DISCUSSION PAPER SERIES

DP12467
(v. 2)

STRUCTURAL CHANGE WITHIN THE SERVICE SECTOR AND THE FUTURE OF BAUMOL'S DISEASE

Akos Valentinyi, Berthold Herrendorf and Georg Duernecker

MACROECONOMICS AND GROWTH

ISSN 0265-8003

STRUCTURAL CHANGE WITHIN THE SERVICE SECTOR AND THE FUTURE OF BAUMOL'S DISEASE

Akos Valentinyi, Berthold Herrendorf and Georg Duernecker

Discussion Paper DP12467
First Published 27 November 2017
This Revision 24 October 2019

Centre for Economic Policy Research
33 Great Sutton Street, London EC1V 0DX, UK
Tel: +44 (0)20 7183 8801
www.cepr.org

STRUCTURAL CHANGE WITHIN THE SERVICE SECTOR AND THE FUTURE OF BAUMOL'S DISEASE

Abstract

Structural change contributed to the past slowdown of U.S. productivity growth by reallocating production to stagnant services sectors with low productivity growth. We ask what the future effect of structural change on productivity growth will be. To provide an answer, we study structural change among goods and different services. We find that there are substitutes for stagnant services, which prevents them from taking over the economy in the long run. Our calibrated model implies that in the future structural change will reduce aggregate productivity growth in the U.S. only by about half as much as in the past.

JEL Classification: O41, O47, O51

Keywords: Baumol's Disease, Productivity Growth Slowdown, Service Sector, structural change

Akos Valentinyi - akos.valentinyi@manchester.ac.uk
University if Manchester, CERS-HAS and CEPR

Berthold Herrendorf - berthold.herrendorf@asu.edu
Arizona Stata University

Georg Duernecker - georg.duernecker@econ.lmu.de
University of Munich, IZA and CEPR

Acknowledgements
This paper incorporates material from our earlier manuscript ``Unbalanced Growth Slowdown''. We have received useful feedback from Zs\'ofia B\'ar\'any, Aspen Gorry, Hannes Malmberg, Marti Mestieri, Rachel Ngai, Richard Rogerson, V. Kerry Smith, Michael Sposi, and Gustavo Ventura, as well as the audiences of presentations at ASU, the BEA, CEPR's ESSIM 2017, CERGE--EI Prague, the Christmas Meeting of the German Expat Economists 2016, the Cowles Conference on Macro 2019, the Economic Growth and Fluctuations Group of the Barcelona Summer Forum 2017, Erasmus University Rotterdam, the European Monetary Forum 2016 at the Bank of England, the Federal Reserve Banks of Atlanta and St. Louis, the Growth and Macro Development Conference in Madrid 2018, the RIDGE Workshop on Growth and Development 2016, the SED Meeting 2017, Southern Methodist University, Sabanci University, the Stockholm School of Economics, the Universities of Barcelona, Frankfurt, Konstanz, Manchester, Munich, North Carolina at Charlotte, and Western Ontario, the Vienna Macroeconomic Workshop 2017, Washington University, and the World Bank. Valentinyi thanks the Hungarian National Research, Development and Innovation Office (Project KJS K 124808). All errors are our own.

Structural Change within the Services Sector and the Future of Cost Disease*

Georg Duernecker (University of Munich, CEPR, and IZA)
Berthold Herrendorf (Arizona State University)
Ákos Valentinyi (University of Manchester, CEPR, and CERS–HAS)

October 2, 2019

Abstract

Structural change contributed to the past slowdown of U.S. productivity growth by reallocating production to stagnant services sectors with low productivity growth. We ask what the future effect of structural change on productivity growth will be. To provide an answer, we study structural change among goods and different services. We find that there are substitutes for stagnant services, which prevents them from taking over the economy in the long run. Our calibrated model implies that in the future structural change will reduce aggregate productivity growth in the U.S. only by about half as much as in the past.

Keywords: Cost Disease; Productivity Growth Slowdown; Services; Structural Change; Substitutability.
JEL classification: O41; O47; O51.

*This paper incorporates material from our earlier manuscript "Unbalanced Growth Slowdown". We have received useful feedback from Zsófia Bárány, Aspen Gorry, Hannes Malmberg, Marti Mestieri, Rachel Ngai, Richard Rogerson, V. Kerry Smith, Michael Sposi, and Gustavo Ventura, as well as the audiences of presentations at ASU, the BEA, CEPR's ESSIM 2017, CERGE–EI Prague, the Christmas Meeting of the German Expat Economists 2016, the Cowles Conference on Macro 2019, the Economic Growth and Fluctuations Group of the Barcelona Summer Forum 2017, Erasmus University Rotterdam, the European Monetary Forum 2016 at the Bank of England, the Federal Reserve Banks of Atlanta and St. Louis, the Growth and Macro Development Conference in Madrid 2018, the RIDGE Workshop on Growth and Development 2016, the SED Meeting 2017, Southern Methodist University, Sabanci University, the Stockholm School of Economics, the Universities of Barcelona, Frankfurt, Konstanz, Manchester, Munich, North Carolina at Charlotte, and Western Ontario, the Vienna Macroeconomic Workshop 2017, Washington University, and the World Bank. Valentinyi thanks the Hungarian National Research, Development and Innovation Office (Project KJS K 124808). All errors are our own.

1 Introduction

It is well established that structural change contributed to the slowdown of aggregate productivity growth in the U.S. by reallocating production to services sectors with relatively low productivity growth. This phenomenon is often referred to as cost disease. In the initial statement of cost disease, Baumol (1967) drew particular attention to the fact that production is even reallocated to stagnant services that have hardly any productivity growth. Subsequent evidence confirmed that indeed several stagnant sectors expanded in terms of employment or value added; see for example Nordhaus (2008). If the stagnant sectors were to slowly take over the economy, they would drive long-run aggregate productivity growth all the way down to zero. Whether that is going to happen depends on the strengths of the income and substitution elasticities that determine the sectoral composition. Although this has been recognized since the work by Smith (1978) and others in the 1970s, to the best of our knowledge, there is little hard evidence on the values of the key elasticities, and so we still do not have a goods sense of how likely Baumol's "apocalyptic" scenario is.

In this paper, we ask the question of how large the effect of structural change on productivity growth will be in the next 50 years. Answering it is of interest in the context of the debate about whether future productivity growth is likely to rebound after the slowdown that started in the 1970s; see for example Fernald and Jones (2014) and Fernald (2016). Answering it is also of interest in the context of GDP growth projections that are crucial inputs into fiscal and monetary policy making. Note that the term cost disease has the connotation of an inefficient outcome in a "sick" economy that, if possible, should be "cured". A different interpretation is that structural change and its consequences are the efficient equilibrium outcome in a "healthy" economy. We do not take a firm stand here on which of the two interpretations is more plausible, but instead focus on the quantitative question of how large the future effect of structural change on productivity growth will be.

We start our analysis by measuring the past effect of structural change on aggregate productivity growth. In this context, it is natural to define productivity as the value added per quality-adjusted labor input. Differences in sectoral productivities then do not reflect differences in sectoral human capital, which is appropriate given that human-capital differences are embodied in workers instead of sectors. Using labor services by sector from the WORLD KLEMS database as the measure of quality-adjusted labor inputs, we find that structural change accounted for around one third of the productivity growth slowdown in the postwar U.S. This is a quantitatively sizeable effect, which is in the same ballpark as existing evidence; see for example Nordhaus (2008).

Understanding the future effect of structural change on productivity growth requires a model that captures how uneven sectoral productivity growth leads to changes in the sectoral composition, and how these changes affect aggregate productivity growth. While most existing models study structural change among the three broad sectors agriculture, manufacturing, and services, Jorgenson and Timmer (2011) argued convincingly that structural change within the services sector is often more important for aggregate outcomes in developed countries. In the U.S. economy, for example, the agricultural sector is tiny compared to the services sector which comprises around 4/5 of aggregate value added. Moreover, the industries of the services sector are not at all homogeneous in terms of growth of productivity and employment. We therefore want to model also what happens *within* the services sector. This leads us to disaggregate economic activity into three different sectors: the goods sector produces tangible output whereas two services sectors produce intangible output; the two services sectors differ in their productivity growth: "progressive" services comprises the services industries with above average productivity growth whereas "stagnant" services comprise the services industries with below average productivity growth.

Our formulation of preferences has two crucial features: the substitutability between the two services may differ from the substitutability between aggregate services and goods ("nested preference structure"); the income elasticities of demand of goods and the two services may differ from one even in the long run ("persistent non-homotheticities"). Boppart (2014) was the first to establish that persistent non-homotheticities are of first-order importance in the context of structural change even in a rich country such as the U.S.

Connecting our model to aggregate data from the postwar U.S. economy, we find the usual features that goods are necessities, aggregate services are luxuries, and goods and aggregate services are complements. More interestingly, we find the new features that progressive services are necessities, stagnant services are luxuries, and the two services are substitutes. Since the new features are critical for our results, we go to great lengths to provide empirical support for them. We first argue that they are required to replicate the broad patterns of structural change within services. We then offer micro evidence from the Consumer Expenditure Survey (CEX henceforth) that the new features are present also at the household level. We lastly show that a careful macro calibration of our model confirms the new features.

Our analysis implies that the future effects of structural change on productivity growth remain limited and are smaller than the past effects. Specifically, our theoretical analysis shows the novel result that the stagnant services can take over our model economy only if their productivity growth is sufficiently *high*. In contrast, if their productivity growth is below a threshold value, then the substitution away from the stagnant services is so strong that their share is driven down to zero. Our model therefore rules out the apocalyptic scenario that the stagnant services industries will drive future aggregate productivity growth all the way down to zero. The surprising part of this analytical result is that it holds although stagnant services are luxuries and it holds irrespective of the strength of the persistent non-homotheticities. Our quantitative analysis goes beyond the theoretical result by establishing that in the next half century the productivity-growth slowdown caused by structural change is about half of what it was in the last half century. Various robustness exercises establish that our quantitative result does not depend on the detailed aspects of the forward simulations of our model.

We also provide intuition for why the future effects of structural change on productivity growth remain limited. In the past, the main effect of structural change on productivity growth came from the reallocation from the goods and to the services sector, because that reallocation was sizeable and average productivity was considerably higher in goods than in services production. In the future, similar reallocation will play a smaller role because by 2016 the goods sectors had shrunk to merely a fifth of the economy, implying that there is not much left to reallocate to services. Instead, it will matter more and more what happens within the services sector. We find that, consistent with our theoretical result, substitutability among progressive and stagnant services implies that stagnant services will not take over the economy. Therefore, the future effect of structural change on productivity growth remains limited.

One may wonder whether there is an advantage of working with our disaggregation into services with low and high productivity growth instead of working with existing disaggregations of services. Popular alternatives include traditional versus non-traditional services as suggested by Duarte and Restuccia (2019); market versus non–market services as used by the guidelines of the System of National Accounts; high-skill-intensive versus low-skill-intensive services as suggested by Buera and Kaboski (2012) and Buera et al. (2018). We establish that none of these alternatives is as informative about productivity growth as our two-sector split. We also establish two additional arguments in support of our two-sector split. It provides good in-sample predictions of aggregate productivity growth. It generates future predictions of aggregate productivity growth that are robust to relaxing our nesting structure and to disaggregating services further. These results suggest that our two-split into progressive and stagnant services is the suitable for answering our question.

The rest of the paper is organized as follows. We start our analysis by presenting evidence on cost disease and the stylized facts of structural change within services. We then develop our model and theoretically characterize its equilibrium dynamics in the limit. We supplement our theoretical results with a quantitative analysis of the calibrated model. We also offer micro evidence in favor of the new features of our utility function (Section 4), conduct robustness analysis (Section 6), review the related literature (Section 7), and conclude (Section 8). An Appendix contains background information about the construction of real value added in the data, the proofs of our theoretical results, and details of our quantitative analysis.

2 Evidence

Our main data source for the postwar U.S. is WORLD KLEMS. Since it stops in 2014, we extend the relevant statistics until 2016 using the BEA–BLS Industry Level Production Accounts. In doing so, we follow the methodology behind the data construction of WORLD KLEMS that Jorgenson et al. (2013) describe.

A distinguishing feature of WORLD KLEMS is that it offers labor services by industry for the U.S. as far back as 1947. Labor services are the sum of raw hours of different labor categories weighted with their relative rental prices. It is critical in our context to use such a quality-adjusted measure of labor input because we consider counterfactuals that reallocate workers with potentially different levels of human capital across sectors. If we used raw hours, instead of labor services, then sectoral productivity differences would include human capital differences. That would be undesirable, because human capital is embodied in workers instead of sectors.

While our focus is on the future productivity effects of structural change, a natural starting point for our analysis is to confirm that the productivity effects of structural change importantly contributed to the past productivity growth slowdown. Studies like Nordhaus (2008) found this to be the case for the postwar U.S. based on BEA data. It is not a foregone conclusion, however, that the past productivity effects of structural change are the same in our WORLD KLEMS data. As mentioned above, our measure of productivity is based on labor services, instead of based of raw hours. In addition, we work with labor productivity instead of TFP, because we are focused on understanding the effects of changes in the sectoral composition in response to the changes in sectoral labor productivity. Our analysis therefore takes as given changes in sectoral labor productivity without decomposing them into the contributions of TFP and capital accumulation.

2.1 Measuring the Productivity-Growth Effect of Structural Change

Measuring the productivity effects of structural change involves decomposing the actual productivity growth into the part that occurred because of structural change and the part that would have occurred without structural change. The decomposition is not entirely straightforward because WORLD KLEMS is build around Törnqvist indexes that are not additive. We deal with the resulting complications by adopting the productivity accounting framework of Nordhaus (2002) to our context.

There are $i = 1, ..., I$ industries. The growth rates between periods t and $t + 1$ of aggregate real value added, Y_t, and aggregate labor services, H_t, are defined as the weighted sums of the industry growth rates:[1]

$$\Delta \log Y_t \equiv \log Y_{t+1} - \log Y_t \equiv \sum_{i=1}^{I} S(P_{it}Y_{it}) \Delta \log Y_{it}, \tag{1a}$$

$$\Delta \log H_t \equiv \log H_{t+1} - \log H_t \equiv \sum_{i=1}^{I} S(W_{it}H_{it}) \Delta \log H_{it}. \tag{1b}$$

$S(P_{it}Y_{it})$ and $S(W_{it}H_{it})$ denote the average shares of industry i's nominal value added and nominal labor compensation in the corresponding economy-wide totals. The averages are taken over the adjacent periods between which the growth rates are calculated:

$$S(P_{it}Y_{it}) \equiv \frac{1}{2}\left(\frac{P_{it}Y_{it}}{\sum_{j=1}^{J} P_{jt}Y_{jt}} + \frac{P_{it+1}Y_{it+1}}{\sum_{j=1}^{J} P_{jt+1}Y_{jt+1}} \right),$$
$$S(W_{it}H_{it}) \equiv \frac{1}{2}\left(\frac{W_{it}H_{it}}{\sum_{j=1}^{J} W_{jt}H_{jt}} + \frac{W_{it+1}H_{it+1}}{\sum_{j=1}^{J} W_{jt+1}H_{jt+1}} \right).$$

(Aggregate) productivity is defined as the real value added per unit of labor services, $LP_t \equiv Y_t/H_t$. Using (1), the growth rate of productivity results as:

$$\Delta \log LP_t = \Delta \log Y_t - \Delta \log H_t = \sum_{i=1}^{I} S(P_{it}Y_{it}) \Delta \log Y_{it} - \sum_{i=1}^{I} S(W_{it}H_{it}) \Delta \log H_{it}$$

$$\Longrightarrow \quad \Delta \log LP_t = \sum_{i=1}^{I} S(P_{it}Y_{it}) \Delta \log LP_{it} + \sum_{i=1}^{I} \Big[S(P_{it}Y_{it}) - S(W_{it}H_{it}) \Big] \Delta \log H_{it}. \tag{2}$$

The first component of the right-hand side is the sum of the growth rates of industry productivity, $\Delta \log LP_{it}$, weighted by the nominal industry-value-added shares, $S(P_{it}Y_{it})$. Since the Törnqvist index is not additive, there is a second component containing the sum of the changes in the labor services, $\Delta \log H_{it}$, weighted by the difference between the industry shares of nominal value added and labor compensation, $S(P_{it}Y_{it}) - S(W_{it}H_{it})$. The difference is a measure of the relative nominal industry productivity.[2]

The counterfactual (aggregate) productivity growth without structural change is the productivity growth that would have occurred if the sectoral value-added shares and the sectoral levels of labor services had remained unchanged at their values from the reference period T: $S(P_{it}Y_{it}) = S(P_{iT}Y_{iT})$ and $\Delta \log(H_{it}) = 0$. Imposing the two conditions on (2), counterfactual

[1]Here, we start directly from value added. Appendix A explains how to calculate value added from gross output and intermediate inputs.

[2]We will establish this within our model in Equation (10) below.

