Accounting for Japan's Lost Score

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Abstract

This paper develops a quantitative framework to evaluate the sectoral origins of economic growth. First, I decompose growth in aggregate growth accounting variables–GDP per working age person, a capital factor, an hours' worked factor, and an implied total factor productivity factor–into sectoral contributions. I decompose the TFP factor growth contribution of a sector into 1) sector-share weighted, within-sector TFP factor growth, and 2) several residual allocative effects. Second, I interpret structurally the observed sectoral contributions by comparing them to those predicted by a multi-sector neoclassical growth model. Using the framework to account for Japan's economic growth slowdown I find that, empirically, two factors quantitatively dominated Japan's slowing GDP per working age person in the 1990s. First, a large decline in aggregate TFP growth relative to the 1980s, driven by 1) slower within-*industrial* sector TFP growth, and 2) negative residual effects due to faster value-added reallocation towards services which mediated a larger impact of the sector for aggregate capital deepening. Second, a large fall in hours worked per working age person, originating mainly in smaller industrial sector contributions. In the 2000s, continued GDP per working age person and aggregate TFP growth decay were due largely to slower within-*service* sector TFP growth. In the 2010s, anemic aggregate TFP factor growth equal to just 18 percent of its 1980s value was depressed by zero service sector TFP growth; a modest growth rate recovery in GDP per working age person originated in rapid increases in hours worked per working age person, via roughly equal increases in industrial and service sector contributions. A calibrated three-sector growth model *absent* frictions, featuring sectoral TFP time series as inputs, reproduces closely the time-series from 1980–2018 of a) hours shares of sectors, b) GDP per working age person, and c) the aggregate TFP factor. It captures quite well a) sample-average aggregate TFP growth, b) aggregate TFP growth rate changes across decades, c) the decomposition of aggregate TFP factor growth into total "within-sector" TFP and total residual contributions of sectors, and d) "within-sector" TFP growth contributions of agriculture, industry, and services. The model cannot replicate the sources of, or sectoral contributions to, observed–albeit small–TFP growth residual effects. More importantly, the model's predicted hours factor (hours per working age person): 1) captures only 46 percent of the decline in industry's contribution to the fall in aggregate hours factor growth in the 1990s; 2) declines in the 2000s, while hours factor growth is positive in the data; 3) captures only 47 percent of observed average hours factor growth in the 2010s; and 4) allocates too much of the 2010s increase in aggregate hours factor growth to industry. A higher intertemporal elasticity of substitution, a higher Frisch elasticity, and an aggregate labor (policy) wedge resolve some, but exacerbate other, model failures.

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Key words: Economic Growth, Neoclassical Growth Model, Structural Change, Total Factor Productivity, Japan.

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1. Introduction

Ending the nation's "economic growth miracle", Japan suffered two decades–a "lost score"–of much slower GDP per working age person growth from 1991 through 2010 relative to her impressive growth performance in previous post-war decades. I document here that Japan's growth slowdown was due largely to a slowing of aggregate productivity growth, and that productivity growth slowing has persisted into a third decade since the great recession of 2008–2009. Specifically, I show that although Japan has witnessed modest improvement in GDP per working age person growth since 2010 to roughly two percent–a rate commonly associated with long-run "trend growth"–this is attributable not to faster productivity growth but to rapid increases in hours worked per working age person. Since 2010, Japan's aggregate TFP growth has marginally improved, but to just 18 percent of its 1980s value, while average labor productivity growth declined for a third consecutive decade. In addition, capital deepening ceased entirely after 2010, suggesting that Japan may be converging to a shallower trend growth path. These facts portend a return to slower growth in living standards in Japan in the future; growth theory implies that technology-driven productivity growth alone–not labor input growth–drives sustainable increases in output per person. Why has this large and persistent productivity and economic growth slowdown in Japan occurred? The goal of this paper is to make a modest contribution to an answer by investigating empirically and theoretically the sectoral origins of Japan's GDP per working age person and TFP growth since 1990.

Several literatures motivate identifying sectoral contributions to the aggregate productivity and economic slowdown in Japan. In a contribution to the great depressions methodology pioneered by Cole and Ohanian (1999) and Kehoe and Prescott (2002, 2007), Hayashi and Prescott (2002) conjecture that Japan's aggregate TFP slowdown in the 1990s may be attributable to industrial policy which effectively subsidized relatively inefficient manufacturing sector firms. In an analysis of the role of structural transformation for aggregate productivity, Duarte and Restuccia (2010) argue that all examples in their international dataset of countries that exhibit slower, stagnating, and declining aggregate productivity growth are accounted for by low levels and growth rates of service sector productivity. A large firm-level misallocation literature, originating in the seminal contributions of Restuccia and Rogerson (2008) and Hsieh and Klenow (2009), implies that "average" sector-level misallocation reduces metrics of aggregate TFP levels. Additionally, several recent empirical analyses of Japan's growth and productivity slowdown have emphasized the importance for policy prescriptions and international productivity comparisons of identifying sector-level sources, of which

Fukao, Kim, and Kwon (2021), and Jorgenson, Nomura, and Samuels (2016) are just two notable examples.

In this paper, I develop a quantitative framework to, first, measure sectoral contributions to GDP per working age person, capital and labor input factors, and aggregate TFP factor growth in the data and, second, provide insight into the economic mechanisms driving observed sectoral contributions by comparing them to those predicted by a multi-sector neoclassical growth model. The empirical sectoral contributions to economic growth and economic growth factors that I characterize have analogues in the solutions of the multi-sector growth model. Moreover, model-based estimates of sectoral contributions can be "re-constituted", reversing the decomposition calculations, into model-based analogues of aggregate macroeconomic variable growth rates. Model-based estimates of sectoral contributions and aggregate growth rates are not only metrics to evaluate the quantitative performance of the model; to the extent that they accurately reproduce the data, they provide structural interpretations of observed aggregate and sectoral growth accounting results. I apply the framework to analyze the sectoral sources of Japan's economic and productivity growth slowdown.

The basis for my sectoral decompositions of growth in GDP per working age person and TFP is the growth accounting framework adopted by Kehoe and Prescott (2002, 2007). In this framework, GDP per working age person is accounted for by three aggregate growth factors: A capital (deepening) factor, an hours-worked factor, and a TFP factor. The beauty of this specific growth accounting is its interpretation in the context of the balanced growth path of a one-sector neoclassical growth model; on a balanced growth path, the capital factor (a function of the capital-output ratio) and hours factor (hours per working age person) are constant, and growth in GDP per working age person derives solely from TFP factor growth. I calculate an empirical decomposition into sectoral contributions of growth in i) GDP per working age person, ii) the aggregate capital factor, and iii) aggregate hours factor. The decompositions are exact and based solely on aggregation of sectoral into economy-wide metrics of each variable in the data. The difference between a sector's contribution to GDP per working age person growth and its contributions to aggregate capital and hours factor growth rates measures that sector's total contribution to aggregate TFP factor growth. The sum of sectoral total contributions to aggregate TFP factor growth exactly equals aggregate TFP factor growth. Assuming Cobb-Douglas production functions govern sectoral value-added, the aggregate TFP factor growth contribution of a sector can be further decomposed into two sources: i) sector-share weighted, "within-sector/own" TFP factor growth, and ii) residual effects due to a) changes in the sector's relative value-added price, b) the sector's capital income share relative to the economy-wide capital income share, and c) evolution of the sector's value-added share. I develop a similar sectoral accounting for labor productivity, measured by GDP per hour worked. For the sake of brevity, I present most of the labor productivity results in appendix A.3. To summarize, sectoral contributions to GDP per hour worked can be characterized by i) sector-share weighted, "within-sector/own" value added per hour growth, and ii) residual effects due to a) changes in the sector's relative value-added price, and b) evolution of the sector's share of hours worked.

My model-based estimates of sectoral contributions to GDP per working age person, capital hours, and TFP factor growth are derived from simulation of a calibrated three sector model of structural change and growth. The model is closely related to that presented by Herrendorf, Rogerson, and Valentinyi (2014). Sectoral value added is produced by perfectly competitive firms in the three major sectors of economic activity–agriculture, industry, and services. Firms produce value added using sector-specific Cobb-Douglas technologies employing labor and capital services, and value-added of the three sectors is consumed by households. I modify the model to allow for final government consumption of value added produced by the three sectors. I also allow for the final investment expenditure of households to fall on the value added produced by all three sectors, rather than specifying a separate value-added investment production sector, a specification that is easier to reconcile with sectoral final use data. There is no money in the model, nor any real or financial frictions in my benchmark calibration of the model in which I assume that aggregate and sectoral allocations are the efficient outcomes of perfectly competitive markets *absent* distortions. Model-predicted aggregates and aggregate growth factors are constructed by summing sectoral allocations, using sectoral prices as weights wherever the equilibrium price of a variable differs across sectors. The aggregate TFP factor is calculated by taking the ratio of model-predicted aggregate GDP per working age person to the capital and hours factors. Sectoral contributions to growth in all aggregate growth accounting variables, including the TFP factor, are calculated exactly as in the data.

Empirically, I find a large and persistent decline in aggregate TFP factor growth after 1990 is the primary source of slower average growth in GDP per working age person and GDP per hour worked from 1991 through 2010 relative to the 1980s. An economically significant decline in hours worked per working age person also contributed to slower growth in GDP per working age person in the 1990s, while an economically significant increase in hours worked per working age person produced modest growth rate recovery in GDP per working age person in the 2010s. Because in the 2010s TFP factor growth was an anemic 18 percent of its 1980s value and the capital-output ratio declined, growth in GDP per hour worked declined for a third consecutive decade after the great recession.

Sectoral decompositions show that in the 1990s two factors quantitatively dominated the aggregate TFP growth slow-down: 1) Slower "within" industrial sector TFP factor growth; and 2) a negative service sector residual effect, due to a larger impact of the sector for aggregate capital deepening mediated through faster value-added reallocation towards the service sector. By substantially reducing TFP factor growth, these sectoral contributions also reduced growth in GDP per working age person and GDP per hour worked relative to the 1980s. Additionally, an economically significant decline in industrial-sector hours per working age person was the main source of decline in aggregate hours factor growth in the 1990s and contributed to slower GDP per working age person growth. By contrast, continued aggregate TFP growth decay in the 2000s was due largely to slower "within" service sector TFP factor growth. That the decline in GDP per working age person growth in the 2000s relative to the 1990s was relatively modest was mainly a manifestation of faster growth in industrial and service sector hours per working age person, despite the great recession. Similarly, the 2011–2018 period saw modest growth rate *recovery* in GDP per working age person due to rapid growth in aggregate hours worked per working age person accomplished through roughly equal increases in the hours factor contributions of industry and services. The continued decline in labor productivity growth was due to almost equal declines in the capital-deepening contributions of industry and services, while aggregate TFP factor growth after 2010 remained depressed due to zero service sector contributions.

I calibrate the three sector model's industry-level and aggregate parameters so that the model replicates a) Japan's national account data for 1980, and b) a table based on 1980 input-output data which represents final use of sectoral value-added by households, the government, and the (exogenous) external sector. I construct value added use by sector using a method developed by Herrendorf, Rogerson, and Valentinyi (2013). Elasticity parameters are based on extant empirical estimates. Sectoral TFP factors, the working population, sectoral net exports, and the fraction of GDP accounted for by total government consumption at each date are exogenous data inputs to the model. Despite its simplicity, the model matches quite closely the time series evolution of sectoral shares of economic activity, GDP per working age person, GDP per hour worked, and the aggregate TFP factor. This success includes the model producing a great recession and recovery of proximately the right magnitude and persistence, and a temporary negative GDP per working age person growth effect of the 2011 earthquake which is observed in the data. The model also does a decent job of matching aggregate growth accounting facts–with three notable exceptions which I discuss below–and sectoral contributions to aggregate growth factors, including total sectoral contributions to aggregate TFP factor growth. It also captures quantitatively the decomposition of aggregate TFP factor growth into a total "within-sector" TFP growth and total residual effect. In addition, the model's predictions for share-weighted, "within-sector" TFP factor growth contributions to aggregate TFP factor growth of each of the three major sectors of economic activity are close to those observed in the data.

However, the model fails to replicate the decomposition of residual effects for aggregate TFP factor growth into the three sources–relative price, capital-income share, and value-added reallocation effects–and especially for agriculture and services. In particular, the model does not reproduce well sectoral relative price contributions or sectoral value-added reallocation contributions to aggregate TFP factor growth. It is possible that incorporating intermediate inputs in the sectoral production functions would improve the model's performance in matching sectoral shares, relative prices, and–hence–residual effects. Nonetheless, residual effects together account for only a small portion of total sectoral contributions to aggregate TFP growth.

