We discuss our different models' predictions in the context of results predicting the future GDP share of health spending presented in Fonseca et al. (2023).[7]

Figures D.15a and D.15b present the predicted evolution of prices and health-expenditure shares for calibrations (1) and (2) together, while Figures D.15c and D.15d decompose the health expenditure increase by prices, p_t, and aggregate quantities, H_t, for calibrations (1) and (2) respectively. If relative markups continue to grow at the rate we estimate from 1955-2015 out to 2100, we predict the health share of spending will rise by 12.6 percentage points to almost 40% by 2050. Without relative markup growth (red line in Figure D.15b) the health share is essentially flat. But, most of the rise in the health share of spending is *directly* due to rising relative prices. On their own, relative prices rise by 34% from 2020-2050 in calibration (1), but in that same model the quantity of health consumption, H_t, rises by 214%. Without markup growth the quantity of health consumption rises by 89%, simply due to technological change and population aging.

Our results contrast a bit with those of Fonseca et al. (2023) who find that price increases will mostly be responsible for rising GDP shares of health outlay into the twenty-first century. However, comparing our results to theirs is not so simple, since they treat health prices as exogenous, calibrating them to match cross-country heterogeneity in health spending and health outcomes. Our relative price, p_t, however, is a GE object (as is H_t) which varies in response to three primary channels — 1) relative markups; 2) relative TFPs; 3) relative efficiencies/qualities driving the composition of demand. Even when relative markups do not rise after 2015 leading to flat relative prices after 2020 (calibration (2)), total health spending rises because the quantity of health spending rises, which drives up the health-expenditure share. Turning back to the main text and inspecting counterfactuals in Figure 8, it can be seen by looking at the brown lines that when the model only features technical change (varying relative TFPs), relative prices are flat but the expenditure share of health rises. This is because we estimate that after 1975 the health sector is the faster growing sector in terms of TFP. In the spirit of the classical structural change literature (see Ngai and Pissarides (2007)), the sector with relatively faster growing TFP eventually comes to dominate in terms of the quantity of output, consistent with our predictive findings here.

[7] We specifically compare our results in this appendix to the growth accounting exercise in Online Appendix A.3.3 of Fonseca et al. (2023).

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