Table 1: The Effect of Structural Change on Productivity Growth

Period	Sector Shares from Data	Sector Shares from 1947–67
1947–1967	2.31%	2.18%
1996–2016	1.06%	1.32%
Productivity Growth Slowdown	1.25	0.86
Effect of Structural Change	0.39	

Note: Productivity is real value added per unit of labor services; annual averages.

productivity growth without structural change results as:

$$\Delta \log LP_t(T) \equiv \sum_{i=1}^{I} S(P_{iT}Y_{iT})\Delta \log(LP_{it}). \tag{3}$$

The productivity-growth effect of structural change is the difference between actual and counterfactual productivity growth. Subtracting (3) from (2), we get:

$$\Delta \log LP_t - \Delta \log LP_t(T)$$
$$= \sum_{i=1}^{I} \left[S(P_{it}Y_{it}) - S(P_{iT}Y_{iT})\right]\Delta \log LP_{it} + \sum_{i=1}^{I} \left[S(P_{it}Y_{it}) - S(W_{it}H_{it})\right]\Delta \log H_{it}. \tag{4}$$

The first component captures the interaction between sectoral composition changes and sectoral productivity *growth*. It equals the sum of the actual industry productivity growth rates weighted by the differences between the nominal industry-value-added shares in the current and reference period, $S(P_{it}Y_{it})-S(P_{iT}Y_{iT})$. If, for example, industry i has relatively weak productivity growth, then reallocating value added to it decreases aggregate productivity growth. The second component captures the interaction between sectoral composition changes and sectoral productivity *levels*. If, for example, $S(P_{it}Y_{it}) - S(W_{it}H_{it})$ is below average, then industry i is relatively unproductive and reallocating labor services to it has a negative effect on productivity growth in the period of the reallocation.

We follow Nordhaus (2008) in focusing on the total productivity-growth effect of structural change without decomposing it into the two components.[3] The main advantage is that while the total effect remains the same, the decomposition changes with the degree of disaggregation. We want to avoid dealing with that because our model will obviously not feature all 65 industries of WORLD KLEMS.

Table 1 reports the productivity-growth effect of structural change in the postwar U.S. The

[3]They are sometimes referred to as the Baumol and the Denison effect.

table compares the first 20 years of our sample, 1947–1967, with the last 20 years, 1996–2016. The column entitled "Data" reports the actual growth rates that are calculated according to (2) using the actual sectoral composition while the column entitled "1947–67" reports the counterfactual growth rates that are calculated according to (3) imposing that there had not been structural change. We find that the actual productivity growth rate fell by 1.25 percentage points from 2.31% in 1947–67 to 1.06% in 1996–2016. This, of course, is a manifestation of the widely discussed productivity growth slowdown. The counterfactual productivity growth rate fell less by only 0.86 percentage points from 2.18% to 1.32%. The difference of $1.25 - 0.86 = 0.39$ percentage points can be attributed to structural change. We therefore conclude that structural change contributed $0.39/1.25 \approx 1/3$ to the overall slowdown in productivity growth. This is a sizeable effect![4]

The fact that structural change importantly reduced productivity growth in the postwar U.S. raises the question why the recent literature on structural change has paid relatively little attention to the phenomenon. Duernecker et al. (2017) argue that the likely reason is the strong focus of the literature on aggregate BGPs. In many models of structural change, an aggregate BGP exists if GDP growth is measured in terms of a current numeraire (for example, goods of the current period). Since by construction productivity growth is constant along an aggregate BGP, it is tempting to conclude that the productivity growth slowdown is not an issue. In contrast, Duernecker et al. (2017) show that this conclusion is misleading; if one measures GDP growth as it is done in the data, then the productivity growth slowdown resulting from structural change plays an important role even along standard aggregate BGPs.[5] In our quantitative analysis, we therefore make sure to measure GDP and labor productivity in the same way in the model as it is done in the data from WORLD KLEMS.

2.2 Disaggregating Services

Understanding the future productivity-growth effect of structural change requires a tractable model of structural change that balances two considerations. On the one hand, a "realistic" model with dozens of sectors, subsectors, and industries would be impenetrable. On the other hand, a "convincing" model ought to capture the first-order effects, in particular within the already sizeable services sectors. As a compromise between the considerations, we propose a three-sector split that first disaggregates the economy into the broad sectors of goods and services and then disaggregate services further into the sub-sectors that have fast and slow productivity growth. We use the standard definition of the goods sector as comprising all industries

[4]Our period of investigation includes the Great Recession, which was a period of lower than average productivity growth. We have verified that stopping before the Great Recession would not importantly alter the results.

[5]In independent work, Leon-Ledesma and Moro (2017) also observed that a productivity growth slowdown results from structural change if value added is measured as it is in the data. We will discuss their work in more detail in Section 7 below.

that produce tangible value added, namely, agriculture, construction, manufacturing, mining, and utilities. The services sector comprises the remaining industries, which produce intangible value added. The services sector with fast (slow) productivity growth contain all services industries that have average productivity growth above (below) the average productivity growth of services over the postwar period.[6] Following Baumol et al. (1985), we call the two services subsectors sectors "progressive" and "stagnant" services. Table 2 lists the services industries in declining order of their average productivity growth rates; progressive services industries are above the line and stagnant services industries are below the line.

Two important arguments in favor of using the three-sector split are that it is robust over time and that it speaks directly to differences in productivity growth. Starting with the first argument, if we split our period 1947–2016 into the three subperiods 1947–1970, 1970–1993, and 1993–2016, then the sector assignment of Table 2 is consistent with productivity growth in at least two subperiods for all but five services industries. Since the exceptions are all around the cut off, reassigning them to the other services subsector would not affect our results. Turning to the second argument, we emphasize that alternative disaggregations of services that exist in the literature are not as informative about productivity growth as our three-sector split. To begin with, the split into traditional versus non-traditional services as suggested by Duarte and Restuccia (2019) is based on final expenditure categories and therefore does not directly speak to value added. Two other popular splits are market versus non–market services, as used by the guidelines of the System of National Accounts, and high-skill- versus low-skill-intensive services, as suggested by Buera et al. (2018).[7] Although they are both based on value added, Table 2 shows that they capture differences in productivity growth only imperfectly. While the seven services industries with the fastest productivity growth are all market services, six of the seven services industries with the slowest productivity growth are as well. While four of the seven services industries with the fastest productivity growth are high-skill-intensive services, five of the seven services industries with the slowest productivity growth are as well.

Looking ahead, our analysis below will establish three further arguments in favor of using our three-sector split: it leads to a demand system with sensible parameter values that are consistent with both micro and macro evidence; it makes accurate in-sample predictions of productivity growth; it makes similar out-of-sample predictions of productivity growth as considerably more disaggregated sector splits.

[6] Note that using the median instead of the average would not affect the classification at all.

[7] We use the BEA–BLS Industry Level Production Account, 1998–2016, to construct the last two-sector split. Industries of the high-skill-intensive services sector pay a higher share of labor compensation to skilled workers than the services sector does on average, where skilled workers are those who have at least a college degree.

Table 2: Two–Sector Splits of Services

Services Industries in Declining Order of U.S. Productivity Growth	Progressive (1) vs. Stagnant (2)	Market (1) vs. Non-market (2)	Low-skilled (1) vs. High-skilled (2)
Pipeline Transportation	1	1	1
Broadcasting and Telecommunications	1	1	2
Air Transportation	1	1	1
Wholesale Trade	1	1	1
Publishing Industries (includes Software)	1	1	2
Securities, Commodity Contracts, Investment	1	1	2
Waste Management and Remediation Services	1	1	1
Water Transportation	1	1	1
Rental and Leasing Services, Lessors of Intangible Assets	1	1	1
Social Assistance	1	2	1
Railroad Transportation	1	1	1
Administrative and Support Services	1	1	1
Retail Trade	1	1	1
Truck Transportation	1	1	1
Insurance Carriers and Related Activities	1	1	2
Motion Picture and Sound Recording Industries	1	1	2
Performing Arts, Spectator Sports, Museums, Related Activities	1	1	2
Warehousing and Storage	1	1	1
Miscellaneous Professional, Scientific, Technical Services	1	1	2
Management of Companies and Enterprises	1	1	2
Accommodation	2	1	1
Federal General Government	2	2	1
Federal Reserve Banks, Credit Intermediation, Related Activities	2	1	2
Real Estate	2	2	2
Educational Services	2	2	2
Ambulatory Health Care Services	2	2	2
Computer Systems Design and Related Services	2	1	2
Data Processing, Internet Publishing, other Information Services	2	1	2
Legal Services	2	1	2
Hospitals, Nursing and Residential Care Facilities	2	2	2
Federal Government Enterprises	2	2	2
State and Local General Government	2	2	2
Amusements, Gambling, Recreation Industries	2	1	1
Other Transportation and Support Activities	2	1	1
State and Local Government Enterprises	2	2	2
Food Services and Drinking Places	2	1	1
Other Services, except Government	2	1	1
Transit and Ground Passenger Transportation	2	1	1
Funds, Trusts, other Financial Vehicles	2	1	2

Note: Based on average annual labor productivity growth in the postwar U.S.;
39 services industries from WORLD KLEMS.

2.3 Stylized Facts

Table 3 provides summary productivity growth statistics for our disaggregation in the postwar U.S. Two features stand out. First, there is substantial variation across subperiods. While most sectors experienced a slow down in productivity growth starting in the 1970s, productivity growth of progressive services slowed down later in the 1990s. Second, there is considerable heterogeneity across sectors. Over the whole sample period 1947–2016, average productivity growth in goods exceeded that of services by a factor 1.7, even though average productivity growth in progressive services was higher than in goods.[8]

At a more disaggregate level than that of Table 3, there is even more heterogeneity: while the eight top performing services industries all exceeded two percent average annual productivity growth, the bottom eight services industries all showed negative average annual labor productivity growth. These facts confirm the observation of Baumol et al. (1985) that the service sector "contains some of the economies most progressive activities as well as its most stagnant". In comparison, there is considerably less heterogeneity within the goods sector where only two industries had negative average productivity growth: Forestry, Fishing and Related Activities; Oil and Gas Extraction. Since it is safe to assume that neither one of them is going to take over the U.S. economy in the future, the evidence supports our choice not to disaggregate the goods sector and focus instead on what happens within the services sector.

Table 3: Postwar U.S. Productivity Growth

	1947–2016	1947–1967	1972–1992	1996–2016
Aggregate	1.56	2.30	1.16	1.06
Goods sector	2.11	2.87	1.30	1.91
Service sector	1.25	1.80	1.06	0.82
Progressive services	2.35	2.68	2.59	1.78
Stagnant services	0.33	0.77	0.10	0.12

Note: Productivity is real value added per labor services; annual averages in %.

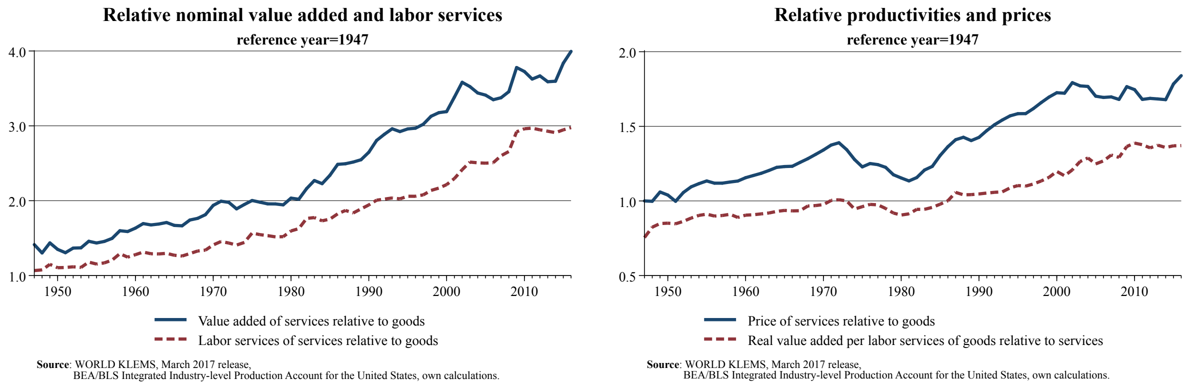
We now turn to documenting the stylized facts of structural change for our disaggregation. Figure 1 plots the sector compositions along with the relative prices and productivities in the postwar U.S. economy. The reference year is 1947 for all graphs (that is, real value added and labor services are expressed in 1947 dollars) and the relative prices in 1947 are normalized to one. The upper panel is about goods versus services and shows the usual patterns: the shares

[8]Note that the low productivity growth of stagnant services industries may in part reflect unmeasured quality improvements; see for example Byrne et al. (2016). We initially ignore this possibility and take the numbers from WORLD KLEMS at face value. In Subsection 6.2 below, we then show that this way of proceeding yields an upper bound of the future productivity-growth effect of structural change. Since our main conclusion is that the future effect of structural change on productivity growth remains limited, unmeasured quality improvements cannot overturn it.

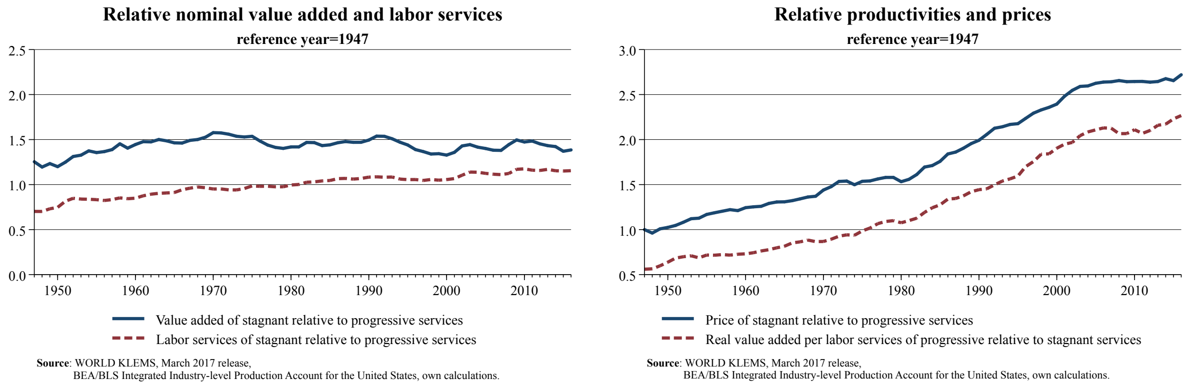
of services in employment and in value added increased; the relative price of services increased while the relative productivity of services decreased. The lower panel is about stagnant and progressive services and shows several new patterns: the share of stagnant services in total services employment increased; the share of stagnant services in total services value added increased until the 1970s and then flattened out; the relative price of stagnant services increased over the whole period, with an acceleration after 1970s; the relative productivity of progressive services increased over the whole period, with an acceleration after 1970s. The new patterns will be crucial when we discipline the parameters of our model below.

Figure 1: Postwar U.S. Structural Transformation

Goods versus Services



Progressive and Stagnant Services



In this section, we have established that the past growth effect of structural change is quantitatively important. We have also constructed a three-sector split that is suitable for analyzing the future growth effect of structural change and we have established the stylized facts of structural change for that three-sector split. We now turn to constructing a model that will help us analyze the macro implications of structural change among the three sectors.

3 Model

3.1 Environment

There are three sectors producing goods, progressive services, and stagnant services, which are indexed by g, p, and u. Note that we use the index u for stagnant ("unprogressive") services because s is taken for aggregate services. In each sector, value added is produced with labor services:

$$Y_{it} = A_{it} H_{it}, \quad i = g, p, u, \tag{5}$$

where Y_i, A_i, and H_i denote value added, total factor productivity, and labor services in sector i, respectively. Note that the linear specification (5) implies that sectoral TFP equals labor productivity in our model, $A_{it} = Y_{it}/H_{it}$. When we connect our model to the data, we will identify A_{it} with labor productivity from the data, implying that we will feed into the model the effects of exogenous TFP changes as well as capital accumulation.

There is a measure one of identical households. Each household is endowed with a finite number of labor services that are inelastically supplied and can be used in all sectors.

Preferences over goods and services are described by two nested, non–homothetic CES utility functions. The utility from the consumption of goods and aggregate services, C_{gt} and C_{st}, is given by:

$$C_t = \left(\alpha_g^{\frac{1}{\sigma_c}} C_t^{\frac{\varepsilon_g - 1}{\sigma_c}} C_{gt}^{\frac{\sigma_c - 1}{\sigma_c}} + \alpha_s^{\frac{1}{\sigma_c}} C_t^{\frac{\varepsilon_s - 1}{\sigma_c}} C_{st}^{\frac{\sigma_c - 1}{\sigma_c}} \right)^{\frac{\sigma_c}{\sigma_c - 1}}. \tag{6a}$$

Aggregate services are given by a non–homothetic CES aggregator of the consumption from the two service sub–sectors, C_{pt} and C_{ut}:

$$C_{st} = \left(\alpha_p^{\frac{1}{\sigma_s}} C_t^{\frac{\varepsilon_p - 1}{\sigma_s}} C_{pt}^{\frac{\sigma_s - 1}{\sigma_s}} + \alpha_u^{\frac{1}{\sigma_s}} C_t^{\frac{\varepsilon_u - 1}{\sigma_s}} C_{ut}^{\frac{\sigma_s - 1}{\sigma_s}} \right)^{\frac{\sigma_s}{\sigma_s - 1}}. \tag{6b}$$

α_i are weights, $\sigma_i \geq 0$ are the elasticities of substitution, and $\varepsilon_i > 0$ capture income effects.