Perhaps more importantly, the model cannot match quantitatively the decline in the industrial sector's contribution to growth in hours per working age person in the 1990s and, partly as a result, underpredicts the 1990s decline in GDP per working age person growth. The model also cannot match the observed increase in hours per working age person in the 2000s which occurs despite the great recession, and hence overpredicts the decline in GDP per working age person growth in the 2000s relative to the 1990s. Nor can the model match the large industrial and service sector contributions producing rapid hours and, hence, relatively rapid GDP per working age person growth in the 2010s. Specifically, the model captures only 46 percent of the decline in industry's contribution to the fall in aggregate hours factor growth in the 1990s, it predicts a decline rather than the observed increase in hours factor growth in the 2000s, it captures only 47 percent of observed average hours factor growth in the 2010s, and allocates too much of the 2010s increase in aggregate hours factor growth to industry. Each of these decades features significant government intervention in labor markets which the model does not reflect; as a result, the efficient, undistorted hours allocations of households predicted by the model cannot replicate the allocations observed in the data. Specifically, in the late 1980s and early 1990s Japan mandated a reduction in the length of the working week, and this is associated with a relatively large decline in average hours worked per employed person (Hayashi and Prescott (2002), Betts (2021). In the 2000s, it has been argued that Japanese firms insulated employees from job losses in the great recession via "labor hoarding" (Steinberg and Nakane (2011)), and it is well known that the 2010s featured systematic policies by prime minister Abe to raise labor force participation by women, immigrants, and retiree-age members of the working age population.

I explore whether the model's performance in matching aggregate and sectoral hours per working age person can be improved without introducing distortions measured by "wedges" which represent generic distortions in the labor market. Specifically, I conduct two sensitivity analyses allowing for higher elasticities of intertemporal substitution and labor supply, respectively. Higher elasticities improve the model's ability to match the decline in industry's contribution to hours growth in the 1990s, and the average growth rate of hours per working age person in the 2010s. However, the high elasticity variants produce an even larger decline of the hours factor in the 2000s than does the benchmark model, and overpredict the magnitude of increase in industry and service sector hours factor contributions in the 2010s relative to the 2000s. Irrespective of the limited improvements they elicit in model performance, the high aggregate elasticity values that I experiment with are generally thought to be empirically implausible. Incorporating an aggregate labor wedge which represents a distortion in (or tax on) the household's intra-temporal choice of hours worked relative to leisure also does not improve the overall fit of the model relative to the benchmark specification, although it does increase predicted hours factor growth marginally in the 2000s and substantively in the 2010s. I show that to account for hours factor growth in a model with an aggregate labor wedge, and empirically plausible (benchmark) elasticities of intertemporal substitution and labor supply, requires that the introduction of a second, intertemporal wedge which taxes savings and stimulates labor supply growth.

My results imply that investigation of how best to model the labor market policies enacted in Japan and the effects of those policies for household decision making would be a productive line of research in better accounting for Japan's hours and GDP per working age person growth experience since 1980.

The framework developed in this paper for analyzing Japan's secular growth slowdown is similar to that of Jeong (2020), which he uses to analyze Korea's structural transformation and positive growth experience since 1960. Jeong adopts a two-sector (agriculture and non-agriculture) neoclassical growth model as the basis for his Korean growth accounting, and includes land as a production factor, emphasizing the importance of land reallocation across sectors as a source of structural change and growth for an emerging economy. I have assumed that land reallocation across sectors was trivial for Japan after 1980, following rapid industrialization with agriculture already accounting for a small percentage of economic activity. In addition, Jeong focuses on decomposing output per capita and labor productivity rather than output per working age person and TFP. Specifically, Jeong decomposes output per capita growth into a) within-sector employment rate growth, b) reallocation of employment across sectors, c) within-sector labor productivity growth, and d) changes in the sectoral allocation of hours worked. His aggregate labor productivity decomposition in c) and d) is very similar to my labor productivity growth decomposition presented in appendix A.3, however, Jeong does not explicitly show any decomposition of aggregate TFP growth (although his framework would generate one). Jeong's modeling exercise focuses on quantifying the "wedges" associated with the first order condition at every choice margin, and his calibration choices and strategy are very different from mine. Diewert (2015) and Oulton (2016) also lay out empirical decompositions of aggregate labor productivity and TFP in both sectoral value-added production frameworks–which are very similar to mine–and gross output production frameworks.

My paper is close in spirit to Hayashi and Prescott (2002), who use a neoclassical growth accounting framework to show that slower TFP growth was the largest source of Japan's 1990s slowdown, with a smaller role for declining average hours due to the mandated reduction in the length of the working week. They argue that a one-sector neoclassical growth model does a good job of accounting for the aggregate slowdown during the 1990s. They hypothesize that misguided subsidies to inefficient firms and declining industries may be responsible for misallocating a higher portion of resources in favor of low productivity growth entities and sectors, discouraging investments (in efficient firms and industries) that could raise productivity growth. They cite Japan's "Temporary Measures for the Stabilization of Specific Depressed Industries" from 1978 to 1983 as an example of such subsidies, when the rate of annual TFP growth declined from over 2 percent in the preceding three to six years to just 0.64 percent. My results imply that, for the most part, the efficient allocations generated by a multi-sector competitive equilibrium growth model does a decent job of replicating Japan's aggregate TFP growth experience after 1990. More generally, my framework can be interpreted as a multi-sector application of the great depressions methodology followed by Hayashi and Prescott (2002) and originating in Cole and Ohanian (1999) and Kehoe and Prescott (2002) and (2007).

The paper also contributes new evidence to a large empirical literature analyzing the sectoral origins and persistence of Japan's aggregate economic and productivity slowdown since the 1990s. Baily, Bosworth, and Doshi (2020), Fukao et al. (2004), Fukao (2013), Fukao et al. (2015), and Fukao et al. (2021) are just a few precursors that have shown aggregate labor productivity and TFP growth slowdown as the main source of Japan's economic growth slowdown and examined sectoral origins. In these and many related research papers, aggregate TFP is measured using different datasets, and alternative aggregate growth and development accounting models are utilized to derive it. Fukao and various coauthors, in a long-term project using their own constructed productivity database–the Japanese Industrial Productivity (JIP)–also reach the conclusion that Japan's slow economic growth relative to preceding post-war decades is the result of a long-term slowdown in productivity growth. They use different growth accounting frameworks than that adopted here of Cole and Ohanian (1999) and Kehoe and Prescott (2002, 2007), however. In addition, they often include a labor "quality" measure which yields rather different implications for the evolution of labor productivity. Baily, Bosworth and Doshi examine metrics of within-sector productivity growth to infer sectoral contributions to aggregate TFP slowing, but do not explicitly decompose aggregate into sectoral contributions. Fukao and various coauthors in multiple papers use sectoral productivity estimates based on the JIP dataset. They deploy a variety of explicit sectoral decompositions with alternative interpretations of sectoral contributions to aggregate productivity growth, none of which are the same as mine. Jorgenson, Namura, and Samuels (2018) construct and study different productivity measures than I do, using PPP adjusted data, and focus on measuring the sectoral origins of productivity differences between Japan and the United States. None of the resulting papers generate model-based estimates of sectoral contributions to aggregate productivity growth for the purposes of interpreting their results, however.

The next two sections describe the data, empirical decompositions of growth accounting variables and aggregate TFP, and the empirical results. Section 4 presents the three-sector competitive equilibrium growth model, and section 5 details its calibration. Section 6 presents the results of simulating the calibrated model and compares model-generated data to the empirical results of sections 2 and 3, and sensitivity analysis. Section 7 concludes.

2. Data Analysis

I measure all data at the annual frequency, drawing original series from the OECD STAN database, the System of National Accounts of Japan (JSNA), and the United Nations Population Dataset. I describe data series, sources, and calculations of variables in detail in the data appendix.

2.1 Output per working age person and output per hour worked

The two panels of figure 1 show the evolution of real output per working age person and the evolution of real output per hour worked by employees in Japan from 1980 through 2018. The two panels of figure 2 depict the annual growth rates of the same two variables from 1981 through 2018–output per working age person, and output per hour worked. Real output is real GDP measured in chained 1980 yen. In figure 1a, I divide real GDP by the number of working age people, namely, the population of those aged 16 years to 65 years. In figure 1b, I divide real GDP by the number of hours worked by employees.

Figure 1a shows that, following rapid growth through the 1980s, output per working age person grew more slowly on average after 1990, and even after the recovery year, 2010, following the great recession of 2008–2009. The level of real output per working age person declined in 1993, 1998, and 1999 as well as in the great recession years of 2008 and 2009. Figure 2a shows that the annual growth rate of output per working age person began to decline in 1991, after peaking at 5.75 percent in 1988. The growth rate fell sharply from 1991 through 1993, and again in 1997 and 1998, and in 2001. On average the growth rate remained much lower than its 1988 peak from 1992 through the great recession when it plummeted in 2008 and 2009. By 2018, growth in output per working age person had not once returned to its 1988 peak.

The first column of numbers in table 1 shows that the average annual growth rate of output per working age person fell from 3.64 percent in the 1980s to 1.27 percent in the 1990s, fell further to 1.21 percent from 2001 through 2010, and rose modestly from 2011 through 2018 to 2.04 percent. Excluding the great recession years 2008-2010 from the decade of the 2000s, the average growth rate from 2001 through 2007 was 1.72 percent. The average growth rate of output per working age person for the entire pre-great recession period from 1991 through 2007 was 1.46 percent, roughly 40 percent of its 1980s average of 3.64 percent. Similarly, from 1991 through 2018, including the great recession and recovery years, the average growth rate of output per working age person was 1.47 percent. Even omitting the impact of the great recession of 2008–2009, Japan has experienced almost 30 years of much slower output per adult growth since 1991, relative to the 1980s. Relative to the commonly adopted global "trend" growth rate of 2 percent per year, Japan suffered two decades–a lost score–of slower output per working age person growth from 1991 through 2010.

Figures 1b and 2b show the behavior of labor productivity measured by output per hour worked by employees, from 1980 through 2018. Evidently, labor productivity exhibits faster growth than output per working age person in the 1990s, but much slower growth on average after 2000 and, especially, after the great recession of 2008-2009. The second column of numbers in table 1 corroborates this; from 1981 through 1990 the average growth rate was 3.05 percent, but fell to 1.64 percent from 1991 through 2000, to 0.60 percent from 2001 through 2010, and 0.49 percent from 2011 through 2018. If I exclude the great recession years 2008-2010 from the decade of the 2000s, the average growth rate from 2001 through 2007 was just 0.83 percent. The average growth rate of output per hour worked for the entire pre-great recession period from 1991 through 2007 was 1.30 percent, roughly 43 percent of its 1980s average of 3.05 percent. Similarly, from 1991 through 2018, including the great recession and recovery years, the average growth rate of output per hour was 0.94 percent, less than one third of its 1980s value. More strikingly, the average growth rate of output per hour after 2000 was just 0.55 percent per year, only 18 percent of its 1980s value and 23 percent of its growth rate from 1981 through 2000. Japan has experienced almost three entire decades of much slower output growth per hour worked since 1991, relative to the 1980s, and an even greater productivity growth slowdown since 2000.

The difference between the behavior of output per working age person and output per hour simply reflects the evolution of hours worked per working age person; these data imply that they fell in the 1990s and rose in the 2000s and 2010s.

2.2 Growth accounting for output per working age person and output per hour worked

Growth accounting exercises can identify the main sources of slower growth in output per working age person and output per hour worked in Japan after 1990, and the origins of the post-2010 recovery in output per working age person.

Specifically, I assume the aggregate production function takes the Cobb-Douglas form,

$$Y_t = A_t K_t^{\alpha} H_t^{1-\alpha}. \tag{1}$$

Here, Y_t is aggregate output, K_t denotes the capital stock, H_t denotes aggregate hours worked, $A_t \equiv \Gamma_t \gamma^{t(1-\alpha)}$ is TFP, where γ denotes the "trend" growth rate, and α is capital's income share. I denote the number of working age people by N_t. Some algebra yields an expression for output per working age person as the product of three growth factors: A TFP factor, a capital factor, and an hours' worked factor,

$$\left(\frac{Y_t}{N_t}\right) = A_t^{\frac{1}{1-\alpha}} \left(\frac{K_t}{Y_t}\right)^{\frac{\alpha}{1-\alpha}} \left(\frac{H_t}{N_t}\right). \tag{2}$$

In addition, using (2) it is straightforward to derive output per hour worked as a product of the capital and TFP factors,

$$\left(\frac{Y_t}{H_t}\right) = A_t^{\frac{1}{1-\alpha}} \left(\frac{K_t}{Y_t}\right)^{\frac{\alpha}{1-\alpha}}. \tag{3}$$

Taking logs and time derivatives on both sides of (2) and (3) yields the growth rate equations that I use in the growth accounting, where I approximate the instantaneous growth rate of a variable by its discrete-time, annual net growth rate.