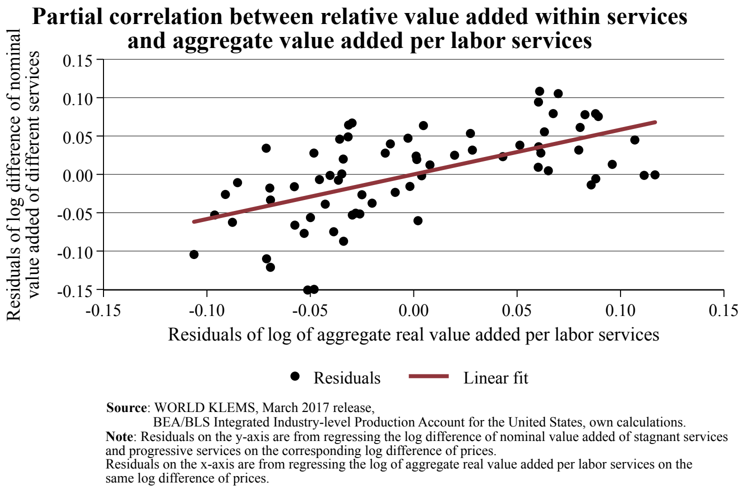
Our formulation of utility is over the sectoral value added components of final expenditures, instead of over sectoral final expenditures. This is possible because every final-expenditure bundle may be decomposed into its value-added components via the use of input-output tables; see Herrendorf et al. (2013) for more details. Taking the value-added perspective implies that a maintained assumption for our analysis is that the input-output relationships that link final expenditures to value added are relatively stable over time.[9] The non–homothetic CES utility

[9]Sposi (2019) is a recent example that studies explicitly the role of input–output linkages in the context of

functions we are using go back to the work of Hanoch (1975) and Sato (1975) on implicitly additive utility and production functions. It has recently been introduced to the literature on structural change by Comin et al. (2018). For $\varepsilon_i = 1$, the expressions in (6) reduce to the standard CES utility that implies homothetic demand functions for each consumption good. For $\varepsilon_i \neq 1$, the level of utility, C_t, affects the weight attached to the consumption goods. The nested structure (6a)–(6b) is a novel feature of our work.

Given our focus on the productivity-growth effects of structural change, the most important feature of the (6) is that it remains non-homothetic even as consumption grows without bound. Boppart (2014) and Comin et al. (2018) established that this is consistent with the available evidence for goods and services in rich countries like the U.S. Figure 2 establishes that this is also consistent with the evidence for the two service subsectors that we consider here. Controlling for changes in relative prices, the figure provides a measure of the income elasticities of the two services by plotting the relative value added within the services sector against aggregate value added per labor services. Clearly, there is a positive long-run slope, which would be inconsistent with utility specifications that converges to homothetic utility functions.

Figure 2: Persistent Income Effects within Services



We complete the description of the environment with the resource constraints:

$$C_{it} \leq Y_{it}, \quad i = g, p, u, \tag{7a}$$

$$\sum_{i=g,p,u} H_{it} \leq H_t. \tag{7b}$$

structural change.

3.2 Discussion

Our model does not distinguish between TFP growth and investment as separate determinants of sectoral labor productivity growth, implying that TFP growth equals labor productivity growth. This is unlikely to be an issue for the U.S. because along a balanced growth path (BGP henceforth) aggregate TFP and aggregate capital both grow at the same constant rate. Moreover, standard models of structural change assume that the capital-labor ratios are equalized across sectors so that relative sectoral TFPs and labor productivities are equal. Herrendorf et al. (2015) showed that this assumption works reasonably well when one studies structural change in the U.S. In contrast, distinguishing between sectoral TFP growth and capital growth is likely to matter in middle-income and developing countries where capital is scarce and transition dynamics often play a role; see Acemoglu and Guerrieri (2008) for further discussion.

Liberalizations of international trade are a driver of productivity growth, because they imply access to the most advanced technologies. The exogenous sectoral labor productivity processes that we feed into our model will reflect the productivity effect of liberalizations of international trade. What our model does not capture is that international trade may lead to differences between the sectoral value added that the domestic economy produces and the sectoral value added that it absorbs. This is not likely to be of first-order importance when the trade share is as small as it is in the U.S.

One implication of abstracting from investment and international trade is that by construction GDP equals consumption and the features of preferences shape the reallocation among sectors. How suitable a model with this feature is for answering our question depends on whether it can match the sectoral reallocation within GDP. Below, we will confirm the result of previous work that for the U.S. it can. The long-run trends in the changes of the sectoral shares within consumption and investment are similar, the trade share is small, and the economy is close to a BGP. As a result, one can find a preference specification which captures structural change in GDP without separately considering investment and international trade.

3.3 Equilibrium Analysis

In the data, the nominal labor productivities per efficiency unit are not equalized across sectors, which leads to contemporaneous effects of structural change on aggregate productivity. To capture them, we introduce a sector-specific wedge τ_{it} that firms pay per unit of wage payments. We rebate the receipts back to household through a lump-sum transfer $T_t = \sum_{i=g,p,u} \tau_{it} W_t H_{it}$, where W_t denotes the economy-wide wage per unit of labor services. With the wedge, the problem of firm $i = g, p, u$ becomes:

$$\max_{H_{it}} P_{it} A_{it} H_{it} - (1 + \tau_{it}) W_t H_{it}.$$

The first–order conditions imply that

$$\frac{P_{it}}{P_{gt}} = \frac{(1+\tau_{it})A_{gt}}{(1+\tau_{gt})A_{it}}, \quad i = p, u. \tag{8}$$

Combining this with the specification of the production function in (5), we obtain:

$$\frac{P_{it}C_{it}/H_{it}}{P_{gt}C_{gt}/H_{gt}} = \frac{1+\tau_{it}}{1+\tau_{gt}}, \quad i = p, u. \tag{9}$$

As intended, the wedges imply gaps between the nominal sectoral labor productivities; a sector with a relatively large wedge has relatively large labor productivity. Note that, as usual, only relative wedges matter. We will therefore set $\tau_{gt} = 0$ in the quantitative part of our analysis. Note too that, in equilibrium, the aggregate productivity measure (2) from Section 2.1 becomes:

$$\Delta \log LP_t = \sum_{i=1}^{I} S(P_{it}A_{it}H_{it})\Delta \log P_{it}A_{it} + \sum_{i=1}^{I} \Big[S((1+\tau_{it})H_{it}) - S(H_{it})\Big]\Delta \log H_{it}. \tag{10}$$

We can see that when τ_{it} is relatively large, then sector i has relatively large labor productivity and $S(P_{it}C_{it}) - S(W_{it}H_{it}) = S((1+\tau_{it})H_{it}) - S(H_{it})$ is relatively large, so reallocating labor to sector i contemporaneously increases aggregate labor productivity. This confirms the claim made in Section 2.1 above that $S(P_{it}C_{it}) - S(W_{it}H_{it})$ is a measure of relative sectoral labor productivity.

To solve the household problem, we split it into two "layers". The outer layer of the problem is about allocating a given C_t between C_{gt} and C_{st}. Solving the outer layer amounts to:

$$\min_{C_{gt},C_{st}} P_{gt}C_{gt} + P_{st}C_{st} \quad \text{s.t.} \quad \left(\alpha_g^{\frac{1}{\sigma_c}} C_t^{\frac{\varepsilon_g-1}{\sigma_c}} C_{gt}^{\frac{\sigma_c-1}{\sigma_c}} + \alpha_s^{\frac{1}{\sigma_c}} C_t^{\frac{\varepsilon_s-1}{\sigma_c}} C_{st}^{\frac{\sigma_c-1}{\sigma_c}}\right)^{\frac{\sigma_c}{\sigma_c-1}} \geq C_t, \quad C_t \text{ given,}$$

Appendix B.2 shows that the first–order conditions imply:

$$\frac{P_{st}C_{st}}{P_{gt}C_{gt}} = \frac{\alpha_s}{\alpha_g}\left(\frac{P_{st}}{P_{gt}}\right)^{1-\sigma_c} C_t^{\varepsilon_s-\varepsilon_g}, \tag{11a}$$

$$P_t = \left(\alpha_g C_t^{\varepsilon_g-1} P_{gt}^{1-\sigma_c} + \alpha_s C_t^{\varepsilon_s-1} P_{st}^{1-\sigma_c}\right)^{\frac{1}{1-\sigma_c}}, \tag{11b}$$

where P_t is the aggregate price index and $P_tC_t \equiv \sum_{i=g,p,u} P_{it}C_{it}$.

The inner layer of the household problem is about allocating a given C_{st} between C_{pt} and

C_{ut}. Solving the inner layer amounts to:

$$\min_{C_{pt},C_{ut}} P_{pt}C_{pt} + P_{ut}C_{ut} \quad \text{s.t.} \quad \left(\alpha_p^{\frac{1}{\sigma_s}} C_t^{\frac{\varepsilon_p-1}{\sigma_s}} C_{pt}^{\frac{\sigma_s-1}{\sigma_s}} + \alpha_u^{\frac{1}{\sigma_s}} C_t^{\frac{\varepsilon_u-1}{\sigma_s}} C_{ut}^{\frac{\sigma_s-1}{\sigma_s}}\right)^{\frac{\sigma_s}{\sigma_s-1}} \geq C_{st}, \quad C_t, C_{st} \text{ given.}$$

Note that in solving the inner problem, C_t is taken as given, and so in principle the minimization problem is the same as that for a CES utility. Appendix B.1 shows that the first–order conditions imply that

$$\frac{P_{ut}C_{ut}}{P_{pt}C_{pt}} = \frac{\alpha_u}{\alpha_p}\left(\frac{P_{ut}}{P_{pt}}\right)^{1-\sigma_s} C_t^{\varepsilon_u-\varepsilon_p}, \tag{12a}$$

$$P_{st} = \left(\alpha_p C_t^{\varepsilon_p-1} P_{pt}^{1-\sigma_s} + \alpha_u C_t^{\varepsilon_u-1} P_{ut}^{1-\sigma_s}\right)^{\frac{1}{1-\sigma_s}}. \tag{12b}$$

where P_{st} is the price index of services.

The solutions to the minimization problem make economic sense only if the consumption index $C_t = C(C_{gt}, C_{pt}, C_{ut})$ that follows by substituting (6b) into (6a) satisfies the basic regularity conditions such as monotonicity and quasi-concavity. To ensure that this is the case, we restrict the parameters as follows:

Assumption 1

- *If* $\sigma_c < 1$, *then* $\sigma_c < \min\{\varepsilon_g, \varepsilon_s\}$ *and* $\varepsilon_s > 1$. *If* $\sigma_c > 1$, $\sigma_c > \max\{\varepsilon_g, \varepsilon_s\}$ *and* $\varepsilon_s < 1$.
- *If* $\sigma_s < 1$, *then* $\sigma_s < \min\{\varepsilon_p, \varepsilon_u\}$. *If* $\sigma_s > 1$, *then* $\sigma_s > \max\{\varepsilon_p, \varepsilon_u\}$.

Proposition 1 *The expenditure function*

$$\begin{aligned} E_t(C_{gt}, C_{pt}, C_{ut}, C_t) &\equiv P_t C_t \\ &= \left(\alpha_g C_t^{\varepsilon_g-\sigma_c} P_{gt}^{1-\sigma_c} + \alpha_s C_t^{\varepsilon_s-\sigma_c}\left(\alpha_p C_t^{\varepsilon_p-1} P_{pt}^{1-\sigma_s} + \alpha_u C_t^{\varepsilon_u-1} P_{ut}^{1-\sigma_s}\right)^{\frac{1-\sigma_c}{1-\sigma_s}}\right)^{\frac{1}{1-\sigma_c}}. \end{aligned} \tag{13}$$

is continuous, strictly increasing, concave, homogenous of degree one and differentiable in prices if prices are strictly positive. If Assumption 1 holds, then the expenditure function is also strictly increasing in C_t.

Proof in Appendix B.2.

The fact that E_t is strictly increasing in C_t implies that there a one-to-one mapping between C_t and E_t. Hence, standard duality theory implies that the regularity conditions of E_t from the previous proposition imply that:

Corollary 1 *The utility function is strictly increasing in* C_{it} *and is quasi–concave.*

3.4 Equilibrium Dynamics

Although it is impossible to solve for the equilibrium dynamics in closed form, we are able to characterize how the model behaves qualitatively. We begin with structural change between goods and services. Since the model is formulated in discrete time, it is convenient to use growth factors, which we denote by "hats". For a generic variable X_t:

$$\widehat{X}_t \equiv \frac{X_{t+1}}{X_t} = 1 + \Delta \log X_t,$$

where $\Delta \log X_t$ is the growth rate defined in Subsection 2.1 above. Dividing (11a) for periods $t+1$ and t by each other, we obtain:

$$\widehat{\left(\frac{P_{st}C_{st}}{P_{gt}C_{gt}}\right)} = \widehat{\left(\frac{P_{st}}{P_{gt}}\right)}^{1-\sigma_c} \widehat{C}_t^{\varepsilon_s-\varepsilon_g}. \tag{14}$$

The first term on the right–hand side is the relative price effect and the second term is the income effect. Note that the latter depends only on the *difference* $\varepsilon_s - \varepsilon_g$, implying that the two ε_i will not be separately identified in our calibration and estimation exercises. Thus, we have to normalize one of them in such a way that we do not violate Assumption 1 given the choice of the other parameters.

We make the standard assumptions that goods and aggregate services are complements, goods are necessities, and services are luxuries:[10]

Assumption 2 $0 < \sigma_c < 1$ *and* $\varepsilon_s - \varepsilon_g > 0$.

Expression (14) shows that our model then generates the observed structural change from goods to services if P_{st}/P_{gt} and C_t both grow. Moreover, if P_{st}/P_{gt} and C_t both keep growing, then it is business as usual in the structural change literature, because the services sector takes over the economy in the limit.[11]

We continue with the structural change between the two services subsectors. Combining equations (9) and (12a), we obtain:

$$\widehat{\left(\frac{P_{ut}C_{ut}}{P_{pt}C_{pt}}\right)} = \widehat{\left(\frac{P_{ut}}{P_{pt}}\right)}^{1-\sigma_s} \widehat{C}_t^{\varepsilon_u-\varepsilon_p}. \tag{15}$$

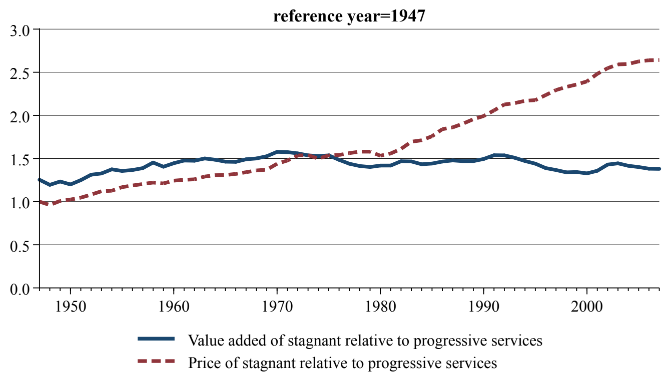
To fit the data as shown in Figure **??**, we will need to assume that the two service subsectors are substitutes, progressive services are a necessity, and stagnant services are a luxury:

Assumption 3 $1 < \sigma_s$ *and* $\varepsilon_u - \varepsilon_p > 0$.

[10]See for example Echevarria (1997), Ngai and Pissarides (2007), and Herrendorf et al. (2013). Our calibration and estimation exercises below will generate parameter values that are consistent with this assumption.

[11]Our calibration below will generate parameter values that are consistent with P_{st}/P_{gt} and C_t both growing.

Figure 3: Relative Prices and Expenditures in Services



Source: WORLD KLEMS, March 2017 release,
BEA/BLS Integrated Industry-level Production Account for the United States, own calculations.

Since P_{ut}/P_{pt} increases over time, Assumption 3 implies that the relative price effect, which is the first term on the right–hand side of equation (15), increases the expenditure of stagnant services relative to progressive services. In contrast, the income effect, which is the second term on the right–hand side, increases the relative expenditure of stagnant services. The net effect is analytically ambiguous.

In the next sections, we will provide hard evidence from micro estimations and a macro calibration for the features in Assumptions 2–3. Here, we build some initial intuition for why they are required to replicate the patterns of structural change within the service sector. Figure 3 shows that until around 1970 the price of stagnant relative to progressive services increased along with the corresponding expenditure ratio. After 1970, the increase in the relative price accelerated while the expenditure ratio flattened out. If stagnant services are luxuries and progressive services are necessities, then the increasing C_t increases their ratio over the whole period. If stagnant and progressive services are substitutes, then the increasing P_{ut}/P_{pt} decreases their ratio over the whole period. To replicate the observed pattern, the first effect must dominate before 1970 and the two effects must offset each other after 1970. Note that alternative parameter constellations would not be able to generate the observed patterns. If the two services were complements, then after 1970 the expenditure ratio of stagnant over progressive services would increase by more than before 1970, which would be counterfactual. Therefore, the two services must be substitutes. Given that, if the stagnant services were necessities and progressive services were luxuries, then the expenditure ratio of stagnant over progressive service would decrease during the whole period. Again, this would be counterfactual.