The convenience of the decomposition of output per working age person and output per hour represented by (2) and (3) is that, on a balanced growth path of a one-sector neoclassical growth model growth in which hours worked are endogenously determined by households, growth in output per working age person and in output per hour worked derives solely from growth in the TFP factor. Specifically, if TFP grows at a constant rate, $A_t = \Gamma_0 \gamma^{t(1-\alpha)}$, and the working age population grows at a constant rate given by $N_t = \mathrm{N}_0 n^t$, output per working age person and the TFP factor grow at the trend growth rate γ. Output and the capital stock both grow at the gross rate γn, and total hours grow at the rate of the working population, n, so that the capital and hours factors are constant; TFP factor growth is the sole source of sustained growth in output per working age person and output per hour worked in (2) and (3).

2.2.1 Data

To compute the capital-output ratio, I divide the nominal value of the economy's total stock of fixed capital by nominal GDP, a choice limited by data availability as I describe in the data appendix. Notice that the nominal capital-output ratio reflects not only changes in the volume of capital relative to output but also in the relative price of capital in terms of output. Hours per working age person is simply the ratio of total hours of employees to the working population of adults aged 16 to 65. I measure the TFP factor by taking the ratio of real output per working age person to the product of the capital factor and hours factor, using Hayashi and Prescott's (2002) estimate of the capital income share in Japan in the 1980s, 0.362.

2.2.2 Accounting for output per working age person

Figure 3a plots the normalized (1980=100) level of each growth factor on the right-hand side of equation (2) against the normalized (1980=100) level of output per working age person. Table 2 presents a decennial accounting of the annual average growth rate of output per working age person from 1981 through 2018, including a modified decennial analysis for the 2000s in which I omit the great recession years 2008–2010.

The data in figure 3a imply that Japan deviated substantially from its balanced growth from about 1991 until the end of the sample. Both the capital factor and labor factor vary significantly relative to their balanced growth paths (constant values) over the post-1990 sub-sample. Moreover, after 2000 TFP factor growth is mild and appears rather weakly related to output per working age person growth, in contrast to the preceding years. Specifically, the observed increase over the sample period in output per working age person is attributable to a) increases in the TFP factor, especially prior to 2000, b) modest capital deepening from about 1989 until 2009, and c) increasing hours worked per working age person in the mid-2000s and, especially, after 2010. The TFP factor exhibited slower growth from 1990 onwards relative to the 1980s, and especially in the 2000s–including a sharp downturn during the great recession, through the end of the sample period. Slower TFP factor growth depressed growth in output per working age person in the 1990s and 2000s, but in both decades was somewhat offset by mild capital deepening. Output per working age person grew systematically more quickly than the TFP factor after the great recession solely due to growth in hours per working age; the capital factor declined on average.

In table 2, the first column of numbers shows the average annual growth rate of output per working age person for each period. The second through fourth columns of numbers show the measured contribution of each growth factor on the right hand-side of equation (2) to the growth rate of output per working age person. The table shows that an average annual growth rate of output per working age person in the 1980s exceeding 3 percent was mainly accounted for by fast TFP factor growth. The capital factor was roughly constant. Of the 2.37 percentage point decline in average output per working age person growth in the 1990s relative to the 1980s, most was accounted for by a decline in average TFP factor growth by 2.07 percentage points. In addition, there was a 0.94 percentage point decline in average annual growth of hours per working age person. As Hayashi and Prescott (2002) and Betts (2021) observe, the greater deceleration in hours per working age person was attributable to much lower average hours worked per employee, likely in part attributable to a mandated reduction in the length of the working week over the period 1988 through 1993. Modest capital deepening somewhat offset these two sources of declining growth. The further decline of average growth in output per working age person in the 2000s relative to the 1990s by 0.06 percentage points was driven by continued depressed TFP factor growth, which fell by an additional 0.89 percentage points in the 2000s relative to the 1990s and a small decline in capital factor growth. Despite the great recession, the 2000s witnessed a substantially *higher* growth rate of hours per working age person than the 1990s. When I omit the years 2008–2010 and recalculate average growth rates for the period 2001–2007, qualitatively the same behavior of each growth factor obtains; however, faster growth of the hours factor dominated quantitatively slower growth in the TFP factor so that output per working age person growth rate improved relative to the 1990s.

Finally, the 2010s witnessed partial recovery of output per working age person growth relative to the 2000s, to 2.04 percent per year – the sample average growth rate. This occurred despite a significant reduction in capital deepening relative to any prior decade and anemic, if modestly improved, TFP factor growth. Faster output per working age person growth was largely attributable to higher hours per working age person growth, which grew at an extraordinary 1.54 percent per year. The modest improvement in TFP factor growth relative to the 2000s of 0.46 percentage points meant that TFP factor growth remained much lower, even, than its growth rate during the "lost decade" of the 1990s. Total factor productivity growth has suffered three lower growth decades.[1]

2.2.3 Accounting for output per hour worked

The data in figure 3b shows that output per hour worked in Japan also deviated significantly from its balanced growth path from about 1991 until the great recession, due to capital deepening that offset notable decline in the TFP factor growth rate. The modest improvement in TFP factor growth after 2010 was associated with a decline in the capital factor. Table 3 shows a decennial accounting for the growth rate of output per hour worked in terms of the TFP and capital factors on the right-hand side of equation (3). Rapid growth in output per hour worked in the 1980s exceeding 3 percent was due entirely to TFP factor growth. The capital factor was roughly constant. Output per hour worked growth in the 1990s was 1.31 percentage points lower per year on average than in the 1980s. Of this decline, all was accounted for by a decline in the TFP factor growth rate by 2.07 percentage points, while moderate capital deepening offset the effect of decline in the TFP factor growth rate. The average growth rate of output per hour worked in the 2000s relative to the 1990s declined by a further 1.04 percentage points, driven by continued depressed TFP factor growth, although there was also a small decline in capital factor growth. During the 2010s, there was further decline relative to the 2000s, not recovery, of average growth in output per hour worked in contrast to average growth in output per working age person. This further decline in labor productivity growth was due to recession in the capital-output factor, while TFP growth modestly increased.

To summarize, while Japan has suffered a "lost score" relative to trend in output per working age person growth since 1991, she has experienced three decades of lost TFP and labor productivity growth. The recovery of output per working age person in the 2010s is attributable to rapid hours worked per working age person growth, occurring despite anemic TFP factor growth and a recession in the capital factor. The growth accounting results imply that Japan's aggregate TFP factor is the dominant source of slower growth in output per working age person growth since 1991, with a smaller role played by a declining hours factor in the 1990s. Slower TFP growth is also the origin of a large decline in output per hour worked growth in the 1990s and 2000s to which a reduction in capital deepening also contributed in the 2010s.

[1] In Appendix A.1, I compare my growth accounting results directly to those of Hayashi and Prescott (2002), with the results presented in table A1 and figure A1.

3. Sectoral decomposition of Japan's TFP and labor productivity growth

In this section, I develop a sectoral decomposition of aggregate TFP growth based on the growth accounting for GDP per working age person; an approximation to this decomposition could be derived from the growth accounting for GDP per hour. In appendix A.3, I present a companion sectoral decomposition of GDP per hour worked, which I omit here for brevity. I first record the evolution of value added and shares of labor inputs over the sample period for the three major sectors of economic activity: agriculture, industry (manufacturing, energy, utilities, and construction), and services.

3.1 Sector specific growth and allocations 1980–2018

3.1.1 Sector growth and structural change

I measure real value added by sector in chained 1980 yen at producer prices, based on OECD data and calculated as I describe in the data appendix.

Figure 4a shows the evolution of real value added per working age person in each of the three sectors, normalizing all sectors' real value added to equal 100 in 1980. Over the sample period, real value added of the service sector more than doubled, that of the industrial sector increased by roughly 70 percent, and that of agriculture declined by roughly 35 percent. Notably, while services' value added rose systematically until the great recession of 2008-2009, industry's growth stalled sharply in the 1990s and stagnated until about 2002; industrial sector value added exhibited a roughly flat trend from 1990 until after the great recession. Agricultural value added declined quite steadily from the mid-1980s throughout the sample period, except for a period of stabilization in the second half of the 1990s and short-lived expansion prior to the great recession. Although Japan was a relatively developed OECD country in 1980, the changes in relative outputs of the three major sectors of economic activity represent economically significant shifts in the allocation of economic resources and activity, which I depict in figure 4b.

Because the chain-linked quantity indexes for the three sectors reflect different relative prices, real sectoral shares do not sum to one. In addition, in the theoretical model I analyze there is no money or nominal numeraire so that "nominal" value-added shares in the model are not equivalent to those in the data. I therefore focus on the hours worked shares of sectors to measure changes in the allocation of economic activity and resources across sectors. In figure 4b, I show the employee hours shares of the three major sectors. The figure shows that there is gradual divergence in favor of services' hours share over the sample period, relative to industry and agriculture. The divergence relative to industry is greater after 1990; agriculture's share of hours is always small but increases marginally in the 2000s, before declining again after the great recession.

The three panels of figure 5 show the growth rate of value added (per working age person) in each of the three sectors plotted against the growth rate of GDP (per working age person). Figure 5a shows that value added in agriculture exhibits a highly volatile growth rate over the sample period relative to GDP and is lower on average. In addition, the growth rates appear to co-move inversely. By contrast, figure 5b shows that while industry's value-added growth is also somewhat more volatile than that of GDP, the two variables exhibit highly positive co-movements, and the growth rates appear to be similar on average. Finally, figure 5c shows that services' value-added growth is relatively smooth, and exhibits less strong, although positive, co-movement with that of GDP.

Table 4 quantifies the average growth rates of sectoral value added per working age person by decade. It compares them to the growth rate of real GDP per working age person, reproducing the decennial growth rates from Table 1 for ease of comparison. The secular decline in agriculture's share of economic activity reflects in average annual sectoral value-added growth that is negative in every decade. Agriculture's value-added per working age person declined more rapidly in the 1990s and 2000s than in the 1980s and exhibits relatively fast (but negative) growth in the 2010s. The industrial sector, like that of the aggregate economy, enjoyed high average growth of value-added per working age person in the 1980s, but suffered a dramatic decline in the 1990s. Unlike GDP, industrial value-added grew on average somewhat faster in the 2000s than in the 1990s and exhibited a stronger recovery in the 2010s. While qualitatively all three sectors experienced growth slowdowns in the 1990s, quantitatively the slowdown in agriculture and services–although substantial–were both smaller than that in industry. In addition, services' recovery in the 2010s was smaller than that of industry. The recovery of Japan's aggregate growth rate during the 2010s was mirrored in the growth performance of all three sectors, but the largest improvements were in agriculture and industry.

3.2 Sectoral decomposition of aggregate growth sources

I first decompose GDP per working age person growth into the contributions due to each of the three major sectors, and then decompose the growth rate of each of the capital and labor factors on the right-hand side of (2) into sectoral contributions. Finally, I calculate the difference between a sector's contribution to aggregate output per working age person growth and the sum of its contributions to the capital and hours growth factors; this represents a sector's contribution to aggregate TFP factor growth, and the sum of sectoral TFP factor growth contributions is exactly equal to aggregate TFP factor growth. It bears emphasis that this decomposition is data driven, and independent of any assumption on the functional form of sectoral production functions. It relies solely on two features of the data: First, aggregate nominal value-added and the aggregate nominal capital stock are the sum across sectors of nominal value added and nominal sectoral capital stocks, respectively; and second, aggregate hours is the sum of the hours worked across sectors.

In a second exercise, I decompose each sector's contribution to aggregate TFP factor growth into two portions: i) A sector's "direct" TFP growth contribution; and ii) a sector's residual contribution to aggregate TFP factor growth. The residual contribution of a sector to aggregate TFP factor growth, in turn, reflects a) changes in its relative output price, b) any difference between a sectoral and the economy-wide capital income share, and c) changes in a sector's share of value added. While each source of the residual is not independent across sectors, I show below that there is a small, non-zero net effect for aggregate TFP factor growth of the total residual contributions of sectors. To conduct this decomposition of total sectoral contributions to aggregate TFP factor growth, I assume a specific form for the sectoral production functions. This is sufficient to interpret i) as a direct, sectoral TFP contribution and establish its relationship to actual sectoral TFP, and hence define the residual contribution, ii). For simplicity, I assume that sectoral production functions are value added functions, abstracting from intermediate inputs, and specifically that they share the same Cobb-Douglas form as the aggregate production function, but allow for differing sectoral capital income shares and TFP levels:

$$Y_{i,t} = A_{i,t} K_{i,t}^{\alpha_i} H_{i,t}^{1-\alpha_i}, \qquad i = a, m, s. \tag{4}$$

Here, $A_{i,t} \equiv \Gamma_{i,t} \gamma^{t(1-\alpha_i)}$ is the TFP of sector *i*. Sector *i* value added per working age person is

$$\frac{Y_{i,t}}{N_t} = A_{i,t}^{\frac{1}{1-\alpha_i}} \left(\frac{K_{i,t}}{Y_{i,t}}\right)^{\frac{\alpha_i}{1-\alpha_i}} \left(\frac{H_{i,t}}{N_{\ t}}\right), \qquad i = a, m, s, \tag{5}$$

where the interpretation of each growth factor on the right-hand side of (5) follows those in (2).

In a multi-sector neoclassical growth model, like the one I develop below, this specification of sectoral value-added production functions and TFP factors ensures that when sectoral TFP factors grow at the common constant rate, γ, $(A_{i,t}{}^{\frac{1}{1-\alpha_i}} = \Gamma_{i,0}{}^{\frac{1}{1-\alpha_i}} \gamma^t \ \forall i)$, the aggregate working population grows at a constant rate given by $N_t = N_0 n^t$, and all other exogenous sources of variation are constant, there exists a balanced growth path for the economy. On this path, each sector's value added per working age person growth equals the common trend growth rate, γ, there is no structural change in that the sectoral allocation of capital, labor, and value added, and all sectoral value-added prices are constant. Sectoral capital stocks grow at the same rate (γn), sectoral hours worked grow at the same rate (n), sectoral capital-output ratios and sectoral hours per working age person are all constant. The aggregate economy exhibits balanced growth, in the sense that aggregate capital and aggregate value-added (GDP) grow at the same rates, and the same rates as their sectoral counterparts.

Using (5), a growth accounting can be conducted separately for each sector, *i*, as I have for the aggregate economy and sectoral TFP factors can be derived. I relegate the sectoral growth accounting to appendix A.2, where the production function (5) guides my definition of sectoral TFP factors and the distinction between within-sector TFP growth and residual contributions of sector *i* to aggregate TFP growth.

3.2.1 Sectoral contributions to GDP per working age person

I first decompose GDP per working age person into sectoral contributions. For this, the sum of nominal value added across sectors must exactly equal GDP, a condition satisfied in the (proportionally adjusted) data. Then, the growth rate of GDP per working age person, measured in chained 1980 yen, has the following interpretation in terms of sectoral contributions, where I define a sector's share of nominal value added as $s_{y,i,t} \equiv \left(\frac{Y_{i,t}P_{i,t}}{Y_tP_t}\right)$,

$$\frac{\left(\frac{Y_{t+1}}{N_{t+1}}\right)-\left(\frac{Y_t}{N_t}\right)}{\left(\frac{Y_t}{N_t}\right)} = \sum_{i=a,m,s}\left(\left(\frac{\frac{Y_{i,t+1}}{N_{t+1}}}{\frac{Y_{i,t}}{N_t}}\right)\left(\frac{\frac{P_{i,t+1}}{P_{t+1}}}{\frac{P_{i,t}}{P_t}}\right)-1\right)s_{y,i,t}. \qquad (6a)$$

Here, P_t is the implicit (chained) GDP deflator at date *t* and $P_{i,t}$ is sector *i*'s implicit (chained) value-added deflator at *t*, both derived as the ratio of nominal to real value added measured in chained 1980 yen at producer prices. The relative price-adjusted growth rate of value added per working age person of sector *i*, multiplied by the sector's date *t* nominal value-added share, yields the sector's contribution to–and the sum of these contributions is exactly equal to–GDP per working age person growth. The contribution of sector *i* reflects value-added share weighted "within-sector" value added per working age person growth, and growth over time in its relative output price. It is straightforward to show that the sectoral contributions in (6a) can be approximated by the value-added share weighted sum of net growth rates of real value added and relative prices,

$$\frac{\left(\frac{Y_{t+1}}{N_{t+1}}\right)-\left(\frac{Y_t}{N_t}\right)}{\left(\frac{Y_t}{N_t}\right)} \cong \sum_{i=a,m,s}\left(\left(\frac{\frac{Y_{i,t+1}}{N_{t+1}}-\frac{Y_{i,t}}{N_t}}{\frac{Y_{i,t}}{N_t}}\right)+\left(\frac{\frac{P_{i,t+1}}{P_{t+1}}-\frac{P_{i,t}}{P_t}}{\frac{P_{i,t}}{P_t}}\right)\right)s_{y,i,t}. \qquad (6b)$$

I illustrate the time-series contributions of each of the three major sectors of economic activity in (6a) to the growth rate of GDP per working age person in figure 6. The figure shows that agriculture, although it experiences large within-sector fluctuations in value-added per working age person seen in figure 6, because it represents such a small share of aggregate value added given by $s_{y,a,t}$, has a quantitatively very small contribution to aggregate output per working age person growth. Almost all time-series variation in the aggregate growth rate is accounted for by industry and services. In periods of most severe downturn in GDP per working age person growth, the 1990s and during the great recession, the industrial sector appears to account for much of the slowing. Sectoral contributions to average GDP per working age person growth by decade are quantified in table 5.

Table 5 shows that service sector growth was the largest contributor to rapid aggregate growth in the 1980s, although the industrial sector also contributed substantively. By contrast, the industrial sector contributed most to the *decline* in aggregate output growth in the 1990s relative to the 1980s, although the service-sector also contributed substantively. The service sector was solely responsible for the much smaller decline in aggregate growth in the 2000s relative to the 1990s, while the industrial sector accounted for most of the modest increase in aggregate growth during the 2010s; agriculture contributed more than services to the 2010s average growth rate increase.

3.3.2 Sectoral contributions to growth in the capital factor

I next decompose into sectoral contributions the growth in the capital factor on the right-hand side of (2). I express the growth rate of the measured aggregate capital factor as the sum of sectoral contributions as follows.

Let $s_{k,i,t} \equiv \left(\frac{K_{i,t}P_{ik,t}}{K_{,t}P_{k,t}}\right)$ denote sector i's nominal capital stock share, where $P_{K,t}$ is the date *t* implicit price deflator of the aggregate fixed capital stock, and $P_{ik,t}$ the date *t* implicit price deflator of the sector *i* fixed capital stock. Then

$$\left(\frac{\alpha}{1-\alpha}\right)\left(\frac{\left(\frac{K_{t+1}P_{k,t+1}}{Y_{t+1}P_{t+1}}\right)-\left(\frac{K_tP_{k,t}}{Y_tP_t}\right)}{\left(\frac{K_tP_{k,t}}{Y_tP_t}\right)}\right)$$

$$=\left(\frac{\alpha}{1-\alpha}\right)\sum_{i=a,m,s}\left(\frac{\left(\frac{K_{i,t+1}P_{ik,t+1}}{Y_{i,t+1}P_{i,t+1}}\right)s_{y,i,t+1}-\left(\frac{K_{i,t}P_{ik,t}}{Y_{i,t}P_{i,t}}\right)s_{y,i,t}}{\left(\frac{K_{i,t}P_{ik,t}}{Y_{i,t}P_{i,t}}\right)s_{y,i,t}}\right)s_{k,i,t}. \qquad (7a)$$

Note that each sector's contribution in (7a) reflects not only its own fixed capital-output growth rate between *t* and *t+1,* weighted by its current nominal capital stock share, but also the change in the sector's nominal value-added share between t and $t+1$. If a sector experiences positive nominal value-added share growth between t and $t+1$, this raises (reduces) the impact of that sector's positive (negative) capital-output growth for aggregate capital factor growth between t and $t+1$. It is easy to show that sectoral contributions to aggregate capital deepening can be approximated by the nominal capital share weighted sum of within-sector capital deepening and growth in a sector's value-added share, multiplied by the ratio of the economy-wide capital income share to the economy-wide labor income share, as shown on the right-hand side of equation (7b),

$$\left(\frac{\alpha}{1-\alpha}\right)\left(\frac{\left(\frac{K_{t+1}P_{K,t+1}}{Y_{t+1}P_{t+1}}\right)-\left(\frac{K_tP_{K,t}}{Y_tP_t}\right)}{\left(\frac{K_tP_t}{Y_tP_t}\right)}\right)$$

$$\cong\left(\frac{\alpha}{1-\alpha}\right)\sum_{i=a,m,s}\left(\left(\frac{\frac{K_{i,t+1}P_{ik,t+1}}{Y_{i,t+1}P_{i,t+1}}-\frac{K_{i,t}P_{ik,t}}{Y_{i,t}P_{i,t}}}{\frac{K_{i,t}P_{ik,t}}{Y_{i,t}P_{i,t}}}\right)+\left(\frac{s_{y,i,t+1}-s_{y,i,t}}{s_{y,i,t}}\right)\right)s_{k,i,t}. \quad (7b)$$

Table 6 quantifies the contribution of each sector to the average annual growth rate of the capital factor, in a decennial growth accounting using equation (7a). Average growth over ten-year periods in the aggregate capital factor is small, as theory suggests should be observed; capital adjusts transitorily to exogenous TFP variation to attain a constant capital-output ratio on a balanced growth path. For the period 1981 through 1990, service-sector positive contributions to capital deepening accounted fully for the tiny increase in the aggregate capital factor; there were almost perfectly offsetting negative contributions of agriculture (the largest) and industry. For the period 1991 through 2000, the service sector contributed about 5/6 of relatively large 0.65 percent growth in the capital factor, with industry contributing the remaining portion and agriculture a tiny negative, offsetting contribution. Aggregate capital factor growth declined a little in the 2000s, although there was nonetheless significant capital-deepening in this decade which was entirely attributable to the service sector, while a marginally increased contribution of industry relative to the 1990s was exactly offset by a marginally reduced contribution of agriculture. In the 2010s, growth in the aggregate capital factor again declined, and was slightly negative. The decline was largely attributable to a further fall in the contribution of services, although industry's contribution was also significantly smaller. Over the entire sample period, average growth in the capital factor was modest, and almost all accounted for by the contribution of services. Some of this service sector contribution was accounted for by within service sector capital deepening, as appendix A.2 shows; some was accounted for by the increasing value-added share of services after 1990, weighted by its large share of the total nominal capital stock.

3.3.3 Sectoral contributions to hours per working age person growth

Since the sum of hours worked by employees across the three major sectors of economic activity equals aggregate hours worked by employees, hours per working age person decomposes simply into within-sector contributions, comprising hours-share weighted sectoral hours per working age person growth rates. I denote the hours share of sector *i* by $s_{h,i,t} \equiv \left(\frac{H_{i,t}}{H_t}\right)$. Then,

$$\left(\frac{\left(\frac{H_{t+1}}{N_{t+1}}\right) - \left(\frac{H_t}{N_t}\right)}{\left(\frac{H_t}{N_t}\right)}\right) = \sum_{i=a,m,s} \left(\frac{\left(\frac{H_{i,t+1}}{N_{t+1}}\right) - \left(\frac{H_{i,t}}{N_t}\right)}{\left(\frac{H_{i,t}}{N_t}\right)}\right) s_{h,i,t}. \tag{8}$$

Like the capital factor, hours per working age person should exhibit a zero trend on the balanced growth path of a neoclassical growth model, transitorily adjusting to exogenous TFP deviations from trend to attain a constant value. Table 7 shows that variation in the hours factor, like that of the capital factor, was generally modest over the sample period although surprisingly high during the 2001-2018 period. An increase in hours per working age person during the 1980s was largely attributable to service sector contributions. The industrial sector accounted for a larger portion of the decline in the hours factor's growth rate (it was negative) in the 1990s relative to the 1980s, while the service sector was more important to the increase in hours factor growth in the 2000s relative to the 1990s. Finally, industry and services roughly equally accounted for the large increase in hours growth during the 2010s relative to the 2000s.