When we focus on the long run, we can go further and tightly characterize what happens within the services sector. In preparation of our main theoretical result, we introduce the following notation for expenditure shares:

$$\chi_{jt} \equiv \frac{P_{it}C_{it}}{P_{gt}C_{gt} + P_{st}C_{st}}, \quad i \in \{g, s\},$$
$$\chi_{jt} \equiv \frac{P_{it}C_{it}}{P_{ut}C_{ut} + P_{pt}C_{pt}}, \quad i \in \{p, u\}.$$

Since we know that $\lim_{t\to\infty} \chi_{gt} = 0$, we impose $\chi_{gt} = 0$ and $\chi_{st} = 1$ when we derive our main result. To be able to derive a sharp analytical result, we also set the wedges to zero. In the quantitative analysis conducted below, we will reintroduce them and show that their calibrated parameter values do not overturn the analytical result. Appendix B.3 proves:

Proposition 2 *Let $\chi_{st} = 1$, $\tau_{ut} = \tau_{pt} = 0$, and $\widehat{A}_{ut} = \widehat{A}_u$ and $\widehat{A}_{pt} = \widehat{A}_p$ be constant. If the parameters satisfy Assumptions 2–3, then for all $\widehat{A}_p > 1$ there is a unique $\widehat{A}_u^* = \widehat{A}_u(\widehat{A}_p) \in \left[1, \widehat{A}_p\right)$ such that:*

- *For all $\widehat{A}_u \in \left(0, \widehat{A}_u^*\right)$, $\lim_{t\to\infty} \chi_{pt} = 1$ and $\lim_{t\to\infty} \widehat{LP}_t = \widehat{A}_p$.*
- *For $\widehat{A}_u = \widehat{A}_u^*$, χ_{ut} and χ_{pt} are constant and $\lim_{t\to\infty} \widehat{LP}_t \in \left[\widehat{A}_u^*, \widehat{A}_p\right]$.*
- *For all $\widehat{A}_u \in \left(\widehat{A}_u^*, \widehat{A}_p\right)$, $\lim_{t\to\infty} \chi_{ut} = 1$ and $\lim_{t\to\infty} \widehat{LP}_t = \widehat{A}_u$.*

A key implication of the proposition is that the productivity growth factor is strictly above one in the limit: $\widehat{LP}_t \geq \widehat{A}_u^* > 1$. In particular, the progressive services sector takes over the model economy in the limit if the productivity growth of the stagnant services sector is sufficiently *weak*, that is, $\widehat{A}_u < \widehat{A}_u^*$. And the stagnant services sector takes over the economy in the limit only if its productivity growth is sufficiently *strong*, that is, $\widehat{A}_u^* < \widehat{A}_u < \widehat{A}_p$. In other words, given Assumptions 2–3, Proposition 2 rules out Baumol's apocalyptic scenario that the stagnant services sector has really low productivity growth and takes over the economy.

To build intuition for the result of the proposition, consider what happens for a given $\widehat{A}_p$ when one lowers $\widehat{A}_u$. The income effect in favor of stagnant services becomes weaker because $\widehat{C}_t$ falls; the substitution effect against stagnant services becomes stronger because P_{ut}/P_{pt} rises. In other words, both effects work in the same direction – against C_{ut} and in favor of C_{pt}. If $\widehat{A}_u$ is low enough, that is, $\widehat{A}_u < \widehat{A}_u^* < \widehat{A}_p$, then the combined effect is strong enough to drive χ_{ut} to zero and have C_{pt} take over the economy.

Importantly, the result of the proposition holds for any value of the productivity growth factor of progressive services larger than one, any positive value of the difference between the income elasticities of stagnant and progressive services, and any value of the elasticity of substitution between stagnant and progressive services larger than one. This is noteworthy because the non-homotheticity is persistent so that the difference between the income elasticities of stagnant and progressive services does not converge to zero in the limit. Nonetheless, the proposition shows that even if the difference is arbitrarily large, there is always a sufficiently small, positive productivity growth rate of stagnant services to have progressive services take over. In contrast, in standard models with Stone-Geary preferences, the result would be entirely expected because in the limit the difference between the income elasticities would converge to zero, the utility function would become homothetic, and only the substitution effect would operate. In that case, progressive services will trivially take over in the limit if both services are substitutes.

4 Micro Evidence

Since the parameter constellation within services is key for the main result of our paper, and since we are not aware of existing micro evidence to support it, we now provide some micro evidence ourselves. We use quarterly data on households' consumption expenditures from the CEX. Every household in the CEX is interviewed for up to four consecutive quarters during 1999–2015. We apply standard selection criteria and consider urban households with heads between 25–65 years of age who have participated in all four interview rounds.[12] To account for top coding and outliers we drop households at the bottom and the top 5% of the income and the expenditure distributions. The total number of remaining observations is 87,017.

To be consistent with the formulation of our model, we adopt the value-added representation of expenditures and prices. Hence, we follow Buera et al. (2018) and use the input-output tables to translate observed consumption expenditure into value added. Since, total household expenditures and household's relative prices are likely to be endogenous, we follow Comin et al. (2018) and instrument with the household's income quintile, the household's after-tax income, and a "Hausman"-type relative-price instrument that uses price information excluding the region of the household. According to Comin et al. (2018), *"These price instruments capture the common trend in U.S. prices while alleviating endogeneity concerns due to regional shocks (and measurement error of expenditure)"*.

4.1 Reduced-Form Estimation

The first natural step is to obtain reduced-form estimates of the slopes of the household-level Engel curves. These slopes are not identical to the ε_i in the model because the preferences we use do not aggregate in general and because consumption expenditure, which we use in the estimation, are not equal to GDP, which we use in the calibration. Nonetheless, the Engel curves are informative about the qualitative features of the underlying income effects. We

[12] Aguiar and Bils (2015) and Comin et al. (2018) proceed in a similar way.

follow Aguiar and Bils (2015) and estimate the following models:

$$\log(Y_{it}^n) = \alpha_i + \beta_i \log(E_t^n) + \gamma_i Z_t^n + \nu_{it}^n, \tag{16}$$

where n is the household superscript and the subscript $i \in \{g, s, p, u\}$ indicates goods, services, and progressive and stagnant services, respectively. E_t^n is total household income and Z_t^n is a vector of demographic variables including age, number of earners, and household size. The parameters of interest are the β_i, which measure the income elasticities of household expenditures of category i. We consider two different dependent variables: (i) the log of total household expenditure on good i: $\log(Y_{it}^n) = \log(P_{it}^n C_{it}^n)$; (ii) the log deviation of total household expenditure on good i from average expenditure on good i across all households in the same time period: $\log(Y_{it}^n) = \log(P_{it}^n C_{it}^n) - \log(\bar{P}_{it}\bar{C}_{it})$, which is the specification used by Aguiar and Bils. We estimate (16) by the Generalized Methods of Moments and by Instrumental Variables. The set of instruments includes the same variables as above.

The estimation results are in Table 10 in Appendix C. Across all specifications, we obtain the robust result that $\beta_s > \beta_g$ and that $\beta_u > \beta_p$. In other words, the micro data confirm that services and stagnant services are luxuries and goods and progressive services are necessities. This is exactly what we concluded above from interpreting the macro evidence.

4.2 Structural Estimation

Next, we use the model to derive structural estimation equations. We choose $\alpha_s = 1 - \alpha_g$, $\alpha_p = 1 - \alpha_u$, and $\varepsilon_g = \varepsilon_p = 1$. Note that the resulting parameter values will satisfy Assumption 1. Taking logs of (11a) and (12a) then gives:

$$\begin{aligned}\log(P_{st}^n C_{st}^n) = &\log\left(\frac{1-\alpha_g}{\alpha_g}\right) + (1-\sigma_c)\log(P_{st}^n) - (1-\sigma_c)\log(P_{gt}^n) + (\varepsilon_s - 1)\log(C_t^n) \\ &+ \log(P_{gt}^n C_{gt}^n) + \beta_s X_t^n + \delta_{sr} + \delta_{st} + \nu_{st}^n, \end{aligned} \tag{17}$$

$$\begin{aligned}\log(P_{ut}^n C_{ut}^n) = &\log\left(\frac{1-\alpha_p}{\alpha_p}\right) + (1-\sigma_s)\log(P_{ut}^n) - (1-\sigma_s)\log(P_{pt}^n) + (\varepsilon_u - 1)\log(C_t^n) \\ &+ \log(P_{ut}^n C_{ut}^n) + \beta_u X_t^n + \delta_{ur} + \delta_{ut} + \nu_{ut}^n, \end{aligned} \tag{18}$$

where n is the household superscript, X^n is the vector of household characteristics, δ_r and δ_t denote region and time fixed effects, and ν_i^n is the error term. We include in the vector X^n variables related to age, household size, and the number of earners. We allow for time fixed effects to absorb aggregate consumption shocks. The underlying assumption is that household heterogeneity in time-invariant demand can be fully explained by X^n and δ_r.

All variables of the right-hand side of (17)–(18) except for P_{st} and C_t are observable. (12b) implies that P_{st} is a function of observables and of C_t. This leaves C_t as the only unobservable variable. It is important to realize that C_t is the consumption index implied by the model and is not in general equal to real consumption expenditures from the data.[13] The most natural strategy to deal with this issues is to add the CES aggregator from the model, (6a), as an estimation equation:

$$C_t = \left(\alpha_g^{\frac{1}{\sigma_c}} (P_{gt} C_{gt})^{\frac{\sigma_c - 1}{\sigma_c}} P_{gt}^{\frac{1-\sigma_c}{\sigma_c}} + (1-\alpha_g)^{\frac{1}{\sigma_c}} C_t^{\frac{\varepsilon_s - 1}{\sigma_c}} (P_{st} C_{st})^{\frac{\sigma_c - 1}{\sigma_c}} P_{st}^{\frac{1-\sigma_c}{\sigma_c}}\right)^{\frac{\sigma_c}{\sigma_c - 1}}. \tag{19}$$

We estimate (12b) together with (17)–(19) together. Importantly, our estimation strategy explicitly treats the consumption index C_t and expenditures E_t as different objects.[14]

Table 11 in Appendix C reports the estimation results. Across all specifications, we obtain the robust result that $\varepsilon_s - \varepsilon_g > 1$ and $\varepsilon_u - \varepsilon_p > 1$.[15] Thus, services and stagnant services are again luxuries and goods and progressive services are again necessities. We also obtain the robust result that $\sigma_c < 1 < \sigma_s$, that is, goods and services are complements and progressive and stagnant services are substitutes. This is exactly what we concluded above from interpreting the macro evidence. We now show that the same patterns results also from a rigorous macro calibration.

5 Quantitative Analysis

Before we turn to the details of our quantitative analysis, we emphasize again that the growth of the utility index in the model differs from the Törnqvist index in WORLD KLEMS. Consistency requires that we apply the same measure of GDP growth in the model and in the data. We therefore use the utility index to solve the model, but the Törnqvist index to calculate the model GDP that we compare with the data GDP from WORLD KLEMS. In Duernecker et al. (2017), we demonstrate that proceeding in this way is essential for capturing the productivity growth slowdown.

5.1 Calibration

We make the following normalizations: $A_{g,1947} = P_{i,1947} = 1$ for $i = g, p, u$ and $\tau_{gt} = 0$ for $t = 1947, ..., 2016$. We choose the other two wedges to match the observed relative nominal

[13] The working-paper version of this paper shows formally that the two indexes are different objects when the utility is non–homothetic, implying that their growth factors cannot directly be compared to each other.

[14] An alternative strategy would be to solve one of the first-order conditions for C_t and use the result to substitute C_t out from the other equations. Hanoch (1975) suggested this alternative and Comin et al. (2018) implemented it. We prefer our strategy over the alternative because our strategy imposes on the estimation that C_t be consistent with the model-implied CES aggregator, which is not ensured by the alternative strategy. In any case, we have verified that the alternative strategy would yield qualitatively similar estimation results to ours.

[15] We have also tried other combinations of the fixed effects than those reported in the table but found that the results are broadly unchanged.

labor productivities according to equation (9):

$$\frac{\widetilde{VA_{it}/H_{it}}}{\widetilde{VA_{gt}/H_{gt}}} = 1 + \tau_{it}, \quad i = p, u, \quad t = 1947, ..., 2016, \tag{20}$$

where $VA_{jt} \equiv P_{jt} Y_{jt}$ is nominal value added in sector j and "tildes" denote observations from the data. The upper left panel of Figure 4 shows the resulting wedges.

The normalizations $A_{g,1947} = P_{g,1947} = 1$ imply that nominal and real labor productivity of the goods sector equal one in 1947:

$$\frac{VA_{g,1947}}{H_{g,1947}} = \frac{Y_{g,1947}}{H_{g,1947}} = 1.$$

We choose $\{A_{gt}\}_{t=1948,...,2016}$ to match the observed growth of the real labor productivity of the goods sector after 1947 according to equation (5):

$$\frac{\widetilde{Y_{gt+1}/H_{gt+1}}}{\widetilde{Y_{gt}/H_{gt}}} = \frac{A_{gt+1}}{A_{gt}}, \quad t = 1947, ..., 2016. \tag{21}$$

We choose the other two sectoral TFPs, $\{A_{it}\}_{t=1947,...,2016}$ for $i = p, u$, to match the observed relative prices. Using equation (8), the wedges, and the normalizations $A_{g,1947} = P_{i,1947} = 1$, this gives:

$$\frac{\widetilde{P}_{it}}{\widetilde{P}_{gt}} = (1 + \tau_{it}) \frac{A_{gt}}{A_{it}}, \quad i = p, u, \quad t = 1947, ..., 2016. \tag{22a}$$

The upper right panel of Figure 4 plots the implied sectoral TFPs.

Combining (20) with (22) shows that the previous choices imply we have matched relative real productivities:

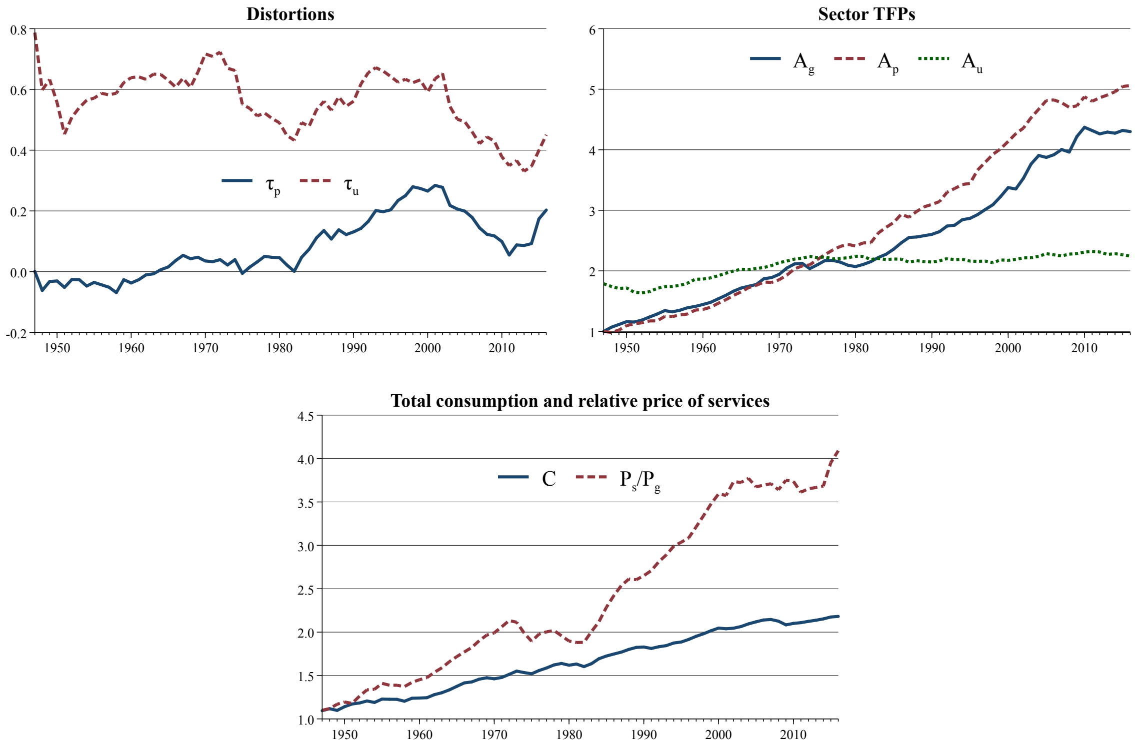
$$\frac{\widetilde{Y_{it}/H_{it}}}{\widetilde{Y_{gt}/H_{gt}}} = \frac{\widetilde{VA_{it}/H_{it}}}{\widetilde{VA_{gt}/H_{gt}}} \frac{\widetilde{P}_{gt}}{\widetilde{P}_{it}}, \quad i = p, u, \quad t = 1947, ..., 2016. \tag{23}$$

Given the normalizations, (21) implies we have matched real labor productivity in the goods sector in all years. Therefore, we have matched real labor productivity in all sectors and all years.

We are left with ten parameters to calibrate: the four relative weights $\{\alpha_g, \alpha_s, \alpha_p, \alpha_u\}$, the two elasticities $\{\sigma_s, \sigma_c\}$, and the four parameters governing the income effects $\{\varepsilon_g, \varepsilon_s, \varepsilon_p, \varepsilon_u\}$. As in the structural estimation, we normalize ε_g and ε_p, making sure that the choices satisfy Assumption 1. We also impose that $\alpha_s = 1 - \alpha_g$ and $\alpha_u = 1 - \alpha_p$.