3.4 Sectoral contributions to aggregate TFP factor growth

The difference between sector *i*'s contribution to output per working age person derived from equation (6a) and the sum of sector *i*'s contributions to capital factor growth and hours per working age person growth derived from equations (7a) and (8) respectively is a measure of that sector's contribution to aggregate TFP factor growth. The *total contribution of sector i* to aggregate TFP factor growth, which I denote by $CTFPF_{i,t}$, is given by equation (9a),

$$CTFPF_{i,t} = \left(\frac{\left(\frac{Y_{i,t+1}}{N_{t+1}}\right)\left(\frac{P_{i,t+1}}{P_{t+1}}\right)-\left(\frac{Y_{i,t}}{N_t}\right)\left(\frac{P_{i,t}}{P_t}\right)}{\left(\frac{Y_{i,t}}{N_t}\right)\left(\frac{P_{i,t}}{P_t}\right)}\right)s_{y,i,t} - \left(\frac{\alpha}{1-\alpha}\right)\left(\frac{\left(\frac{K_{i,t+1}P_{ik,t+1}}{Y_{i,t+1}P_{i,t+1}}\right)s_{y,i,t+1}-\left(\frac{K_{i,t}P_{ik,t}}{Y_{i,t}P_{i,t}}\right)s_{y,i,t}}{\left(\frac{K_{i,t}P_{ik,t}}{Y_{i,t}P_{i,t}}\right)s_{y,i,t}}\right)s_{k,i,t} - \left(\frac{\left(\frac{H_{i,t+1}}{N_{t+1}}\right)-\left(\frac{H_{i,t}}{N_t}\right)}{\left(\frac{H_{i,t}}{N_t}\right)}\right)s_{h,i,t}. \qquad (9a).$$

The total contribution of sector *i* to aggregate TFP can be approximated by the difference on the right-hand side of equation (9*b*),

$$CTFPF_{i,t} \cong \left(\left(\frac{\frac{Y_{i,t+1}}{N_{t+1}}-\frac{Y_{i,t}}{N_t}}{\frac{Y_{i,t}}{N_t}}\right)+\left(\frac{\frac{P_{i,t+1}}{P_{t+1}}-\frac{P_{i,t}}{P_t}}{\frac{P_{i,t}}{P_t}}\right)\right)s_{y,i,t} - \left(\frac{\alpha}{1-\alpha}\right)\left(\left(\frac{\frac{K_{i,t+1}P_{ik,t+1}}{Y_{i,t+1}P_{i,t+1}}-\frac{K_{i,t}P_{ik,t}}{Y_{i,t}P_{i,t}}}{\frac{K_{i,t}P_{ik,t}}{Y_{i,t}P_{i,t}}}\right)+\left(\frac{s_{y,i,t+1}-s_{y,i,t}}{s_{y,i,t}}\right)\right)s_{k,i,t} - \left(\frac{\left(\frac{H_{i,t+1}}{N_{t+1}}\right)-\left(\frac{H_{i,t}}{N_t}\right)}{\left(\frac{H_{i,t}}{N_t}\right)}\right)s_{h,i,t}. \qquad (9b).$$

A sector's total contribution to aggregate TFP growth reflects within-sector growth in value added per working age person relative to within-sector growth in the capital-output ratio and hours per working age person growth, just as a sector's "own" TFP factor growth rate does. A sector's own TFP factor growth rate implied by equation (5) and calculated for each of the three major sectors of economic activity in Japan in appendix A.2, is

$$TFPF_{i,t} = \left(\frac{\left(\frac{Y_{i,t+1}}{N_{t+1}}\right)-\left(\frac{Y_{i,t}}{N_t}\right)}{\left(\frac{Y_{i,t}}{N_t}\right)}\right)-\left(\frac{\alpha_i}{1-\alpha_i}\right)\left(\frac{\left(\frac{K_{i,t+1}P_{ik,t+1}}{Y_{i,t+1}P_{i,t+1}}\right)-\left(\frac{K_{i,t}P_{ik,t}}{Y_{i,t}P_{i,t}}\right)}{\left(\frac{K_{i,t}P_{ik,t}}{Y_{i,t}P_{i,t}}\right)}\right) - \left(\frac{\left(\frac{H_{i,t+1}}{N_{t+1}}\right)-\left(\frac{H_{i,t}}{N_t}\right)}{\left(\frac{H_{i,t}}{N_t}\right)}\right). \qquad (10)$$

However, the sectoral TFP factor growth contributions in (9a) and (9b) also reflect 1) growth in a sector's relative price of value added, which mediates the impact of its own real value-added growth on aggregate output growth, 2) growth in the sector's value-added share, which mediates the aggregate impact of the sector's capital deepening, and 3) a sector's current shares of value added, capital stock, and hours. Finally, note that a sector's contribution to capital factor growth in (9a) and (9b) reflects the economy-wide capital income share rather than the sector-specific capital income share which appears in its own TFP factor growth rate in (10).

Figure 7a shows the time series of TFP factors (10) for each sector, and the aggregate TFP factor, normalizing the three series to equal 100 in 1980, and figure 7b shows the associated growth rates of TFP factors by sector given by equation (10) plotted with that of the aggregate TFP factor. Figure 7a shows that, over the entire sample period, the aggregate TFP factor grew by slightly less than the TFP factor in industry, slightly more than that in services, and much more than that in agriculture. The agricultural TFP factor rose more rapidly than that of both the industrial and service sector during the 1980s, although all three sectors experienced relatively rapid TFP growth. However, agricultural TFP fell sharply in the 1990s until the mid-2000s, before recovering and outperforming the other two sectors after the great recession through the end of the sample period. The industrial sector's TFP factor grew more rapidly in the 1980s than at any time until after the great recession; in both periods, industrial sector TFP outperformed service sector TFP, with the latter stagnating and even declining slightly from the early 2000s onwards. Table 8 records average annual TFP factor growth rates for each sector by decade and reproduces aggregate TFP factor growth rates in the first column of numbers. The table shows that the dramatic slow-down in aggregate TFP factor growth in the 1990s relative to the 1980s was associated with slower TFP factor growth in all three major sectors, however, the slowdown in the service sector was relatively mild. By contrast, the second substantial aggregate TFP growth slow-down occurring in the 2000s was associated with a dramatic slowing of service sector TFP factor growth, while TFP factor growth in industry was only marginally slower than in the 1990s and that in agriculture marginally higher. The modest improvement in aggregate TFP factor growth in the 2010s, however, was associated with substantial increases in TFP growth in agriculture and industry but a negligible increase in that of services; service sector TFP growth has been depressed since 2000. Although almost equal on average over the entire sample period to service sector TFP factor growth, as the last row of numbers shows, agricultural TFP factor growth fluctuates wildly. As appendix A.2 discusses, this reflects a large capital factor impact for measured TFP growth mediated through a very high capital income share. Agriculture's TFP factor growth is the highest of any sector in the 1980s and 2010s, and negative, and lower than any other sector in the 1990s and 2000s.

Figure 8 plots the total sectoral contributions to aggregate TFP growth given by (9a). The figure shows that in the 1980s–a decade of fast aggregate TFP factor growth, and during the 1990s and 2000s– two decades of slowing aggregate TFP factor growth, both service and industrial sector contributions played a significant role in aggregate TFP factor growth changes. Agriculture also appears to play a positive role for TFP factor growth in the 1980s, however this is relatively small. The TFP contributions of industry and services both generally co-move positively with aggregate TFP growth, although the strength of co-movement by sector varies over the sample period. For example, service sector contributions appear to play a larger role than those of industry in the aggregate TFP decline during the great recession, and a smaller role in the subsequent recovery.

Table 9 shows the sectoral decomposition of aggregate TFP factor growth by decade. The last row of numbers shows that, on average over the entire sample period, industry and services contribute roughly equally to aggregate TFP factor growth of 1.20 percentage points annually and agriculture contributes a much smaller amount. Looking at the remaining rows of numbers in the table, it is striking that services' contribution to aggregate TFP factor growth is essentially zero after 2000. Agriculture's contribution is generally smaller than that of either sector, but even this is larger than the contribution of services in the 2010s. Agriculture's contribution, although small, is positive in all decades except the 2000s, despite exhibiting negative within-sector TFP growth in both the 1990s and 2000s. Decade by decade, aggregate TFP factor growth is accounted for by different sectors' contributions. Rapid annual aggregate TFP factor growth of more than 3 percent in the 1980s represented contributions of roughly 1.5 percentage points from the service sector, 1.35 percentage points from industry, and 0.15 percentage points from agriculture. The reduction of average aggregate TFP growth in the 1990s relative to the 1980s of more than 2 percentage points is attributable to reductions in sectoral contributions of 1.08 percentage points from industry, 0.83 percentage points from services, and 0.16 percentage points from agriculture; all three sectors play a role in the aggregate TFP slowdown of the 1990s, but industry's role is largest. An additional 0.89 percentage point reduction in aggregate TFP factor growth in the 2000s is largely attributable to a decline in the service sector's contribution, however: There is a 0.69 percentage point reduction in services' contribution, a 0.18 percentage point reduction in industry's contribution, and only a 0.03 percentage point reduction in agriculture's contribution. Finally, the modest increase of roughly 0.46 percentage points in average annual TFP factor growth in the 2010s relative to the 2000s is attributable largely to an increased contribution of industry by 0.39 percentage points, with a small increase in the contribution of agriculture of 0.1 percentage points; services' contribution declined marginally.

3.5 Decomposing sectoral contributions to aggregate TFP factor growth

I now quantify the extent to which the sectoral contributions to aggregate TFP factor growth in figure 8 and table 9 reflect the within-sector TFP factor growth rates illustrated in figures 7a and 7b and table 8, rather than changes in the composition of economic activity and in relative prices which are also reflected in each sector's total contribution in equations (9*a*) and (9*b*), $CTFPF_{i,t}$.

To simplify notation, in what follows I let $y_t \equiv \frac{Y_t}{N_t}, y_{i,t} \equiv \frac{Y_{i,t}}{N_t}$, and $k_{i,t} \equiv \frac{K_{i,t}P_{i,k,t}}{Y_{i,t}P_{i,y,t}}$. I first decompose the total TFP factor growth contribution of sector *i*, $CTFPF_{i,t}$ in equation (9a) into two components. The first component is a modified within-sector TFP factor growth rate, in which the growth rates of value added per working age person, the capital factor, and hours factor are weighted by the date *t* value of sector *i* 's share of nominal value added, sector *i*'s share of nominal capital, and sector *i*'s share of employee hours, respectively. I call this the sector *i* weighted TFP growth contribution and denote this by "$WTFPF_{i,t}$"; I think of this as the "direct" contribution of sector *i* to aggregate TFP factor growth, weighed by its importance in aggregate economic activity and resources. A second term constitutes a well-defined residual. Specifically, I express sector *i*'s total contribution to aggregate TFP growth as

$$CTFPF_{i,t} = WTFPF_{i,t} + RESID_{i,t}, \tag{11a}$$

where:

$$WTFPF_{i,t} \equiv \left(\frac{y_{i,t+1}-y_{i,t}}{y_{i,t}}\right)s_{y,i,t} - \left(\frac{\alpha_i}{1-\alpha_i}\right)\left(\frac{k_{i,t+1}-k_{i,t}}{k_{i,t}}\right)s_{k,i,t} - \left(\frac{\frac{H_{i,t+1}}{N_{t+1}}-\frac{H_{i,t}}{N_t}}{\frac{H_{i,t}}{N_t}}\right)s_{h,i,t}, \tag{11b}$$

$$RESID_{i,t} \equiv \frac{y_{i,t+1}}{y_{i,t}}\left(\frac{\frac{P_{i,t+1}}{P_{t+1}}-\frac{P_{i,t}}{P_t}}{\frac{P_{i,t}}{P_t}}\right)s_{y,i,t} - \left(\left(\frac{\alpha}{1-\alpha}\right)-\left(\frac{\alpha_i}{1-\alpha_i}\right)\right)\left(\frac{k_{i,t+1}-k_{i,t}}{k_{i,t}}\right)s_{k,i,t}$$
$$-\left(\frac{\alpha}{1-\alpha}\right)\frac{k_{i,t+1}}{k_{i,t}}\left(\frac{s_{y,i,t+1}-s_{y,i,t}}{s_{y,i,t}}\right)s_{k,i,t}. \tag{11c}$$

The residual contribution of sector *i* to aggregate TFP factor growth, $RESID_{i,t}$, constitutes three elements. First, a sector's residual contribution to aggregate TFP growth between *t* and *t+1* is higher if there is an increase between *t* and *t+1* in the price of that sector's value added relative to the price of GDP, $\left(\frac{P_{i,t+1}}{P_{t+1}}/\frac{P_{i,t}}{P_t}\right) > 1.$ As equations (6a) and (6b) show, an increase in sector *i*'s relative output price increases the impact for aggregate output per working age person growth–and hence aggregate TFP factor growth–of sector *i*'s own value-added per working age person growth. The converse statement applies if a sector's relative price declines over time. Second, if a sector's capital income share exceeds the economy-wide capital income share, this depresses its weighted TFP contribution to aggregate TFP factor growth relative to its total TFP factor contribution. A larger sectoral capital income share than economy-wide capital income share magnifies the impact of capital deepening in the sector's (weighted) TFP factor growth rate relative to the sector's total (actual) contribution to aggregate capital deepening. Its weighted TFP contribution thus excessively depresses measured aggregate TFP growth. A positive adjustment to the sector's residual contribution to aggregate TFP factor growth corrects for this. The converse statements apply for a sector with a smaller than economy-wide capital income share. Third, an increase in the sector *i*'s value-added share from *t* to *t+1*, $\left(\frac{s_{y,i,t+1}-s_{y,i,t}}{s_{y,i,t}}\right) > 0$, increases the sector's impact for aggregate capital factor growth, which decreases the sector's total contribution to aggregate TFP factor growth. Sector *i*'s weighted TFP contribution thus overstates the sector's contribution to aggregate TFP factor growth relative to the sector's total contribution, and a negative residual effect adjusts for this by accounting for the increase in the sector's value-added share. The converse statement holds if there is a decline in a sector's value-added share. I examine the magnitudes of these three elements of the residual term for each sector, *i*.

I refer to the three factors in the residual term of sector *i* as the relative output price factor, denoted $RELYP_{i,t}$, capital income share adjustment, denoted $CAPINC_{i,t}$ and value-added reallocation factor, denoted $VREALL_{i,t}$. Their sum equals the total residual contribution of sector *I*, where

$$RELYP_{i,t} \equiv \frac{y_{i,t+1}}{y_{i,t}}\left(\frac{\frac{P_{i,t+1}}{P_{t+1}}-\frac{P_{i,t}}{P_t}}{\frac{P_{i,t}}{P_t}}\right) s_{y,i,t}, \qquad (12a)$$

$$CAPINC_{i,t} \equiv -\left(\left(\frac{\alpha}{1-\alpha}\right)-\left(\frac{\alpha_i}{1-\alpha_i}\right)\right)\left(\frac{k_{i,t+1}-k_{i,t}}{k_{i,t}}\right) s_{k,i,t}, \qquad (12b)$$

$$VREALL_{i,t} \equiv -\left(\frac{\alpha}{1-\alpha}\right)\frac{k_{i,t+1}}{k_{i,t}}\left(\frac{s_{y,i,t+1}-s_{y,i,t}}{s_{y,i,t}}\right) s_{k,i,t}. \qquad (12c)$$

These are "indirect" or "allocative" influences of a sector on measured aggregate TFP factor growth, relative to the direct effect of the sector's weighted TFP factor contribution; no residual factor is independent across sectors. If one sector's relative price growth rises, at least one other's must fall; if one sector's capital income share is high relative to the economy-wide capital income share then another sector's must be low; if one sector enjoys a reallocation of value added in its favor, another sector must suffer a decline in its value-added share. This does not imply that the net effect summed over sectors of residual factors is exactly zero, however, as the residual effects of a sector are weighted by its growth rate of value-added or capital. The total residual effect for aggregate TFP factor growth is small relative to the total weighted TFP contribution of sectors, but not negligible.

3.5.1 Weighted TFP factor and residual contributions of sectors

The sum over sectors of weighted TFP contributions can be thought of as a measure of the aggregate productivity growth effect of within-sector TFP factor growth. In figure 9a, I decompose aggregate TFP factor growth into a) the sum over sectors of the weighted sectoral TFP factor growth rates, and b) the sum over sectors of residual contributions. Table 10 summarizes the decennial accounting of aggregate TFP factor growth into these total weighted TFP factor and residual contributions.

Both the figure and table indicate that, typically, aggregate TFP factor growth is dominated by the total weighted TFP contributions of sectors, with a small role for total residual contributions. Figure 9a shows that the annual co-movements of aggregate TFP growth and weighted TFP contributions of sectors are strong and positive. Nonetheless, the table shows that in the 1980s residual effects accounted for about one-fifth of aggregate TFP growth, while in the 2000s they were more important than the total weighted TFP contributions of sectors and responsible for the positive aggregate TFP growth observed. In addition, table 10 shows that as much as *one-third* of the decline in aggregate TFP factor growth in the 1990s relative to the 1980s was attributable to residual effects, with the remaining two-thirds attributable to decline in the weighted TFP contributions of sectors. By contrast, the decline of aggregate TFP factor growth in the 2000s relative to the 1990s and its modest improvement in the 2010s, are solely attributable to the weighted TFP contributions of sectors.

I decompose the total weighted TFP contribution to aggregate TFP factor growth by sector in figure 9b, and the total residual contribution by sector in figure 9c. Notice the different scales of vertical axes in the two graphs; residual contributions of sectors are relatively small. Figure 9b shows that agriculture's weighted TFP growth contribution, like the sector's total TFP contribution, is the smallest of the three. Agriculture's very small share of value added, capital, and hours account for the tiny role its TFP factor growth plays in weighted TFP factor growth. The weighted TFP contributions of both industry and services are large. Industry's weighted TFP contribution co-moves most closely with the total weighted TFP contribution of sectors throughout the sample period, but especially during the great recession and recovery years 2008–2010. Both industry and services have lower weighted TFP contributions, on average, after the 1980s than during the 1980s. The weighted TFP contribution of industry declines sharply after 1989, and those of agriculture and services decline after 1990; the total weighted TFP contribution of sectors clearly declines after 1990, as figure 9a showed.

Figure 9c shows that the residual contributions of the industrial and services sectors are strongly inversely correlated, as one might expect. The residual contribution of agriculture is, like its weighted TFP contribution, small and it is roughly zero in last few years of the sample. By contrast, while the residual contributions of the industrial and service sectors are typically smaller in magnitude than each sector's weighted TFP contribution to aggregate TFP growth, they are not trivial. While the total residual contribution to aggregate TFP factor growth is small, because sectoral residual contributions are not independent and offset each other, each sector's residual contribution is not necessarily small as a portion of its total contribution to aggregate TFP factor growth.

The three panels of figure 10 show the decomposition of each *sector's* total contribution to aggregate TFP growth into its weighted TFP and residual components, where the sum of the weighted TFP factor and residual contribution for sector *i*, $CTFPF_i$, is not shown but the weighted TFP and residual contributions are instead plotted against aggregate TFP factor growth. Figure 10a shows that agriculture's direct and residual contributions, and hence its total contribution, to aggregate TFP factor growth are small. Agriculture's residual contribution marginally raises its total contribution to aggregate TFP growth, on average, until the last decade of the sample. Figure 10b shows that industry's weighted TFP contribution and its residual contribution frequently co-move inversely, but its residual contribution is insufficiently large to offset its weighted TFP contribution; its direct TFP contribution is partially offset by residual factors. By contrast, services' weighted TFP contribution appears to positively co-move with its residual contribution in general, so the sector's residual effects exacerbate its direct TFP factor contribution. In contrast to those of the industrial sector, services' weighted TFP factor and residual contributions appear to become less important for aggregate TFP factor growth towards the end of the sample.

In table 11, I show the decennial accounting for aggregate TFP factor growth by sector, and by weighted TFP and residual contributions. The first column of the table replicates the total weighted TFP growth and residual contributions of sectors presented in table 10. Comparing the first two rows of numbers in the table, the large slowdown in aggregate TFP factor growth in the 1990s, relative to the 1980s, is attributable to two main factors. First, by far the most important factor is a large decline in the weighted TFP contribution of the industrial sector, as figures 9b and 10b also show. This largely reflects the decline in actual TFP factor growth in the sector, seen in Table 8. The decline in industrial sector TFP factor growth has a substantive impact because industry represented a relatively large share in economic activity on average during the 1980s and 1990s. There is also a substantive, but much smaller, decline in agriculture's direct TFP contribution; this reflects a large negative sectoral TFP growth rate in the 1990s weighted by agriculture's small shares of value added and primary production factors. The second most important factor for the decline in measured aggregate TFP growth is a substantial decline in the service sector *residual*. This also substantially depressed the total residual contribution of sectors to aggregate TFP growth, reducing it by 0.2 percentage points per year in the 1990s relative to the 1980s. The negative residual effect of services for aggregate TFP growth in the 1990s is also evident in figures 9c and 10c.

By contrast, the substantial decline in aggregate TFP factor growth in the 2000s relative to the 1990s was mainly attributable to a large fall in the service sector's weighted TFP contribution, reflecting a large fall in services' TFP factor growth, seen in table 8. This, because services represented a large share of economic activity, had a substantial impact on the total weighted TFP factor contribution of sectors. The dominance of this factor in driving aggregate TFP growth in the 2000s is suggested by figures 9b and 10c, although the industrial sector's weighted TFP contribution declined more sharply than that of services in the great recession years 2008 and 2009. Notably, had the service sector residual not increased significantly, the sector's own TFP growth slowdown would have had an even greater negative impact for aggregate TFP growth. In the 2000s, industry experienced a relatively small decline in average TFP factor growth, and in its weighted TFP factor and residual contributions to aggregate TFP factor growth. On average, the contributions of industry were quite stable in the 2000s relative to the 1990s; notably, there was no recovery in industrial TFP factor growth or aggregate TFP factor contributions whatsoever. Agriculture's total contribution declined further, relative to the 1990s, and the decline is due to contraction in its residual contribution. However, the total residual contribution of sectors for aggregate TFP growth increased in the 2000s relative to the 1990s, with recovery of the service sector residual contribution.

In the 2010s, a modest increase in aggregate TFP factor growth was attributable to modestly higher weighted TFP contributions of all three sectors, although the largest rise was in the industrial sector, which is evident in figures 9b and 10b. A negative service sector residual contribution reduced the total contribution of the sector and produced a negative total residual contribution of sectors to aggregate TFP factor growth, somewhat offsetting the improvement due to faster sectoral TFP growth. Finally, the last rows of data in the table reveal that on average over the full sample period services contributed marginally more to aggregate TFP growth than industry *only* due to services' larger residual effect. Average TFP growth in industry was much higher, as seen in table 8, and contributed a larger weighted TFP contribution to aggregate TFP growth.

Figure 11a displays the total residual contribution to aggregate TFP factor growth, and its decomposition into the three residual factors summed over sectors. The figure shows that by far the most important source of annual fluctuations in the residual contribution to aggregate TFP growth is relative value-added price effects. In addition, there is a significant depressing effect for aggregate TFP growth of value-added reallocation in the 1990s. In figures 11b through 11d, I display each of the three residual effects respectively, broken down by sector.

Figure 11b shows the relative price contributions to the residual by sector. The relative price contribution of agriculture is very small, and positively co-moves with that of industry, if weakly. The relative price contributions of industry and services are larger and co-move inversely. For much of the sample, the relative price contribution of services is positive and that of industry negative; the price of services was typically rising relative to that of industry from the late-1980s until after the great recession. On average, the relative price effect of agriculture is zero. More generally, the total effect of relative price movements for the residual contribution to aggregate TFP growth is largely positive in the 1980s, negative in the 1990s, and roughly zero thereafter.

Capital income share adjustments by sector are illustrated in figure 11c and are very small; notice the different vertical axis scale relative to the other panels of figure 11. The contributions to the capital income share adjustment of industry and services are tiny, since the capital income shares of these two sectors are close to the economy-wide capital income share. Agriculture accounts for almost all capital income share adjustments in the residual, as agriculture has a much larger capital income share than the economy-wide share. The sign of the capital income adjustment, therefore, depends on whether the capital-output ratio in agriculture increased or decreased during a given year.

Value added reallocation effects by sector are in figure 11d. The reallocation effects of industry and services exhibit a strong inverse co-movement with opposite signs. The reallocation effect of services for the residual was largely negative until the 2010s and quantitatively dominated the largely positive reallocation effect of industry over the same period. As value added was reallocated into services and out of industry, this increased the impact for aggregate capital-deepening of capital deepening in the service sector and diminished that of industry. Consequently, services' weighted TFP contribution is "overstated", and that of industry "understated", relative to the two sectors' respective total contributions to aggregate TFP factor growth. Negative service sector and positive industrial sector value-added reallocation effects in the residual reflect this. The role of agriculture for the reallocation residual is trivial.

Table 12 quantifies sectoral contributions to aggregate TFP factor growth via residual sources in a decennial sectoral accounting of the aggregate residual contribution. The table clearly shows that a declining, but positive, relative price effect, and a more negative value-added reallocation effect, are jointly responsible for services' negative residual in the 1990s, reducing the sector's total and residual contributions to aggregate TFP growth. At the same time, industry exhibited a large negative relative price effect in the 1990s and a positive value-added reallocation effect. More generally, the table shows that in each decade until the 2010s, services' negative value-added reallocation effect quantitatively dominated industry's positive effect. In the 1990s and 2000s, the industrial and service sector value-added reallocation effects for within-sector residual contributions were muted by offsetting relative price effects. All residual effects were much smaller in the 2010s. The residual effects of agriculture were quantitatively small except for the positive capital-income share effect in the 1990s, which resulted in a non-trivial positive total residual contribution to aggregate TFP growth of the sector. Agriculture is also the most important source of the negative total residual effect in the 2010s through a negative capital income share contribution; all other residual contributions were small.