This leaves six parameters, $\{\alpha_g, \alpha_p, \sigma_s, \sigma_c, \varepsilon_s, \varepsilon_u\}$ to calibrate. We calibrate them by jointly

Figure 4: Implications of the Calibration



targeting the two nominal-value-added ratios given by (11a) and (12a) in all years:

$$\frac{VA_{st}}{VA_{gt}} = \frac{\alpha_s}{\alpha_g}\left(\frac{(1+\tau_{st})A_{gt}}{A_{it}}\right)^{1-\sigma_c} C_t^{\varepsilon_s-\varepsilon_g}, \tag{24}$$

$$\frac{VA_{ut}}{VA_{pt}} = \frac{\alpha_u}{\alpha_p}\left(\frac{(1+\tau_{ut})A_{pt}}{(1+\tau_{pt})A_{ut}}\right)^{1-\sigma_s} C_t^{\varepsilon_u-\varepsilon_p}, \qquad t = 1947, ..., 2016. \tag{25}$$

To be precise, we choose the six parameters to minimize the squared deviations of VA_{it}/VA_{jt} from $\widetilde{VA_{it}/VA}_{jt}$. When solving for the right-hand-side ratios, we take into account that the consumption index is given by (6a) and we impose that sectoral labor services satisfy the feasibility constraint (7b):

$$\sum_{i\in\{g,p,u\}} H_{it} = H_t = \sum_{i\in\{g,p,u\}} \widetilde{H}_{it}, \tag{26}$$

where the right-hand side is given by the data. The upper panels of Figure 5 show that we match well the trends of relative-nominal-sectoral value added. We also match well the non-targeted employment shares.

To compare aggregate productivity implied by the model with the data, we need a measure of GDP (aggregate value added) per labor service in the model. We construct GDP by using the Thörnqvist index as it is done in WORLD KLEMS. Real and nominal GDP in the reference period 1947 follow from the normalizations $A_{g,1947} = P_{g,1947} = 1$ and the first-order conditions (8):

$$Y_{1947} = VA_{1947} = H_{1947} + \tau_{p,1947} H_{p,1947} + \tau_{u,1947} H_{u,1947}.$$

Real GDP in the other years follows from the accumulated, annual growth rates:

$$Y_T = Y_{1947} \frac{Y_{1948}}{Y_{1947}} \dots \frac{Y_T}{Y_{T-1}} = \exp\left(\log Y_{1947} + \sum_{t=1947}^{T-1} \Delta \log Y_t \right), \quad T = 1948, ..., 2016, \tag{27}$$

where the growth rates $\Delta \log Y_t$ are given by:

$$\Delta \log Y_t = \sum_{i=g,p,u} \frac{1}{2} \left(\frac{1}{\sum_{j=g,p,u} \frac{VA_{jt}}{VA_{it}}} + \frac{1}{\sum_{j=g,p,u} \frac{VA_{j,t+1}}{VA_{i,t+1}}} \right) \Big(\log Y_{i,t+1} - \log Y_{it} \Big). \tag{28}$$

Aggregate productivity follows by dividing the GDP measure (27) by total labor services from the data, $LP_t \equiv Y_t / \widetilde{H}_t$. We divide by $\widetilde{H}_t$ instead of by H_t because the quality–adjusted sectoral labor inputs from WORLD KLEMS are non-additive indexes:

$$H_t = \sum_{i \in \{g,p,u\}} \widetilde{H}_{it} \neq \widetilde{H}_t.$$

Since the difference between $\sum \widetilde{H}_{it}$ and $\widetilde{H}_t$ is quantitatively non negligible, we use $\sum \widetilde{H}_{it}$ when we solve the model but $\widetilde{H}_t$ when we compute the measure of model productivity that we compare with the data. Note that we must take $\widetilde{H}_t$ from the data because it does not have a counterpart that we could generate within the model.

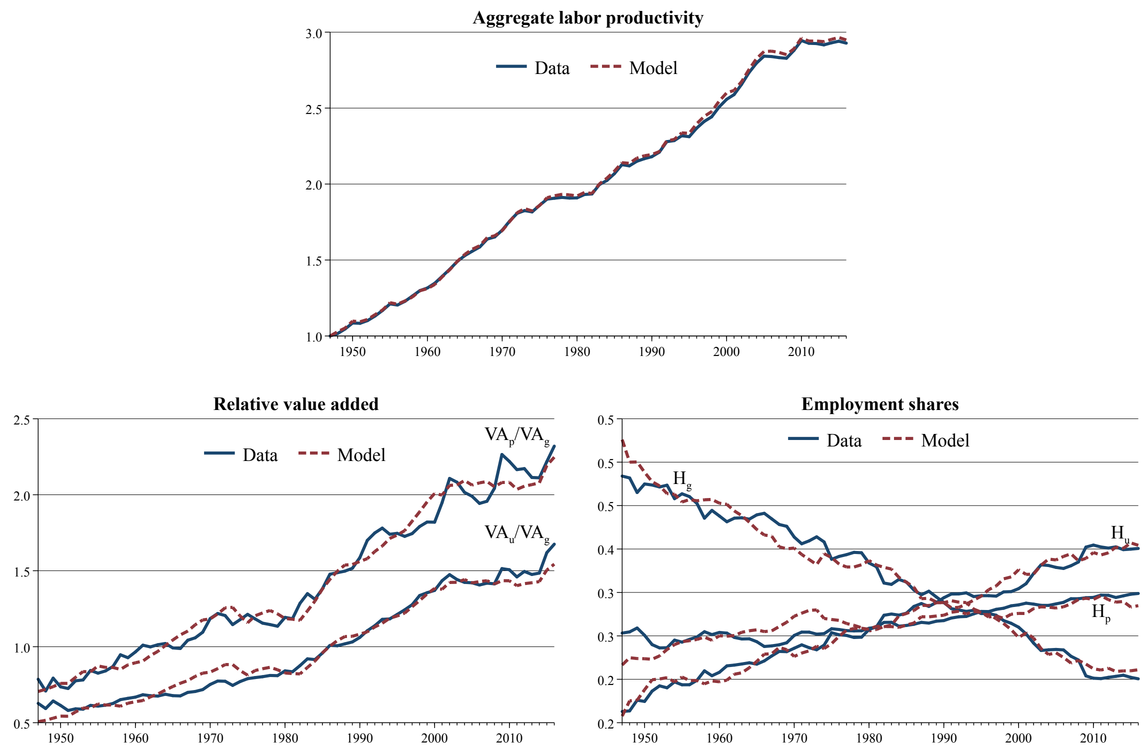
The upper panel of Figure 5 shows that the calibrated series for (aggregate) productivity from the model and the data lie right on top of each other, implying that the model passes the "smell test" for being suitable for our purposes. The reason for why the model does well is that it matches closely both components of the GDP measure (27): by construction, it matches perfectly the real sectoral productivity growth; it also matches closely the relative-nominal-sectoral value added and thus the Thörnqvist shares. And, of course, it matches aggregate labor services by construction.

Table 4: Calibrated Preference Parameters

α_g	α_p	σ_c	σ_s	$\varepsilon_s - \varepsilon_g$	$\varepsilon_u - \varepsilon_p$
0.48	0.42	0.30	1.03	0.32	0.11

The calibrated parameters are in Table 4. We find that goods and services are complements ($\sigma_c < 1$); goods are necessities and services are luxuries ($\varepsilon_s - \varepsilon_g > 0$); services with high and low productivity growth are substitutes ($\sigma_s > 1$); progressive services are necessities and stagnant services are luxuries ($\varepsilon_u - \varepsilon_p > 0$). Three remarks about the calibration results are at order. First, for appropriate normalizations of ε_g and ε_p, Assumptions 1–2 are satisfied. Second, it is noteworthy that the parameters of the macro calibration have the same qualitative features as the structural micro estimates; see Tables 4 and Column (2) of Table 11 in Appendix C. As a note of caution, we should add that there is no sense in which the macro and micro values should exactly equal to each other, because the non-linear CES utility function we are using does not in general aggregate across different households. Third, the lower panel of Figure of 4 shows that the calibrated parameters imply model sequences $\{C_t, P_{st}\}_{t=1947,\ldots,2016}$ that have upward trends. This justifies our assumption in the theory part that both C_t and P_{st}/P_{gt} are increasing.

Figure 5: Value Added, Employment, and Aggregate Productivity – Model and Data



5.2 Predictions

We now obtain predictions by simulating our model forward. To have roughly similar horizons for the past and the future productivity-growth slowdowns, we choose 1996–2016 as our reference period and compare what happened between 1947–1967 and 1996–2016 with what will happen between 1996–2016 and 2046–2066. We assume that between 2017–2066, the variables $\{A_{gt}, A_{pt}, A_{ut}, \sum_{i\in\{g,p,u\}} \widetilde{H}_{it}, \widetilde{H}_t\}$ grow at the same constant, average rates as they did "in the past" and the wedges $\{\tau_{pt}, \tau_{ut}\}$ equal the average of their "past values". We consider three possibilities for what the past means: 1996–2016; 1986–2016; or 1976–2016. To speak to whether Baumol's "apocalyptic" scenario might happen, we add a counterfactual that takes the values from 1996–2016 while imposing $\Delta \log A_u = 0$. Since past wedges fluctuate quite a bit without showing a clear trend, we will conduct robustness analysis in Subsection 6.1 below and establish that our results are not sensitive to the specification of the process of future wedges.

Table 5 shows the predicted future growth rates of aggregate labor productivity if the future aggregate variables are calculated as just described.[16] The first important observation is that average productivity growth during 2017–66 is predicted to stay far away from zero. Moreover, average productivity growth during 2046–2066 is just below that during 2017–2066, suggesting that the model generates only a limited future productivity-growth slowdown. A different way of making the same point is to focus on the productivity growth slowdown between the periods 1996–2016 and 2046–66. The first three rows show that it is at most 0.19 percentage points. Even in the extreme case of the last row, it is 0.29 percentage points only. To put these numbers into perspective, recall that the historical productivity-growth slowdown between 1947–1967 and 1996–2016 reported in Table 1 above was 1.25 percentage points, with 0.39 percentage points attributable to structural change. In other words, even in the last row the future effect of structural change on productivity growth is predicted to be less than three quarters of its past effect ($0.29/0.39 < 3/4$). And in the other rows, the future effect is predicted to be less than one half of its past effect ($0.19/0.39 < 1/2$).

Table 5: Predicted Productivity Growth 2017–2066

Exogenous Variables Based on Averages over	2017–2066	1996–2016	2046–2066	Slowdown (col. 4 – 3)
1996–2016	0.89%	1.04%	0.85%	0.19
1986–2016	0.91%	1.04%	0.88%	0.16
1976–2016	0.93%	1.04%	0.91%	0.13
1996–2016, $\Delta \log A_{ut} = 0$	0.79%	1.04%	0.75%	0.29

Note: Productivity is real value added per labor services; annual averages.

Obviously, the quality of the prediction depends on the quality of the model one uses and what one feeds into it. We have already argued above that our model passes the minimal "smell test" that it accounts closely for the productivity dynamics in the postwar US. To build further confidence in the suitability of our model for answering our question, we add a straightforward

[16] Background information on the other inputs is in Table 12 in Appendix D.

in-sample prediction exercise. In particular, we re-calibrate the model to match the same data targets as above, but now for the shorter period 1947–1996. Moreover, we assume again that the exogenous variables continue to grow at their average rates over the last 20 years of the calibration period, which now is 1976–1996. We then use the re-calibrated model to predict productivity growth for the remaining 20 years 1996–2016 for which we have data. The re-calibrated model predicts 1.03% average annual productivity growth for 1996–2016. This is reassuringly close to the actual 1.06% productivity growth!

5.3 Intuition

The are two reasons why our model predicts that the future effects of structural change on aggregate productivity growth are smaller than the past effects. First, as we saw above, goods have higher productivity growth than services and structural change reallocates economic activity from goods to services. Over time, the importance of the implied productivity-growth slowdown declines. In particular, while between 1947 and 2016 the value-added share of the goods sector decreased by 24 percentage points from 45% to 21%, our analysis implies that until 2066 it will decrease further only by an additional 9 percentage points to 12%. Second, for the calibrated parameter values there is little reallocation within the services sector. In fact, our analysis implies that the value-added share of stagnant services in total services is almost the same in 1947 and 2066 (58% versus 59%). In other words, the stagnant services sectors is not at all taking over the economy in the next half century.

Table 6: Predicted Value Added Shares and Productivity Growth in the Long Run (in %)

		2066	2100	2500	3000	3500	4000
$\Delta \log A_u = 0.2$:	$P_gC_g/\sum P_iC_i$	11.7	7.9	0.07	0.00	0.0 0	0.00
	$P_pC_p/\sum P_iC_i$	35.8	37.2	39.9	39.6	39.3	38.9
	$P_uC_u/\sum P_iC_i$	52.5	54.9	60.0	60.4	60.7	61.1
	$\Delta \log LP_t$	0.85	0.79	0.64	0.64	0.63	0.63
$\Delta \log A_u = 0.8$:	$P_gC_g/\sum P_iC_i$	12.3	8.5	0.11	0.00	0.00	0.00
	$P_pC_p/\sum P_iC_i$	35.2	36.4	36.0	31.5	27.0	22.3
	$P_uC_u/\sum P_iC_i$	52.5	55.1	63.9	68.5	73.0	76.9
	$\Delta \log LP_t$	1.17	1.12	0.98	0.94	0.90	0.86
$\Delta \log A_u = 0$:	$P_gC_g/\sum P_iC_i$	11.5	7.7	0.05	0.00	0.00	0.00
	$P_pC_p/\sum P_iC_i$	35.9	37.5	41.2	42.2	43.1	44.0
	$P_uC_u/\sum P_iC_i$	52.5	54.8	58.8	57.8	56.9	56.0
	$\Delta \log LP_t$	0.75	0.68	0.55	0.56	0.57	0.59

Note: Productivity is real value added per labor services; line "$\Delta \log A_u = 0.20$" corresponds to the baseline case.

It is interesting to put the last statement into the context of Proposition 2, which established that for a given $\widehat{A}_p \in (1, \infty)$ there is a unique threshold value of productivity growth for stagnant services, $\widehat{A}_u^* \in (1, \widehat{A}_p)$, at which the composition of the services sector does not change in the limit. A natural interpretation of our quantitative results is that our calibration must generate parameter values very close to the threshold value.[17] The numerical analysis brings out the additional, key property of our model that the convergence to one of the two corners is very slow indeed if the parameters are not exactly at the threshold values. To flash this out more clearly, we have simulated our model forward several thousand years for three different productivity growth rates of stagnant services: 0.2% (as calibrated), 0% (lower than calibrated), and 0.8% (higher than calibrated). To avoid misinterpretation, we stress that we do not at all attempt to predict the future for hundreds of years ahead, not to speak of until the year 4000. We report simulations that far ahead into the future solely to understand what the model dynamics look like in the very long run.

Table 6 reports the results. Consider first what happens until 2500 at which point the goods sector has disappeared for all practical purposes (i.e., it has less than 1% of value-added share) and the services sectors have taken over. For all three parameter values, the value-added shares of goods and productivity growth both decrease until 2050, and the decreases in productivity growth are by similar percentage points. This can be understood as the effects of reallocating from goods to services dominating the other effects. After 2500, the effects of reallocating from goods to services have all but disappeared and the dynamics differ among the three parameter values exactly as implied by Proposition 2. For the calibrated $\Delta \log A_u = 0.2$, the composition of services and productivity growth remain roughly constant, which must mean that the calibrated value is close to the threshold value of productivity growth. If we raise $\Delta \log A_u$ to 0.8, then we are above the threshold productivity growth, in which case the stagnant services take over and productivity growth falls to their lower growth rate. If we lower $\Delta \log A_u$ to 0, then we are below the threshold productivity growth, in which case the progressive services take over and productivity growth rises to their higher growth rate. Interestingly, in both cases, the dynamics are extremely slow, and so the economy does not get close to the limit within the "near future" (i.e., half a century) that we care about in our predictions.

The upshot is that for the near future there is no sign whatsoever that the stagnant services may take over the economy and drive productivity growth anywhere close to zero. We conclude that our analysis provides no support for Baumol's "apocalyptic" scenario.

[17] We cannot formally establish this because the Proposition is formulated for zero wedges whereas the calibrated model includes non-zero wedges.

6 Robustness Analysis

This section establishes that the previous findings are robust in various directions. In particular, we change the future evolution of wedges, take into account the possibility of underestimated quality improvements in services, and disaggregate further than into just three sectors.

Table 7: Wedges and Predicted Productivity Growth for 2046–2066

τ_p	τ_u	$\Delta \log LP_t$
aver	aver	0.85
max	max	0.86
max	min	0.85
min	max	0.87
min	min	0.85

Note: Productivity is real value added per labor services; annual growth rates in %; average, max, min taken over 1996–2016; line "aver" corresponds to the baseline case, line "1996–2016" of Table 5.

6.1 Different Wedges

We first establish that our predictions are robust to different specifications of future wedges. As the upper left panel of Figure 4 showed, the calibrated series of the wedges fluctuate without showing any clear trend. Above, we therefore assumed that the future values of the wedges equal the average values over the three past periods 1996–2016, 1986–2016, and 1976–2016. Table 7 explores all combinations of the minimum and maximum values of τ_p and τ_u over the period 1996–2016. It is remarkable that the predicted aggregate productivity growth rate hardly changes.

6.2 Mismeasured Quality

We have already touched on the possibility that the lower productivity growth of some service industries may in part come from the fact that quality improvements in services are hard to measure. So far, we have taken the numbers from WORLD KLEMS at face value and have pretended that there are no under-estimated quality improvements. Now, we look more seriously at the implications of under-estimated quality improvements and substantiate the claim made in Subsection 2.3 above that our predictions provide an upper bound for how much structural change reduces productivity growth.