4. Model

In this and the following three sections, I develop a simple three-sector growth model, describe its calibration, and evaluate its ability to replicate the facts recorded in sections 2 and 3, respectively. I briefly present the model economy in this section and document some analytical properties of its equilibrium.

I consider a three-sector neoclassical growth model, in which time is discrete and indexed by *t*, and the length of *t* is one year. The three sectors, indexed by *j*, are agriculture (*a*), industrial (*m*), and services (*s*). Perfectly competitive firms produce the value added of each industry using capital and labor services, which are mobile across sectors. Factor markets are also perfectly competitive. In addition, a representative household derives utility from consuming a composite of the three sectors' value added and leisure, supplies labor and capital services to firms, and saves by investing in new physical capital.

4.1 Production

Sector *j* produces value added using the Cobb-Douglas production function

$$v_{j,t} = \Delta_{j,v} A_{j,t} \left(k_{j,t}\right)^{\alpha_j} \left(n_{j,t}\right)^{1-\alpha_j}, \forall j. \tag{13}$$

Here, $k_{j,t}$ and $n_{j,t}$ are capital and labor services employed in sector *j* at date *t*, α_j is capital's share of value added in sector *j*, $A_{j,t} \equiv \Gamma_{j,t} \gamma^{t(1-\alpha_j)}$ is total factor productivity in industry *j*, and $\Delta_{j,v}$ is a constant scaling factor to facilitate calibration. Value added has price (and unit cost) $p_{j,t}$. TFP is one of three exogenous sources of variation in the model, and evolves according to

$$\frac{A_{j,t+1}}{A_{j,t}} = \frac{\Gamma_{j,t+1}}{\Gamma_{j,t}}\gamma^{t(1-\alpha_j)} = 1 + \sigma_{A,j,t}\,, \forall t, j.$$

As I assumed in the empirical work above, on a balanced growth path, the TFP of sector *j* grows at the constant growth rate $\frac{\Gamma_{j0}}{\Gamma_{j0}}\gamma^{(1-\alpha_j)} = \gamma^{(1-\alpha_j)} = 1 + \sigma_{A,j}$, and its TFP factor, $A_{j,t}{}^{1/(1-\alpha_j)}$, at the constant, economy wide TFP factor growth rate $\gamma = (1 + \sigma_{A,j}\,)^{1/(1-\alpha_j)}$.

The firm's profit maximization problem is

$$\max_{\{k_{j,t}\,,n_{j,t}\}}\left(p_{j,t}\,v_{j,t} \;- r_t\,k_{j,t} \;- w_t\,n_{j,t}\,\right). \tag{14}$$

In (14), r_t and w_t are the competitively determined rental and wage rates, respectively.

4.2 Households

There are four sources of demand for the value added of sectors: Private consumption of households, private household investment, government consumption, and exogenous foreign demand–net exports. The determination of the net exports of a sector is not modeled explicitly and in the calibrated model net exports by sector is a source of exogenous variation.

4.2.1 Household consumption and investment

The household has N_t identical members at every date. Each member is endowed with one unit of productive time to be allocated between hours worked and leisure. The number of household members, and hence the total productive time endowment, grows exogenously. Specifically, the working population (all household members are assumed to allocate time between hours worked and leisure) evolves according to

$$\frac{N_{t+1}}{N_t} = \left(1 + \sigma_{N,t}\right), \forall t.$$

Working population growth is a third source of exogenous variation in the model. On a balanced growth path, the working population grows at the constant rate $\frac{N_{t+1}}{N_t} = (1 + \sigma_N) = n, \forall t.$ Total hours worked by the household at date *t* is n_t, and total household leisure is $l_t = N_t - n_t$. The household is also endowed with the initial physical capital stock, $k_0 > 0$, at date 0 and supplies this in-elastically to date-0 production. Capital accumulates with final investment by households, X_t, according to the law of motion

$$k_{t+1} = (1 - \delta)k_t + X_t. \tag{15}$$

Here, δ is the depreciation rate.

The final investment good purchased by households is produced by perfectly competitive firms. A representative investment firm aggregates purchases of sector *j* value added, $x_{j,t}$, to produce the final investment good that is purchased by households,

$$X_t = \Delta_x \left(\sum_{j=a,m,s} {\omega_{x,j}}^{1/\vartheta} \left(x_{j,t}\right)^{1-1/\vartheta}\right)^{\vartheta/(\vartheta-1)}. \tag{16}$$

Here, $\omega_{x,j}$ governs the share of industry *j* output in investment, $\vartheta > 0$ is the elasticity of substitution between investment purchases from different industries, and Δ_x is a constant scaling factor facilitating calibration. The price of the final investment good is the CES index $P_{x,t}$. The firm maximizes profits subject to the production function (16), and taking as given the price index $P_{x,t}$, and input prices $p_{j,t}$,

$$max\, P_{x,t}X_t - \sum_j p_{j,t}x_{j,t}. \tag{17}$$

The household maximizes lifetime utility by choice of per working age person consumption of a composite good and leisure at each date,

$$u(C,l) = \sum_{t=0}^{\infty} \beta^t U\left(\left(\frac{C_t}{N_t}\right), \left(1 - \frac{n_t}{N_t}\right)\right) N_t, \tag{18}$$

where $0 < \beta < 1$ is the discount factor. I assume that the period utility function, $U\left(\left(\frac{C_t}{N_t}\right), \left(1 - \frac{n_t}{N_t}\right)\right)$, in (18) takes the nested, constant elasticity of substitution (CES) form,

$$U\left(\left(\frac{C_t}{N_t}\right), \left(1 - \frac{n_t}{N_t}\right)\right) = \frac{\left(\left(\frac{C_t}{N_t}\right)^{\phi} \nu \left(1 - \frac{n_t}{N_t}\right)^{1-\phi}\right)^{\rho} - 1}{\rho}, \tag{19a}$$

where $\rho \geq 0$, the intertemporal elasticity of substitution satisfies, $\sigma = \frac{1}{1-\rho} \geq 0.$ In the benchmark calibrated model economy, I assume that $\rho = 0$ (the inter-temporal elasticity of substitution $\sigma = 1$), and that ν is a constant function equal to one, so that

$$U\left(\left(\frac{C_t}{N_t}\right), \left(1 - \frac{n_t}{N_t}\right)\right) = \phi\, ln\left(\frac{C_t}{N_t}\right) + (1-\phi)\ln\left(1 - \frac{n_t}{N_t}\right). \tag{19b}$$

In extensions of the benchmark economy, I explore two alternative specifications consistent with (18). In one, I allow ρ to deviate from 0 to permit a different (higher) intertemporal elasticity of substitution while ν is equal to one. In a second variant, I maintain an intertemporal elasticity of unity but allow ν to be a function permitting the elasticity of labor supply to deviate substantially from unity, so that the period utility function takes the form,

$$U\left(\left(\frac{C_t}{N_t}\right), \left(1-\frac{n_t}{N_t}\right)\right) = \phi\, ln\left(\frac{C_t}{N_t}\right) + (1-\phi)\frac{\left(1-\frac{n_t}{N_t}\right)^{1-\theta}-1}{1-\theta}. \qquad (19c)$$

Here $1/\theta$ is the Frisch elasticity of labor supply. The utility functions in equations (19a), (19b), and (19c) are consistent with a balanced growth path, when the working age population grows at a constant rate, $\sigma_{N,t} = \sigma_N$, sectoral TFP factors all grow at the common constant rate γ, hours worked per working age person are constant, and consumption per working age person and the wage grow at the same rate as sectoral TFP factors.

In all specifications of the period utility function, C_t is a CES composite over household consumption of industry *j* output at date *t*, $c_{j,t}$, $j = a, m, s$, given by

$$C_t = \Delta_c \left(\sum_{j=a,m,s} \omega_{c,j}{}^{\frac{1}{\varepsilon}}\left(c_{j,t} - \bar{c}_j\right)^{1-\frac{1}{\varepsilon}}\right)^{\frac{\varepsilon}{\varepsilon-1}}. \qquad (20)$$

In this composite, $\omega_{c,j}$ governs the weight on the *j*th sector's value added, $\bar{c}_j > 0$ (< 0) is a required subsistence level of consumption (non-market endowment) of good *j* which allows the income elasticity of consumption demand to differ (from one) over the value added of different sectors, $\varepsilon > 0$ governs (is) the elasticity of substitution between different consumer goods and services (when $\bar{c}_j = 0 \forall j$), and Δ_c is a scaling parameter. The CES price index for final household consumption C_t is $P_{c,t}$.

Household maximization of (18) by choice of consumption, hours worked, and tomorrow's capital stock is subject to (15), (19a), (19b), or (19c), (20), non-negativity constraints on consumption, hours worked, and capital, and the sequence of budget constraints

$$\sum_j p_{j,t} c_{j,t} + P_{x,t} X_t + NX_t \leq (r_t - \delta)(1 - \tau_k) k_t + w_t n_t + T_t. \qquad (21)$$

In (21), τ_k is a constant capital income tax rate, which implies realistic real interest rates in the calibrated model, and T_t is a time-varying a lump sum government transfer which balances the government's budget constraint as I describe next. In addition, NX_t represents the numeraire value of total net exports, the determination of which I do not explicitly model; net exports are exogenously determined foreign savings.

4.2.2 Government consumption

The government consumes the value added of each sector, spending a total amount equal to an exogenously determined fraction of aggregate value added denoted $\bar{g}_t$. To meet its required consumption, the government purchases sector *j* value added, $g_{j,t}$, and aggregates its purchases across sectors to produce the government consumption composite,

$$G_t = \Delta_g \left(\sum_{j=a,m,s} \omega_{g,j}^{1/\varepsilon} \left(g_{j,t}\right)^{1-1/\varepsilon}\right)^{\varepsilon/(\varepsilon-1)}. \tag{22}$$

Here $\omega_{g,j}$ governs the share of industry j final government consumption in the composite, ε is the elasticity of substitution between types of final consumption good, Δ_g is a scaling parameter, and the price of G_t is a CES index $P_{g,t}$. The government's problem is to choose non-negative $g_{j,t}$, $j = a, m, s$, to maximize (22), subject to the required expenditure constraint $\sum_{j=a,m,s} p_{j,t}\, g_{j,t} = \bar{g}_t Y_t$, where

$$Y_t = \sum_{j=a,m,s} p_{j,t} v_{j,t}, \tag{23}$$

is aggregate value added, and subject to a budget constraint that its consumption expenditure, $P_{g,t}G_t$, is no greater than its capital income tax revenue net of lump sum transfers to households.

The budget constraints of the government and household combined with firms' profit maximization problems yield the national budget constraint,

$$P_{c,t}C_t + P_{x,t}X_t + P_{g,t}G_t + NX_t \leq \sum_{j=a,m,s} p_{j.t} v_{j,t}. \tag{24a}$$

Household expenditure on consumption and investment must satisfy the constraint,

$$P_{c,t}C_t + P_{x,t}X_t \leq (1 - \bar{g}_t)Y_t - NX_t. \tag{24b}$$

4.3 Feasibility

At each date t, the resource constraint for sector j is

$$v_{j,t} \geq c_{j,t} + x_{j,t} + g_{j,t} + nx_{j,t}, \forall j, t, \tag{25a}$$

where $nx_{j,t}$ is an exogenous net foreign demand for sector j value added, and $\sum_j p_{j,t} nx_{j,t} = NX_t$. In addition, feasibility for capital services at date t requires

$$\sum_{j=a,m,s} k_{j,t} \leq k_t, \tag{25b}$$

and feasibility for labor services at date t requires that

$$\sum_{j=a,m,s} n_{j,t} \leq n_t. \tag{25c}$$

4.4 Equilibrium

An equilibrium is sequences of prices, allocations for households and governments, and production plans for firms, given exogenous a) sectoral TFP sequences, b) working population sequence, c) constant capital income tax rate, d) government expenditure fraction of aggregate value added, and e) net exports by sector and aggregate net exports, such that: (1) household consumption expenditures by sector, aggregate investment purchases, and hours worked solve the household's utility maximization problem; (2) the production plan and labor and capital purchases for sector j solves the representative sector j firm's profit maximization problem; (3) investment input purchases solve the profit maximization problem of the representative investment firm; (4) government policies satisfy its consumption expenditure requirement and budget constraint; and (5) the sector *j* value added market, the economy-wide market for capital services, and the economy-wide market for labor services clear (hence the resource constraints (25a) through (25c) bind).