To entertain different degrees to which quality improvements in stagnant services are underestimated, and the related price increases of stagnant services are overestimated, consider the following counterfactual price increases:

$$\Delta \log \overline{P}_u = \omega \Delta \log \widetilde{P}_u + (1-\omega)\Delta \log \widetilde{P}_p, \tag{29}$$

where $\omega \in [0,1]$. If $\omega = 1$, then $\Delta \log \overline{P}_u = \Delta \log \widetilde{P}_u$ and there is no underestimation of quality improvements. If $\omega = 0$, then $\Delta \log \overline{P}_u = \Delta \log \widetilde{P}_p$ and the underestimation of quality improvements is so severe that the actual price increases of both services subsectors are the same and their relative price does not change at all. We vary ω between these extremes, recalibrate our model after replacing $\widetilde{P}_u$ in the data by the counterfactual $\overline{P}_u$ from above, take the period 1996–2016 as the past from which we obtain the estimates of future exogenous processes, and redo the prediction exercise.

Table 8 reports the results. Recall that $\omega = 1$ is the previous benchmark case and a lower value of ω corresponds to a more severe underestimation of quality of the value added produced in the service sector with low productivity growth. As ω decreases, the future productivity-growth slowdown becomes smaller and smaller. Therefore, our predictions indeed provide an upper bound of the actual effect of structural change on productivity growth when quality improvements are mismeasured.

Table 8: Quality Mismeasurement and Predicted Productivity Growth

ω	$\Delta \log LP_t$ 1996–2016	$\Delta \log LP_t$ 2046–66	Growth Slowdown
1.00	1.04%	0.85%	0.19
0.75	1.15%	0.98%	0.17
0.50	1.26%	1.11%	0.15
0.25	1.37%	1.24%	0.13

Note: Productivity is real value added per labor services; annual averages;
ω defined in (29); line "1.00" corresponds to the baseline case, line "1996–2016" of Table 5.

6.3 Finer Disaggregations

Our nested utility specification remains tractable, which allows us to derive analytical results and build intuition for the main forces behind the productivity effect of structural change. However, its simplicity does raise two questions: How restrictive is it that we first combine the services sub-sectors and then combine the resulting aggregate services with goods? How restrictive is it that we consider the three categories goods, progressive services, and stagnant services? In this subsection, we relax the nesting structure and increase the number of services sectors to establish that the predictions of our nested utility specification are fairly robust.

Hanoch (1975) and Sato (1975) formulated more general utility functions that allow for many quantities $i = 1, ..., I$, each of which with its own income effect and elasticity parameter. In our context, the relevant class of utility functions satisfies the following equation:[18]

$$1 = \sum_{i=1}^{I} \alpha_i^{\frac{1}{\sigma_i}} \left(\frac{C_{it}}{C_t^{\phi_i}} \right)^{1-\frac{1}{\sigma_i}}, \tag{30}$$

where C_t is a utility function that depends on the consumed quantities $C_{1t}, ..., C_{It}$; α_i are weights; ϕ_i govern the income effects; σ_i and σ_j govern the Allen-Uzawa elasticities of substitution σ_{ij} between i and j (see Hanoch for the explicit elasticity formula). To apply standard consumer theory, the utility function $C_t = U(C_{1t}, ..., C_{It})$ that is implicitly defined by (30) must be globally monotone and quasi–concave. Hanoch (1971) proved that this is the case if $\alpha_i, \phi_i, \sigma_i > 0$ for all $i = 1, \dots, I$; either $\sigma_i > 1\ \forall i$ or $\sigma_i \in [0, 1]\ \forall i$.

To see that Hanoch's class encompasses our utility specifications, set $\phi_i = (\sigma_i - \varepsilon_i)/(\sigma_i - 1)$ in (30):

$$1 = \sum_{i=1}^{I} \alpha_i^{\frac{1}{\sigma_i}} \left(\frac{C_{it}^{\sigma_i - 1}}{C_t^{\sigma_i - \varepsilon_i}} \right)^{\frac{1}{\sigma_i}} \tag{31}$$

The specification of our outer layer, (6a), results if, in addition, we set $\sigma_i = \sigma_c$ and $I = 2$ and rearrange:[19]

$$C_t = \left(\alpha_g^{\frac{1}{\sigma_c}} C_t^{\frac{\varepsilon_g - 1}{\sigma_c}} C_{gt}^{\frac{\sigma_c - 1}{\sigma_c}} + \alpha_s^{\frac{1}{\sigma_c}} C_t^{\frac{\varepsilon_s - 1}{\sigma_c}} C_{st}^{\frac{\sigma_c - 1}{\sigma_c}} \right)^{\frac{\sigma_c}{\sigma_c - 1}}.$$

To obtain the specification of our inner layer, (6b), we set $I = 2$, $\sigma_s = \sigma_i$, and $\varepsilon_i = 1$. Rearranging (31) then gives the CES special case. Our precise specification results if one modifies the weights to $\alpha_p C_t^{\varepsilon_p - 1}$ and $\alpha_u C_t^{\varepsilon_u - 1}$:

$$C_{st} = \left(\left(\alpha_p C_t^{\varepsilon_p - 1}\right)^{\frac{1}{\sigma_s}} C_{pt}^{\frac{\sigma_s - 1}{\sigma_s}} + \left(\alpha_u C_t^{\varepsilon_u - 1}\right)^{\frac{1}{\sigma_s}} C_{ut}^{\frac{\sigma_s - 1}{\sigma_s}} \right)^{\frac{\sigma_s}{\sigma_s - 1}},$$

which is a version of (6b).

We can use (31) to generalize our analysis to category-specific elasticity parameters, $\sigma_i \neq \sigma_j$, and more than two services sectors, $I - 1$. In choosing I and the implied level of disaggregation of services, we need to trade off two considerations. On the one hand, WORLD KLEMS has 39 services industries and one might think that we should "go all the way" and consider

[18]Except for the notation, this is equation (2.16) of Hanoch (1975, page 403). He calls the implied utility functions the constant-ratios-of-elasticities utility class, which is a subclass of his implicitly-additive utility functions.

[19]The specification of Comin et al. (2018) is essentially the same, except they consider the three-goods case with agriculture, manufacturing, and services.

the finest disaggregation possible. On the other hand, as shown by Hanoch, the specification (30) imposes the restriction that σ_{ij} is proportional to σ_i irrespective of whether or not j is a close substitute to i. Hanoch (1975, page 401) argued that this property is more likely to hold if substitution is "of a general nature, rather than specific". That implies that the specification (30) is more suitable for studying relative broad aggregation categories, instead of very fine aggregation categories. As a compromise between the two considerations, we consider the goods sector along with the 10-sector split of services from WORLD KLEMS, and so we will have $i = g, 1, ..., 10$. The rest of the analysis is exactly the same as before, so we do not repeat here. Appendix B.5 contains the solution to the household problem for the resulting split with goods and ten services sectors.

The calibrated parameter values satisfy Hanoch's assumptions because $\alpha_i, \phi_i > 0$ and $\sigma_i \in [0, 1]$ $\forall i = 1, \ldots, I$. Hence, the implied utility function is monotonically increasing in all arguments and quasi concave and the household problem is well defined. Table 9 reports the simulation results. While the predicted productivity growth changes somewhat depending on the specification, overall our result that future productivity growth is well above zero remains valid when we relax the nested structure and go to goods plus 10 services sectors. We have also experimented with a finer 16-sector split and obtained similar simulation results.

Table 9: Finer Dis-aggregations and Predicted Productivity Growth for 2046–66

σ_c, σ_s	$i = g, p, u$	0.85
$\sigma_i \neq \sigma_j$	$i = g, p, u$	0.83
$\sigma_i \neq \sigma_j$	$i = g, 1, ..., 10$	0.76

Note: Productivity is real value added per labor services; annual averages in %; values of exogenous variables averages over 1996–2016; line "$\sigma_c, \sigma_s,\ i = g, p, u$" corresponds to line "1996–2016" of Table 5.

7 Related Literature

Our work is related to the broad debate about whether the past slowdown in productivity growth is temporary or permanent. Antolin-Diaz et al. (2017) and Foerster et al. (2019) offered statistical analyses. Gordon (2016) argued that we picked the "low–hanging fruit" (e.g., railroads, cars, and airplanes) during the "special century 1870–1970" and that more recent innovations pale in comparison. Bloom et al. (2016) provided evidence that supports this view. Fernald and Jones (2014) pointed out that the engines of economic growth like education or research and development require the input of time which cannot be increased ad infinitum. The tendency in this literature is to conclude that low productivity growth rates may be the future norm. Our work adds an additional reason for why future productivity growth rates are not likely to return to past ones: structural change.

Several papers from the recent literature on structural change are directly related to cost disease. The 2004-CEPR-working-paper version of Ngai and Pissarides (2007) mentioned that cost disease can lead to a GDP growth slowdown when GDP growth is calculated with constant relative prices. However, they did not pursue the growth slowdown further but framed their entire analysis in terms of a balanced growth path and constant GDP growth measured in a current numeraire. Moro (2015) provided an interesting model in which cost disease reduces GDP measured with the Fisher index. His analysis differs from our analysis because he focused on the role of differences in the sectoral intermediate-input shares in a cross section of middle- and high-income countries. In independent work, Leon-Ledesma and Moro (2017) asked to what extent structural change may lead to violations of the Kaldor growth facts. In their simulation results, based on the model of Boppart (2014), structural change leads to a growth slowdown of GDP measured with the Fisher index. Although there are obvious similarities with what we do, the following novel features set our work apart: we provide micro and macro evidence on structural change within services; we characterize analytically the limit behavior of a new model with structural change within services; we use our model to predict the future productivity-growth effect of structural change in the US.

We have abstracted from physical capital accumulation, which implies that the services sector takes over our economy in the limit and aggregate productivity growth falls to the services sector's productivity growth. In contrast, in many models of structural change with capital accumulation the services sector does not take over the economy in the limit, because they have the feature that all investment is produced in manufacturing; see for example the class of models summarized in Herrendorf et al. (2013). Since investment does not disappear along a balanced growth path, the manufacturing sector then remains at least as large as the investment sector in the limit. The implication is that, as long as productivity growth is larger in manufacturing than in services, aggregate productivity growth remains larger than productivity growth in the services sector. It is important to realize that this conclusion changes dramatically as soon as one takes into account that structural change also takes place within the investment sector; see for example the models of Acemoglu and Guerrieri (2008) and Herrendorf et al. (2018). In that case, once again the services sector takes over the economy in the limit exactly as it does in the current analysis.

Lastly, our work is related to work on cross–country gaps in sectoral TFP or labor productivity; see for example Duarte and Restuccia (2010), Herrendorf and Valentinyi (2012), Buiatti et al. (2018), and Duarte and Restuccia (2019). The most closely related paper to ours is Duarte and Restuccia (2019), who used the 2005 cross section of the International Comparisons Program of the Penn World Table. Assuming that sectors produce final goods and distinguishing between traditional and non-traditional services, they found that the largest cross–country productivity gaps are in goods and non-traditional services and the smallest cross–country productivity gaps are in traditional services. The main differences to our study are that we are interested in the U.S. time series, assume that sectors produce value added, and distinguish between progressive and stagnant services. Nonetheless, if we used our model to generate a cross section of countries with different levels of aggregate productivity, then it would generate a result that has the same flavor as that of Duarte and Restuccia (2019): the cross–country productivity differences in the goods sector and the progressive services sector are larger than those in the stagnant services sector.

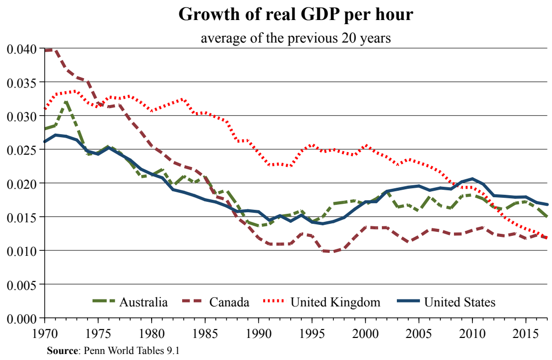
8 Conclusion

We have built and calibrated a model of the productivity effect of structural change. Our model implies that the future effect of structural change on productivity growth in the next 50 years will be about half as big as the past one in the last 50 years. The key novel feature that has been crucial for reaching this conclusion is that we have disaggregated services into progressive and stagnant services. We have documented micro and macro evidence that stagnant services are luxuries, progressive services are necessities, and stagnant and progressive services are substitutes. We have shown that, as a result, stagnant services do not take over the economy in the limit if their productivity growth falls below a positive threshold level, which is in sharp contrast to what existing models of structural change imply.

As a natural first step, we have taken the sectoral growth rates as given and we have explored which consequences the implied changes in the sectoral composition have for future productivity growth. An interesting question for future work is why different sectors show different productivity growth. Young (2014) suggested that continuing selection of workers with different relative productivities may explain part of the differences in sectoral productivity growth. He estimated a Roy model to provide evidence for his thesis. A second interesting question for future work is to study whether the slow growing sectors will continue to grow slowly even when they comprise sizeable shares of the economy. We have made some initial progress on these questions in Herrendorf and Valentinyi (2015).

Our analysis raises the natural follow up question to what extent our results generalize to other countries. A natural starting point is to document that the productivity growth slowdown is a broader phenomenon that occurred also outside the US. To avoid mixing the productivity growth slowdown with declining GDP growth rates after catch-up dynamics that followed World War II, we focus on Australia, Canada, and the United Kingdom, which did not experience major war destruction. Figure 6 depicts the average annual growth rates of their labor productivities in the preceding 20 years. One can see clearly that the productivity growth slow-

Figure 6: The Productivity Growth Slowdown Outside the US



down was a broader than just a U.S. phenomenon.[20]

We think that an important task for future research is to study in detail the effects of structural change on productivity growth in other developed countries. Recent work by Sen (2019) takes a first step in this direction. Conducting a complete postwar analysis for countries other than the U.S. will become feasible once sufficiently long data series on labor services by industry have become available for them.

References

Acemoglu, Daron and Veronica Guerrieri, "Capital Deepening and Non-Balanced Economic Growth," *Journal of Political Economy*, 2008, *116*, 467–498.

Aguiar, Mark and Mark Bils, "Has Consumption Inequality Mirrored Income Inequality?," *American Economic Review*, 2015, *105*, 2725–2756.

Antolin-Diaz, Juan, Thomas Drechsel, and Ivan Petrella, "Tracking the Slowdown in Long–Run GDP Growth," *Review of Economics and Statistics*, 2017, *99*, 343–356.

Baumol, William J., "Macroeconomics of Unbalanced Growth: The Anatomy of the Urban Crisis," *American Economic Review*, 1967, *57*, 415–426.

——, Sue Anne Batey Blackman, and Edward N. Wolff, "Unbalanced Growth Revisited: Asymptotic Stagnacy and New Evidence," *American Economic Review*, 1985, *75*, 806–817.

Bloom, Nicholas, Charles I. Jones, John Van Reenen, and Michael Webb, "Are Ideas Getting Harder to Find?," Manuscript, Stanford University, Palo Alto 2016.

[20]In fact, it looks more pronounced in the other three countries than in the US. Note though that, because of data constraints, the productivity measure used in the figure is GDP per *hour worked*. If instead we used GDP per *labor services* for the U.S. as in the rest of the paper, then the strong rebound of GDP per-hour measure in the last two or so decades would be mitigated.

Boppart, Timo, “Structural Change and the Kaldor Facts in a Growth Model with Relative Price Effects and Non-Gorman Preferences,” *Econometrica*, 2014, *82*, 2167–2196.

Buera, Francisco J. and Joseph P. Kaboski, “The Rise of the Service Economy,” *American Economic Review*, 2012, *102*, 2540–2569.

—–, —–, Richard Rogerson, and Juan I. Vizcaino, “Skill Biased Structural Change,” Manuscript, Washington University at St. Louis 2018.

Buiatti, Cesare, Joao B. Duarte, and Luis Felipe Sáenz, “Why is Europe Falling Behind? Structural Transformation and Services Productivity between Europe and the U.S.,” Manuscript, Univeristy of Illinois 2018.

Byrne, David M., John G. Fernald, and Marshall B. Reinsdorf, “Does the United States Have a Productivity Slowdown or a Measurement Problem,” *Brookings Papers on Economic Activity*, 2016, pp. 109–157.

Comin, Diego, Martí Mestieri, and Danial Lashkari, “Structural Change with Long-Run Income and Price Effects,” Manuscript 2018.

Duarte, Margarida and Diego Restuccia, “The Role of the Structural Transformation in Aggregate Productivity,” *Quarterly Journal of Economics*, 2010, *125*, 129–173.

— and —, “Relative Prices and Sectoral Productivity,” *Journal of the European Economic Association*, 2019, *17*, forthcoming.

Duernecker, Georg, Berthold Herrendorf, and Ákos Valentinyi, “Quantity Measurement, Balanced Growth, and Welfare in Multi–Sector Growth Models,” Discussion Paper 12300, Centre for Economic Policy Research, London 2017.

Echevarria, Cristina, “Changes in Sectoral Composition Associated with Economic Growth,” *International Economic Review*, 1997, *38*, 431–452.

Fernald, John G., “Reassessing Longer–Run U.S. Growth: How Low?,” Federal Reserve Bank of San Francisco Working Paper 2016–18 2016.

— and Charles I. Jones, “The Future of US Growth,” *American Economic Review: Papers and Proceedings*, 2014, *104*, 44–49.

Foerster, Andrew, Andreas Hornstein, Pierre-Daniel Sarte, and Wark Watson, “Aggregate Implications of Changing Sectoral Trends,” Working Paper 2019–16, Federal Reserve Bank of San Franciso 2019.

Gordon, Robert, *The Rise and Fall of American Growth: The US Standard of Living since the Civil War*, Princeton, New Jersey: Princeton University Press, 2016.

Hanoch, Giora, "CRESH Production Functions," *Econometrica*, 1971, *39*, 695–712.

——, "Production and Demand Models with Direct or Indirect Implicit Additivity," *Econometrica*, 1975, *43*, 395–419.

Herrendorf, Berthold and Ákos Valentinyi, "Which Sectors Make Poor Countries so Unproductive?," *Journal of the European Economic Association*, 2012, *10*, 323–341.

—— **and** ——, "Endogenous Sector–Biased Technological Change and Industrial Policy," Discussion Paper 10869, CEPR, London 2015.

——, Christopher Herrington, and Ákos Valentinyi, "Sectoral Technology and Structural Transformation," *American Economic Journal: Macroeconomics*, 2015, *7*, 1–31.

——, Richard Rogerson, and Ákos Valentinyi, "Two Perspectives on Preferences and Structural Transformation," *American Economic Review*, 2013, *103*, 2752–2789.

——, ——, and ——, "Structural Change in Investment and Consumption," Working Paper 24568, National Bureau of Economic Research, Cambridge, MA 2018.

Jorgenson, Dale W. and Marcel P. Timmer, "Structural Change in Advanced Nations: A New Set of Stylised Facts," *Scandinavian Journal of Economics*, 2011, *113*, 1–29.

——, Mun S. H, , and Jon D. Samuels, "A Prototype Industry-Level Production Account for the United States, 1947–2010," Manuscript, National Bureau of Economic Research, Cambridge, MA 2013.

Leon-Ledesma, Miguel and Alessio Moro, "The Rise of Services and Balanced Growth in Theory and Data," Manuscript 2017.

Moro, Alessio, "Structural Change, Growth, and Volatility," *American Economic Journal: Macroeconomics*, 2015, *7*, 259–294.

Ngai, L. Rachel and Christopher A. Pissarides, "Structural Change in a Multisector Model of Growth," *American Economic Review*, 2007, *97*, 429–443.

Nordhaus, William D., "Productivity Growth and the New Economy," *Brookings Papers of Economic Activity*, 2002, *2*, 211–265.

——, "Baumol's Disease: A Macroeconomic Perspective," *The B.E. Journal of Macroeconomics (Contributions)*, 2008, *8*.

Sato, Ryuzo, "The Most General Class of CES Functions," *Econometrica*, 1975, *43*, 999–1003.

Sen, Ali, "Structural Change within the Services Sector, Baumol's Cost Disease, and Cross-Country Productivity Differences," Manuscript, Univeristy of Essex 2019.

Smith, V. Kerry, "Unbalanced Productivity Growth and the Growth of Public Services: A Comment," *Journal of Public Economics*, 1978, *10*, 133–135.

Sposi, Michael, "Evolving Comparative Advantage, Sectoral Linkages, and Structural Change," *Journal of Monetary Economics*, 2019, *103*, 75–87.

Young, Alwyn, "Structural Transformation, the Mismeasurement of Productivity Growth, and the Cost Disease of Services," *American Economic Review*, 2014, *122*, 3635–3667.

Appendix A Calculating Value Added with Thörnqvist Indexes

The WORLD KLEMS 2017 March Release contains nominal and real gross outputs, intermediate inputs, and capital and labor services for 65 industries. In a reference year, nominal and real variables are the same so that the usual relationships hold. Moreover, in the reference year, capital and labor inputs are normalized to equal nominal capital and labor compensation. For all other years, real variables are calculated by calculating their growth rates via Törnqvist indexes. This implies that real industry quantities are additive only in the reference year. In all other years, real value added no longer equals the difference between the real gross output and real intermediate inputs. Here, we describe how real value added at the industry level is constructed. Similar issues arise when one aggregates the 65 industries to the coarser three-sector split considered in the main analysis above.

The first step is to go to the reference year in which real and nominal value added are equal to each other. Real value added then results simply as the difference between gross output and intermediate inputs. The next step is to consider years other than the reference year. One may construct real quantities for these years by starting from the reference year and then applying annual growth rates of the real quantity. To see what is involved, define the growth rate of a generic variable X between periods t and $t+1$ as:

$$\Delta \log X_t \equiv \log X_{t+1} - \log X_t.$$

The growth rates of real gross output, real value added and real intermediate inputs in industry

i are linked by the following identity:

$$\Delta \log GO_{it} = \left[1 - S(P_{it}^{Z} Z_{it})\right] \Delta \log Y_{it} + S(P_{it}^{Z} Z_{it}) \Delta \log Z_{it}, \tag{32}$$

where GO_{it}, Z_{it}, Y_{it}, P_{it}^{GO}, P_{it}^{Z} and P_{it} denote real gross output, real intermediate inputs, real value added, the price of real gross outputs, the price of real intermediate inputs and the price of real value added in industry i. Moreover, $S(P_{it}^{Z} Z_{it})$ denotes the averages over periods t and $t+1$ of the shares of industry i's nominal intermediate inputs in the industry's nominal gross output:

$$S(P_{it}^{Z} Z_{it}) = \frac{1}{2} \left(\frac{P_{it}^{Z} Z_{it}}{P_{it}^{GO} GO_{it}} + \frac{P_{it+1}^{Z} Z_{it+1}}{P_{it+1}^{GO} GO_{it+1}} \right).$$

Note that these shares are meaningful concepts because they are constructed in terms of nominal variables that are additive. We can calculate $\Delta \log(Y_{it})$ by solving equation (32) for $\Delta \log(Y_{it})$, and substituting in $GO_{it}, Z_{it}, P_{it}^{GO} GO_{it}, P_{it}^{Z} Z_{it}$ from WORLD KLEMS:

$$\Delta \log Y_{it} = \frac{\Delta \log GO_{it} - S(P_{it}^{Z} Z_{it}) \Delta \log Z_{it}}{1 - S(P_{it}^{Z} Z_{it})}. \tag{33}$$

Appendix B Derivations and Proofs

Appendix B.1 Equilibrium Conditions with Three Goods

The first–order condition to the outer and inner parts of the household's problem are:

$$P_{it} = \lambda_{ct} \alpha_i^{\frac{1}{\sigma_c}} C_{it}^{-\frac{1}{\sigma_c}} C_t^{\frac{\varepsilon_i - 1}{\sigma_c}} C_t^{\frac{1}{\sigma_c}}, \quad i = g, s, \tag{34a}$$

$$P_{jt} = \lambda_{st} \alpha_j^{\frac{1}{\sigma_s}} C_{jt}^{-\frac{1}{\sigma_s}} C_t^{\frac{\varepsilon_j - 1}{\sigma_s}} C_{st}^{\frac{1}{\sigma_s}}, \quad j = p, u. \tag{34b}$$

To derive (11a) and (12a), divide (34a) for s and g by each other and divide (34b) for h and l by each other, respectively. To derive (11b), multiply both sides of (34a) with C_{it} and add up the resulting equations:

$$P_{gt} C_{gt} + P_{st} C_{st} = \lambda_{ct} \left(\alpha_g^{\frac{1}{\sigma_c}} C_t^{\frac{\varepsilon_g - 1}{\sigma_c}} C_{gt}^{\frac{\sigma_c - 1}{\sigma_c}} + \alpha_s^{\frac{1}{\sigma_c}} C_t^{\frac{\varepsilon_s - 1}{\sigma_c}} C_{st}^{\frac{\sigma_c - 1}{\sigma_c}} \right) C_t^{\frac{1}{\sigma_c}} = \lambda_{ct} C_t^{\frac{\sigma_c - 1}{\sigma_c}} C_t^{\frac{1}{\sigma_c}} = \lambda_{ct} C_t. \tag{35}$$

This equation implies that:

$$P_t = \frac{P_{gt} C_{gt} + P_{st} C_{st}}{C_t} = \lambda_{ct}. \tag{36}$$

Substituting the previous equation into (34a), we obtain:

$$P_{it}^{1-\sigma_c} = P_t^{1-\sigma_c} \alpha_i^{\frac{1-\sigma_c}{\sigma_c}} C_{it}^{\frac{\sigma_c-1}{\sigma_c}} C_t^{(1-\sigma_c)\frac{\varepsilon_i-1}{\sigma_c}} C_t^{\frac{1-\sigma_c}{\sigma_c}},$$

which implies that:

$$\alpha_i C_t^{\varepsilon_i-1} P_{it}^{1-\sigma_c} = P_t^{1-\sigma_c} \alpha_i^{\frac{1}{\sigma_c}} C_{it}^{\frac{\sigma_c-1}{\sigma_c}} C_t^{\frac{\varepsilon_i-1}{\sigma_c}} C_t^{\frac{1-\sigma_c}{\sigma_c}}.$$

Adding over $i = g, s$ yields:

$$\begin{aligned} \alpha_g C_t^{\varepsilon_g-1} P_{gt}^{1-\sigma_c} + \alpha_s C_t^{\varepsilon_s-1} P_{st}^{1-\sigma_c} &= P_t^{1-\sigma_c} \left(\alpha_g^{\frac{1}{\sigma_c}} C_t^{\frac{\varepsilon_g-1}{\sigma_c}} C_{gt}^{\frac{\sigma_c-1}{\sigma_c}} + \alpha_s^{\frac{1}{\sigma_c}} C_t^{\frac{\varepsilon_s-1}{\sigma_c}} C_{st}^{\frac{\sigma_c-1}{\sigma_c}} \right) C_t^{\frac{1-\sigma_c}{\sigma_c}} \\ &= P_t^{1-\sigma_c} C_t^{\frac{\sigma_c-1}{\sigma_c}} C_t^{\frac{1-\sigma_c}{\sigma_c}} = P_t^{1-\sigma_c}, \end{aligned}$$

implying that the price index is given as

$$P_t = \left(\alpha_g C_t^{\varepsilon_g-1} P_{gt}^{1-\sigma_c} + \alpha_s C_t^{\varepsilon_s-1} P_{st}^{1-\sigma_c} \right)^{\frac{1}{1-\sigma_c}}.$$

This is (11b). Similar steps give (12b).

Appendix B.2 Proof of Proposition 1

We start by deriving the expenditure shares of the two services subsectors in total services expenditure. It is helpful to restate the first–order conditions for the inner and outer layer:

$$\frac{P_{ut}C_{ut}}{P_{pt}C_{pt}} = \frac{\alpha_u}{\alpha_p} \left(\frac{P_{ut}}{P_{pt}} \right)^{1-\sigma_s} C_t^{\varepsilon_u-\varepsilon_p}, \tag{37a}$$

$$P_{st} = \left(\alpha_u C_t^{\varepsilon_u-1} P_{ut}^{1-\sigma_s} + \alpha_p C_t^{\varepsilon_p-1} P_{pt}^{1-\sigma_s} \right)^{\frac{1}{1-\sigma_s}}. \tag{37b}$$

$$\frac{P_{st}C_{st}}{P_{gt}C_{gt}} = \frac{\alpha_s}{\alpha_g} \left(\frac{P_{st}}{P_{gt}} \right)^{1-\sigma_c} C_t^{\varepsilon_s-\varepsilon_g}, \tag{37c}$$

$$P_t = \left(\alpha_g C_t^{\varepsilon_g-1} P_{gt}^{1-\sigma_c} + \alpha_s C_t^{\varepsilon_s-1} P_{st}^{1-\sigma_c} \right)^{\frac{1}{1-\sigma_c}}, \tag{37d}$$

where P_{st} and P_t are the price indexes. Multiplying (11b) with C_t leads to

$$P_t C_t = \left(\alpha_g C_t^{\varepsilon_g-\sigma_c} P_{gt}^{1-\sigma_c} + \alpha_s C_t^{\varepsilon_s-\sigma_c} P_{st}^{1-\sigma_c} \right)^{\frac{1}{1-\sigma_c}}. \tag{38}$$

Substituting out P_{st} with (37b) yields

$$E_t \equiv P_t C_t = \left(\alpha_g C_t^{\varepsilon_g - \sigma_c} P_{gt}^{1-\sigma_c} + \alpha_s C_t^{\varepsilon_s - \sigma_c} \left(\alpha_u C_t^{\varepsilon_u - 1} P_{ut}^{1-\sigma_s} + \alpha_{pt} C_t^{\varepsilon_p - 1} P_{pt}^{1-\sigma_s} \right)^{\frac{1-\sigma_c}{1-\sigma_s}} \right)^{\frac{1}{1-\sigma_c}}. \tag{39}$$

For a given C_t, the expenditure function is a nested CES function of prices. Hence, it satisfies the required properties with respect to prices. It is continuous, increasing, concave, homogenous of degree one and differentiable in prices. is clearly monotonically increasing in prices.

Next we show that the expenditure function is strictly increasing C_t. First we derive expressions for the expenditure shares. Note that (37a) implies that:

$$P_{ut} C_{ut} = \alpha_u C_t^{\varepsilon_u - 1} P_{ut}^{1-\sigma_s} \frac{P_{pt} C_{pt}}{\alpha_p C_t^{\varepsilon_p - 1} P_{pt}^{1-\sigma_s}}.$$

Adding $P_{pt} C_{pt}$ to both sides and rearranging yields:

$$P_{ut} C_{ut} + P_{pt} C_{pt} = \left(\alpha_u C_t^{\varepsilon_u - 1} P_{ut}^{1-\sigma_s} + \alpha_p C_t^{\varepsilon_p - 1} P_{pt}^{1-\sigma_s} \right) \frac{P_{pt} C_{pt}}{\alpha_p C_t^{\varepsilon_p - 1} P_{pt}^{1-\sigma_s}},$$

which can be solved for $P_{pt} C_{pt} / (P_{ut} C_{ut} + P_{pt} C_{pt})$ implying

$$\chi_{jt} \equiv \frac{P_{jt} C_{jt}}{P_{ut} C_{ut} + P_{pt} C_{pt}} = \frac{\alpha_j C_t^{\varepsilon_j - 1} P_{jt}^{1-\sigma_s}}{\alpha_u C_t^{\varepsilon_u - 1} P_{ut}^{1-\sigma_s} + \alpha_p C_t^{\varepsilon_p - 1} P_{pt}^{1-\sigma_s}}, \qquad j \in \{p, u\}. \tag{40a}$$

A similar derivation shows that (37c) implies

$$\chi_{jt} \equiv \frac{P_{jt} C_{jt}}{P_{gt} C_{gt} + P_{st} C_{st}} = \frac{\alpha_j C_t^{\varepsilon_j - 1} P_{jt}^{1-\sigma_c}}{\alpha_g C_t^{\varepsilon_g - 1} P_{gt}^{1-\sigma_c} + \alpha_s C_t^{\varepsilon_s - 1} P_{st}^{1-\sigma_c}}, \qquad j \in \{g, s\}. \tag{40b}$$

Next, we take the derivative of E_t with respect to C_t:

$$\begin{aligned} \frac{\partial E_t}{\partial C_t} = \frac{1}{1-\sigma_c} \frac{E_t}{\alpha_g C_t^{\varepsilon_g - \sigma_c} P_{gt}^{1-\sigma_c} + \alpha_s C_t^{\varepsilon_s - \sigma_c} P_{st}^{1-\sigma_c}} \Bigg[& \alpha_g C_t^{\varepsilon_g - \sigma_c} P_{gt}^{1-\sigma_c} \frac{\varepsilon_g - \sigma_c}{C_t} + \alpha_s C_t^{\varepsilon_s - \sigma_c} P_{st}^{1-\sigma_c} \frac{\varepsilon_s - \sigma_c}{C_t} \\ & + \frac{1-\sigma_c}{1-\sigma_s} \frac{\alpha_s C_t^{\varepsilon_s - \sigma_c} P_{st}^{1-\sigma_c}}{\alpha_u C_t^{\varepsilon_u - 1} P_{ut}^{1-\sigma_s} + \alpha_{pt} C_t^{\varepsilon_p - 1} P_{pt}^{1-\sigma_s}} \left(\alpha_u C_t^{\varepsilon_u - 1} P_{ut}^{1-\sigma_s} \frac{\varepsilon_u - 1}{C_t} \alpha_{pt} C_t^{\varepsilon_p - 1} P_{pt}^{1-\sigma_s} \frac{\varepsilon_p - 1}{C_t} \right) \Bigg]. \end{aligned}$$

Using the expression for expenditure shares in (40a) and (40b), we can simplify this as:

$$\frac{\partial E_t}{\partial C_t} = \frac{E_t}{1-\sigma_c} \left[\chi_{gt} \frac{\varepsilon_g - \sigma_c}{C_t} + \chi_{st} \frac{\varepsilon_s - \sigma_c}{C_t} + \frac{1-\sigma_c}{1-\sigma_s} \chi_{st} \left(\chi_{ut} \frac{\varepsilon_u - 1}{C_t} + \chi_{pt} \frac{\varepsilon_p - 1}{C_t} \right) \right].$$

It follows that

$$\frac{\partial E_t}{\partial C_t} = \frac{E_t}{C_t}\left(\chi_{gt}\frac{\varepsilon_g - \sigma_c}{1-\sigma_c} + \chi_{st}\frac{\varepsilon_s - 1}{1-\sigma_c} + \chi_{st}\chi_{ut}\frac{\varepsilon_u - \sigma_s}{1-\sigma_s} + \chi_{st}\chi_{pt}\frac{\varepsilon_p - \sigma_s}{1-\sigma_s}\right). \tag{41}$$

It is easy to verify that Assumption 1 ensures that each term in the bracket is strictly positive. Hence the expenditure function is strictly increasing in C_t for all $\chi_{gt}, \chi_{st}, \chi_{pt}, \chi_{ut} \in [0,1]$. **QED**

Appendix B.3 Proof of Proposition 2

Strategy of the Proof. We start by noting that in the limit, $\chi_{st} = 1$ and the nested utility structure reduces to:

We proceed in four steps. In step 1, we establish the condition under which χ_{ut}/χ_{pt} is constant. In step 2, we show that there is a unique $\widehat{A}_u^* \in \left(1, \widehat{A}_p\right)$ such that χ_{ut}/χ_{pt} is constant in equilibrium. In step 3, we characterize the dynamics of χ_{ut}/χ_{pt} when $\widehat{A}_u \neq \widehat{A}_u^*$. In step 4, we show that the limit growth of GDP is as claimed.

Step 1. Equation (40a) from the previous proof implies that:

$$\frac{\chi_{ut}}{\chi_{pt}} = \frac{\alpha_u}{\alpha_p}\left(\frac{P_{ut}}{P_{pt}}\right)^{1-\sigma_s} C_t^{\varepsilon_u - \varepsilon_p}.$$

Rewriting the equation into growth factors gives:

$$\widehat{\left(\frac{\chi_{ut}}{\chi_{pt}}\right)} = \widehat{\left(\frac{P_{ut}}{P_{pt}}\right)}^{1-\sigma_s} \widehat{C}_t^{\varepsilon_u - \varepsilon_p}.$$

Using equation (8) and that the wedges are assumed to be zero, the previous equation implies that the expenditure shares are constant if and only if:

$$1 = \widehat{\left(\frac{\chi_{ut}}{\chi_{pt}}\right)} = \left(\frac{\widehat{A}_p}{\widehat{A}_u}\right)^{1-\sigma_s} \widehat{C}_t^{\varepsilon_u - \varepsilon_p}. \tag{42}$$

Step 2. Next, we establish a condition under which consumption growth implied by equation (42) is consistent with all equilibrium conditions given $\chi_{st} = 1$. To this end, we consolidate the two equilibrium conditions (37b) and (38) into one, using the expressions for expenditure shares relative to total, (40a) and (40b), the market clearing condition, and the firms' first-order conditions. We state all equations that follow in terms of growth factors ("hats") to be able to relate them to (42).

The equilibrium condition for the service price, (12b), implies that:

$$\left(\frac{P_{st+1}}{P_{st}}\right)^{1-\sigma_s} = \frac{\alpha_u C_{t+1}^{\varepsilon_u-1} P_{ut+1}^{1-\sigma_s} + \alpha_p C_{t+1}^{\varepsilon_p-1} P_{pt+1}^{1-\sigma_s}}{\alpha_u C_t^{\varepsilon_u-1} P_{ut}^{1-\sigma_s} + \alpha_p C_t^{\varepsilon_p-1} P_{pt}^{1-\sigma_s}}.$$

Dividing and multiplying each term in the nominator with the appropriate $C_t^{\varepsilon_j-1} P_{jt}^{1-\sigma_s}$ ($j \in \{p,u\}$), and using (40a), we obtain

$$\widehat{P}_{st}^{1-\sigma_s} = \chi_{ut} \widehat{C}_t^{\varepsilon_u-1} \widehat{P}_{ut}^{1-\sigma_s} + \chi_{pt} \widehat{C}_t^{\varepsilon_p-1} \widehat{P}_{pt}^{1-\sigma_s}. \tag{43}$$

Similarly, use (38) to obtain:

$$\widehat{E}_t^{1-\sigma_c} = \chi_{gt} \widehat{C}_t^{\varepsilon_g-\sigma_c} \widehat{P}_{gt}^{1-\sigma_c} + \chi_{st} \widehat{C}_t^{\varepsilon_s-\sigma_c} \widehat{P}_{st}^{1-\sigma_c}. \tag{44}$$

Now, setting $\chi_{gt} = 0$ and $\chi_{st} = 1$ as well as substituting (43) into (44) yields:

$$\begin{aligned}
\widehat{E}_t^{1-\sigma_c} &= \widehat{C}_t^{\varepsilon_s-\sigma_c} \left(\chi_{ut} \widehat{C}_t^{\varepsilon_u-1} \widehat{P}_{ut}^{1-\sigma_s} + \chi_{pt} \widehat{C}_t^{\varepsilon_p-1} \widehat{P}_{pt}^{1-\sigma_s}\right)^{\frac{1-\sigma_c}{1-\sigma_s}} \\
&= \left(\chi_{ut} \left(\widehat{C}_t^{\frac{\varepsilon_u-1}{1-\sigma_s}+\frac{\varepsilon_s-\sigma_c}{1-\sigma_c}} \widehat{P}_{ut}\right)^{1-\sigma_s} + \chi_{pt} \left(\widehat{C}_t^{\frac{\varepsilon_p-1}{1-\sigma_s}+\frac{\varepsilon_s-\sigma_c}{1-\sigma_c}} \widehat{P}_{pt}\right)^{1-\sigma_s}\right)^{\frac{1-\sigma_c}{1-\sigma_s}}.
\end{aligned} \tag{45}$$

To rewrite the left-hand side, note that $\widehat{E} = \widehat{A}_g$ because for $\chi_{st} = 1$:

$$E_t = \sum_{j\in\{p,u\}} \frac{P_{jt}}{P_{gt}} Y_{jt} = \sum_{j\in\{p,u\}} \frac{A_{gt}}{A_{jt}} A_{jt} H_{jt} = A_{gt} \sum_{j\in\{p,u\}} H_{jt} = A_{gt}, \tag{46}$$

where we used that $Y_{jt} = A_{jt} L_{jt}$, that the firms' first-order conditions imply that $P_{jt}/P_{gt} = A_{gt}/A_{jt}$ given that we assumed $\tau_{jt} = 0$.

Turning now to the right-hand side of (45), we substitute out relative prices with relative productivities from (8). We then arrive at:

$$\widehat{A}_g^{1-\sigma_c} = \left(\chi_{ut} \left(\widehat{C}_t^{\frac{\varepsilon_u-1}{1-\sigma_s}+\frac{\varepsilon_s-\sigma_c}{1-\sigma_c}} \frac{\widehat{A}_g}{\widehat{A}_u}\right)^{1-\sigma_s} + \chi_{pt} \left(\widehat{C}_t^{\frac{\varepsilon_p-1}{1-\sigma_s}+\frac{\varepsilon_s-\sigma_c}{1-\sigma_c}} \frac{\widehat{A}_g}{\widehat{A}_p}\right)^{1-\sigma_s}\right)^{\frac{1-\sigma_c}{1-\sigma_s}}, \tag{47}$$

which is equivalent to:

$$\widehat{A}_p = \widehat{C}_t^{\frac{\varepsilon_p-1}{1-\sigma_s}+\frac{\varepsilon_s-\sigma_c}{1-\sigma_c}} \left[\chi_{ut} \left(\frac{\widehat{A}_p}{\widehat{A}_u}\right)^{1-\sigma_s} \widehat{C}_t^{\varepsilon_u-\varepsilon_p} + \chi_{pt}\right]. \tag{48}$$

Substituting the condition for constant χ_{ut}/χ_{pt}, (42), into (48) and solving, we obtain

$$\widehat{C} = \widehat{A}_p^{\frac{1}{\frac{\varepsilon_p - 1}{1-\sigma_s} + \frac{\varepsilon_s - \sigma_c}{1-\sigma_c}}}.$$

For an equilibrium with constant χ_{ut}/χ_{pt} to exist, $\widehat{C}$ has to satisfy this equation as well as equation (42):

$$\widehat{C}^* = \left(\frac{\widehat{A}_u^*}{\widehat{A}_p}\right)^{\frac{1-\sigma_s}{\varepsilon_u - \varepsilon_p}} = \left(\widehat{A}_p\right)^{\frac{1}{\frac{\varepsilon_p - 1}{1-\sigma_s} + \frac{\varepsilon_s - \sigma_c}{1-\sigma_c}}}. \tag{49}$$

Step 3. We now show that $1 < \widehat{A}_u^* < \widehat{A}_p$. Solving the second equation in (49) for $\widehat{A}_u^*$, we find:

$$\widehat{A}_u^* = \left(\widehat{A}_p\right)^{1 + \frac{\frac{\varepsilon_u - \varepsilon_p}{1-\sigma_s}}{\frac{\varepsilon_p - 1}{1-\sigma_s} + \frac{\varepsilon_s - \sigma_c}{1-\sigma_c}}} = \left(\widehat{A}_p\right)^{\frac{\frac{\varepsilon_u - 1}{1-\sigma_s} + \frac{\varepsilon_s - \sigma_c}{1-\sigma_c}}{\frac{\varepsilon_p - 1}{1-\sigma_s} + \frac{\varepsilon_s - \sigma_c}{1-\sigma_c}}}. \tag{50}$$

If the exponent of $\widehat{A}_p$ on the right-hand side is between 0 and 1, then the assumption that $\widehat{A}_p > 1$ implies that $1 < \widehat{A}_u^* < \widehat{A}_p$. To see that the exponent is indeed between 0 and 1, note that Assumptions 1–3 imply that:

$$\frac{\varepsilon_u - 1}{1-\sigma_s} + \frac{\varepsilon_s - \sigma_c}{1-\sigma_c} = \frac{\sigma_s - \varepsilon_u}{\sigma_s - 1} + \frac{\varepsilon_s - 1}{1-\sigma_c} > 0.$$

Moreover, note that Assumption 3 implies that:

$$\frac{\varepsilon_u - 1}{1-\sigma_s} + \frac{\varepsilon_s - \sigma_c}{1-\sigma_c} < \frac{\varepsilon_p - 1}{1-\sigma_s} + \frac{\varepsilon_s - \sigma_c}{1-\sigma_c}.$$

Step 4. It remains to characterize how χ_{ut} changes if $\widehat{A}_u$ does not satisfy condition (50). Two simple observations are useful. The first one is that the right-hand side of the condition (48) is increasing in $\widehat{C}_t$. The reason is that the assumed parameter values imply that:

$$\begin{aligned} &\varepsilon_u - \varepsilon_p > 0, \\ &\frac{\varepsilon_p - 1}{1-\sigma_s} + \frac{\varepsilon_s - \sigma_c}{1-\sigma_c} > 0. \end{aligned}$$

The second one is that, for any given $\widehat{A}_u$ and $\widehat{A}_p^*$, condition (42) implies that the consumption growth factor $\widehat{C}$ that would be consistent with constant χ_{ut}/χ_{pt} still satisfies:

$$1 = \left(\frac{\widehat{A_p}}{\widehat{A_u}}\right)^{\frac{1-\sigma_s}{\varepsilon_u-\varepsilon_p}} \widehat{C}.$$

Note that given the assumptions on the parameter values, $\widehat{C}$ is decreasing in $\widehat{A_u}$.

Now we are ready to characterise the behavior of χ_{ut} if (49) is not satisfied. Let $\widehat{A_u} \neq \widehat{A_u^*}$ while $\widehat{A_p} = \widehat{A_p}$. Consider first the case of $\widehat{A_u} < \widehat{A_u^*}$. Then, $\widehat{C} > \widehat{C^*}$ and the right-hand side of (48) is larger that the left-hand side. Since the right-hand side of (48) is monotonically increasing in $\widehat{C_t}$, there is a unique $\widehat{C_t} < \widehat{C}$ that satisfies (48). For that $\widehat{C_t}$, χ_{ut}/χ_{pt} is decreasing because the right-hand side of (42) is less than 1. In the other case, $\widehat{A_u} > \widehat{A_u^*}$, similar arguments imply that χ_{ut}/χ_{pt} is increasing.

Since $\chi_{ut}/\chi_{pt} \in [0, 1]$, the standard result applies that on a compact set every sequence has a limit. Since there is only one interior limit, it must be that $\lim_{t\to\infty} \chi_{ut} = 0$ or $\lim_{t\to\infty} \chi_{ut} = 1$ if $\widehat{A_u} \neq \widehat{A_u^*}$. Since χ_{ut} is decreasing if $\widehat{A_u} < \widehat{A_u^*}$, it must be that $\lim_{t\to\infty} \chi_{ut} = 0$ if $\widehat{A_u} < \widehat{A_u^*}$. Since χ_{ut} is increasing if $\widehat{A_u} > \widehat{A_u^*}$, it must be that $\lim_{t\to\infty} \chi_{ut} = 1$ if $\widehat{A_u} > \widehat{A_u^*}$.

For $\chi_{jt} = 1$, (2) implies the following growth factors of C:

$$\Delta LP_j = \Delta A_j, \quad j = p, u. \tag{51}$$

QED

Appendix B.4 Equilibrium Conditions with Many Goods

Recall that the general utility function was characterized by condition (31):

$$1 = \sum_{i=1}^{I} \alpha_i^{\frac{1}{\sigma_i}} \left(\frac{C_{it}^{\sigma_i-1}}{C_t^{\sigma_i-\varepsilon_i}}\right)^{\frac{1}{\sigma_i}} \tag{52}$$

Minimizing consumption expenditure subject to that constraint implies the first-order conditions:

$$P_{it} = \lambda_t \alpha_i^{\frac{1}{\sigma_i}} \frac{\sigma_i - 1}{\sigma_i} C_{it}^{-\frac{1}{\sigma_i}} C_t^{\frac{\varepsilon_i-\sigma_i}{\sigma_i}}.$$

Dividing them by the first-order condition for goods gives the relative demand for the ten service industries $i = 1, ..., 10$:

$$\frac{P_{it}C_{it}}{P_{gt}C_{gt}} = \frac{\alpha_i^{\frac{1}{\sigma_i}}(\sigma_i - 1)/\sigma_i}{\alpha_g^{\frac{1}{\sigma_g}}(\sigma_g - 1)/\sigma_g} \frac{C_{it}^{\frac{\sigma_i-1}{\sigma_i}}}{C_{gt}^{\frac{\sigma_g-1}{\sigma_g}}} C_t^{\frac{\varepsilon_i-\sigma_i}{\sigma_i}-\frac{\varepsilon_g-\sigma_g}{\sigma_g}}. \tag{53}$$

We calibrate the model by using (52) together with (53) for $i = 1, ..., I$.

Appendix C Micro Evidence

Table 10: Results of Reduced-form Estimation

	(1)		(2)	
Panel (a): Dependent variable is $\log(P_{it}^n C_{it}^n)$				
	IV	GMM	IV	GMM
β_g	0.76	0.77	0.77	0.78
	(0.003)	(0.005)	(0.003)	(0.005)
β_g	1.08	1.08	1.08	1.08
	(0.001)	(0.002)	(0.001)	(0.002)
β_p	1.03	1.04	1.07	1.07
	(0.003)	(0.005)	(0.003)	(0.004)
β_u	1.18	1.16	1.12	1.12
	(0.005)	(0.008)	(0.004)	(0.007)
Panel (b): Dependent variable is $\log(P_{it}^n C_{it}^n) - \log(\bar{P}_{it}\bar{C}_{it})$				
β_g	0.74	0.75	0.77	0.78
	(0.003)	(0.005)	(0.003)	(0.005)
β_s	1.02	1.05	1.08	1.08
	(0.002)	(0.004)	(0.001)	(0.002)
β_p	1.01	1.04	1.07	1.06
	(0.003)	(0.005)	(0.003)	(0.004)
β_u	1.06	1.06	1.12	1.12
	(0.005)	(0.007)	(0.004)	(0.006)
Household controls	Y		Y	
Region fixed effects	N		Y	
Year fixed effects	N		Y	
Quarter fixed effects	N		Y	

Note: SE clustered at household level; 87,017 observations.

Table 11: Results of Structural Estimation

	(1)	(2)
σ_c	0.61	0.46
	(0.03)	(0.06)
σ_s	1.23	1.51
	(0.04)	(0.06)
$\varepsilon_s - \varepsilon_g$	0.79	0.51
	(0.07)	(0.06)
$\varepsilon_u - \varepsilon_p$	0.49	0.59
	(0.04)	(0.02)
Household controls	Y	Y
Region fixed effects	N	Y
Year fixed effects	N	Y
Quarter fixed effects	N	Y

Note: SE clustered at household level; 87,017 observations.

Appendix D Inputs for the Simulations

Table 12: Inputs for Table 5

Exogenous Variables Based on	$\Delta \log A_{gt}$	$\Delta \log A_{pt}$	$\Delta \log A_{ut}$	$\Delta \log H_t$	$\frac{\sum_{i\in\{g,p,u\}} \widetilde{H}_{it}}{\widetilde{H}_t}$	τ_{pt}	τ_{ut}
1996–2016	1.92	1.61	0.20	0.14	-0.12	0.18	0.49
1986–2016	1.86	1.82	0.08	0.29	-0.10	0.17	0.53
1976–2016	1.71	2.01	0.02	0.46	-0.08	0.14	0.52