4.5 Analysis

4.5.1 Sectoral allocations and structural change

The unit cost of value added of sector *j* confronted by purchasers of its value added is

$$p_{j,t} = {A_{j,t}}^{-1}{\alpha_j}^{-\alpha_j}\left(1-\alpha_j\right)^{-\left(1-\alpha_j\right)}(r_t)^{\alpha_j}(w_t)^{(1-\alpha_j)}. \tag{26}$$

On a balanced growth path, the wage and TFP factor of sector *j* grow at the same rate, $\gamma,$ and the rental rate on capital is constant, so that the relative price of the sector's value added is constant. Notice that the relative price of value added across sectors depends on sectoral capital shares, and hence rental and wage rates appear in relative prices, in addition to relative sectoral TFPs. However, relative prices depend inversely on relative TFPs in a manner identical to that in a model with homogenous capital income shares across sectors.

From the first order conditions for profit maximization by firms, the relative expenditure and expenditure shares of capital and labor in sector *j* are

$$\frac{r_t k_{j,t}}{w_t n_{j,t}} = \left(\frac{\alpha_j}{1-\alpha_j}\right), \quad \frac{r_t k_{j,t}}{p_{j,t} v_{j,t}} = \alpha_j \ , \quad \frac{w_t n_{j,t}}{p_{j,t} v_{j,t}} \ = \left(1-\alpha_j\right),$$

implying sector *j* factor demand functions

$$k_{j,t} = \alpha_j \frac{p_{j,v,t}}{r_t} v_{j,t}, \quad n_{j,t} = \left(1-\alpha_j\right)\frac{p_{j,t}}{w_t} v_{j,t}. \tag{27}$$

Similarly, optimal household relative consumption expenditure, and consumption expenditure shares for sector *j* value added are

$$\frac{p_{j,t}(c_{j,t}-\bar{c}_j)}{p_{j',t}(c_{j',t}-\bar{c}_{j'})} = \left(\frac{\omega_{c,j}}{\omega_{c,j'}}\right)\left(\frac{p_{j',t}}{p_{j,t}}\right)^{\varepsilon-1}, \qquad \frac{p_{j,t}(c_{j,t}-\bar{c}_j)}{P_{c,t}C_t} = \omega_{c,j}\left(\frac{P_{c,t}}{p_{j,t}}\right)^{\varepsilon-1},$$

implying household demand function for sector *j* value added

$$c_{j,t} = \omega_{c,j}\left(\frac{p_{j,t}}{P_{c,t}}\right)^{-\varepsilon} C_t + \bar{c}_j, \tag{28}$$

where $P_{c,t} = \Delta_c^{-1}\left(\sum_{j=a,m,s}\omega_{c,j}\left(p_{j,t}\right)^{1-\varepsilon}\right)^{\frac{1}{1-\varepsilon}}$. Analogously, optimal government relative consumption expenditure, and expenditure shares for type *j* value added are,

$$\frac{p_{j,t}g_{j,t}}{p_{j',t}g_{j',t}} = \left(\frac{\omega_{g,j}}{\omega_{g,j'}}\right)\left(\frac{p_{j',t}}{p_{j,t}}\right)^{\varepsilon-1}, \qquad \frac{p_{j,t}g_{j,t}}{P_{g,t}G_t} = \omega_{g,j}\left(\frac{P_{g,t}}{p_{j,t}}\right)^{\varepsilon-1} \quad ,$$

implying government demand function for sector *j* value added

$$g_{j,t} = \omega_{g,j} \left(\frac{p_{j,t}}{P_{g,t}}\right)^{-\varepsilon} G_t, \tag{29}$$

with price index $P_{g,t} = \Delta_g^{-1} \left(\sum_{j=a,m,s} \omega_{g,j} \left(p_{j,t}\right)^{1-\varepsilon}\right)^{\frac{1}{1-\varepsilon}}$. Finally, optimal relative investment expenditure, and expenditure shares for sector *j* value added are,

$$\frac{p_{j,t}x_{j,t}}{p_{j',t}x_{j',t}} = \left(\frac{\omega_{x,j}}{\omega_{x,j'}}\right)\left(\frac{p_{j',t}}{p_{j,t}}\right)^{\vartheta-1}, \qquad \frac{p_{j,t}x_{j,t}}{P_{x,t}X_t} = \omega_{x,j}\left(\frac{P_{x,t}}{p_{j,t}}\right)^{\vartheta-1},$$

Implying investment firm demand for sector *j* value added

$$x_{j,t} = \omega_{x,j} \left(\frac{p_{j,t}}{P_{x,t}}\right)^{-\vartheta} X_t, \tag{30}$$

with price index $P_{x,t} = \Delta_x^{-1} \left(\sum_{j=a,m,s} \omega_{x,j} \left(p_{j,t}\right)^{1-\vartheta}\right)^{\frac{1}{1-\vartheta}}$.

Using the optimal demand functions, (28) through (30), the market clearing condition for sector *j* is

$$v_{j,t} = \left(\omega_{c,j}\left(\frac{P_{c,t}}{p_{j,t}}\right)^{\varepsilon} C_t + \bar{c}_j + \omega_{g,j}\left(\frac{P_{g,t}}{p_{j,t}}\right)^{\varepsilon} G_t + \omega_{x,j}\left(\frac{P_{x,t}}{p_{j,t}}\right)^{\vartheta} X_t\right) + nx_{j,t}. \tag{31}$$

Then the value-added share of sector *j* can be expressed, using the right-hand side of (31), as

$$\frac{p_{j,t}v_{j,t}}{VA_t} = \frac{\left(\omega_{c,j}\left(\frac{P_{c,t}}{p_{j,t}}\right)^{\varepsilon-1} P_{c,t}C_t + p_{j,t}\bar{c}_j + \omega_{g,j}\left(\frac{P_{g,t}}{p_{j,t}}\right)^{\varepsilon-1} P_{g,t}G_t + \omega_{x,j}\left(\frac{P_{x,t}}{p_{j,t}}\right)^{\vartheta-1} P_{x,t}X_t\right)}{\sum_{j'} p_{j',t}v_{j',t}}, \tag{32}$$

where aggregate value added is,

$$VA_t = \sum_j p_{j,t}v_{j,t}. \tag{33}$$

Using the demand function for employment in sector *j* from (27), the relative demand for labor in sector *j* and sector *j'*, and sector *j*'s share of employment are

$$\frac{n_{j,t}}{n_{j',t}} = \frac{(1-\alpha_j)p_{j,t}v_{j,t}}{(1-\alpha_{j'})p_{j',t}v_{j',t}}, \qquad \frac{n_{j,t}}{\sum_{j'=a,m,s} n_{j',t}} = \frac{(1-\alpha_j)p_{j,t}v_{j,t}}{\sum_{j'=a,m,s}\left(1-\alpha_{j'}\right)p_{j',t}v_{j',t}}.$$

Substituting from the solutions for value added prices and demands, we have the equilibrium employment share of sector *j* as

$$\frac{n_{j,t}}{N_t} = \frac{(1-\alpha_j)\left(\omega_{c,j}\left(\frac{P_{c,t}}{p_{j,t}}\right)^{\varepsilon-1} P_{c,t}C_t + p_{j,t}\overline{c_j} \quad \omega_{g,j}\left(\frac{P_{g,t}}{p_{j,t}}\right)^{\varepsilon-1} P_{g,t}G_t + \omega_{x,j}\left(\frac{P_{x,t}}{p_{j,t}}\right)^{\vartheta-1} P_{x,t}X_t\right)}{\sum_{j'=a,m,s}\left(1-\alpha_{j'}\right)p_{j',t}v_{j',t}}. \quad (34)$$

The value added and employment share of sector *j* in (32) and (34) deviate due to capital intensity differences across sectors. If capital's share of income were common to sectors, the employment and value-added shares of a sector would be equal. Evidently, structural change in employment and value-added shares of sectors–secular change–results from a) persistent productivity growth differentials which affect relative prices, $p_{j,t}$, as seen in (26); b) aggregate income (value added) growth which reduces the role of the constant non-homothetic term, $\bar{c}_j$; and c) as long as $\omega_{c,j} \neq \omega_{x,j}$, changes in anticipated income growth which alter the household's optimal intertemporal allocation of consumption and labor supply.

Note that when $\varepsilon = \vartheta = 0$, which is the case in the benchmark calibrated economy, the demand functions and associated price indexes take Leontief forms that can be derived directly from the foregoing solutions. For example, in the case of household consumption, at an optimum demand functions, price index, and optimal consumption index are

$$c_{j,t} - \bar{c}_j = \frac{\omega_{c,j}P_{c,t}C_t}{\sum_j \omega_{c,j}p_{j,t}} = w_jC_t, \quad (35a)$$

$$P_{c,t} = \sum_j \omega_{c,j}p_{j,t}, \quad (35b)$$

$$C_t = \frac{c_{j,t} - \bar{c}_j}{\omega_{c,j}}, \forall j. \quad (35c)$$

Analogous results hold for investment and government consumption. In this case, (changes in) relative prices are irrelevant for structural change. However, income growth, and changes in anticipated income growth, will nonetheless impact sectoral allocations through income effects attributable to non-homothetic preferences and inter-temporal substitution.

4.5.2 Optimal aggregate household allocations and aggregate metrics

The intra-temporal optimality condition for per capita household leisure is simply,

$$\frac{l_t}{N_t} = 1 - \frac{n_t}{N_t} = \left(\frac{1-\psi}{\psi}\right)\left(\frac{P_{c,t}C_t}{w_tN_t}\right). \quad (36)$$

In the case of an intertemporal elasticity of substitution equal to 1, the Euler equation is simply

$$\frac{\beta P_{c,t}C_t/N_t}{P_{c,t+1}C_{t+1}/N_{t+1}} = \frac{P_{x,t}}{(1-\delta(1-\tau_{rk}))P_{x,t+1} + r_{t+1}(1-\tau_{rk})}. \quad (37a)$$

More generally, optimal inter-temporal allocations are dictated by the condition,

$$\left(\frac{\beta P_{c,t}C_t/N_t}{P_{c,t+1}C_{t+1}/N_{t+1}}\right)\left(\left(\frac{C_{t+1}/N_{t+1}}{C_t/N_t}\right)^{\psi}\left(\frac{l_{t+1}/N_{t+1}}{l_t/N_t}\right)^{1-\psi}\right)^{\rho} = \frac{P_{x,t}}{(1-\delta(1-\tau_{rk}))P_{x,t+1}+r_{t+1}(1-\tau_{rk})}. (37b)$$

Finally, I define the aggregate capital stock as simply the sum of capital stocks across sectors,

$$k_t = \sum_j k_{j,t}.$$

Physical capital is not traded in the model, and so there is no model-based market price estimate. However, capital services are exchanged among households and firms in factor markets, and with perfect capital mobility across sectors command a common rental price in all *j* sectors. Clearly, capital shares in the model do not, therefore, correspond exactly to nominal capital shares in the data. In the model, labor services are traded at a unique wage rate, and so total hours worked are measured by the simple sum across sectors of hours worked within each sector,

$$n_t = \sum_j n_{j,t}.$$

Hours' shares in the model do correspond to hours shares in the data (although labor compensation shares would not do so). I define aggregate TFP using model-based estimates of aggregate variables as

$$A_t = \frac{GDP_t}{{k_t}^{\alpha}{n_t}^{1-\alpha}},$$

using the same economy-wide capital income share (0.362) as I apply in my empirical analysis (and which is therefore consistent with the sectoral capital income shares estimated in the data). I compute real GDP in this case as a Laspeyres chain of the real value added of the three sectors, using sectoral prices in (26). This is more consistent with the measure of real GDP in the data than is aggregate value added, VA_t, in equation (33) in the model. However, it is worth noting that–in either case–the numeraire for sectoral value-added prices in the model and the numeraire for sectoral value-added prices in the data obviously differ. I discuss the measurement of these objects in more detail in the calibration section below, and in the data appendix.

4.6 Computing equilibrium

For given initial conditions, if a) policy variables converge to constant values, b) the growth rates of the total household time endowment (population) and sectoral TFP converge to constants, with equal TFP growth rates across sectors, c) the consumption function parameters $\bar{c}_j, \forall j$ converge to zero, and d) net exports in each sector converge to constants, the economy converges to a unique balanced growth path. The balanced growth path features growth in value added and capital per working age person within each sector equal to the common TFP factor growth rate, constant prices of sectoral value added and a constant rental rate of capital, and constant sectoral allocations (no structural change). At the aggregate, household level, "nominal consumption", investment, and government consumption all grow at the same constant rate as aggregate value added, and the relative price of the aggregate investment good is constant. I compute the model's transition to this steady state, calibrating the model's parameters to match Japan's 1980 national accounts and sectoral value-added shares, and inputting data on each of the exogenous variables from 1981 through 2018. I assume that the economy converges to its balanced growth path by 2080.

5. Calibration

The calibration comprises three parts:

1. I calibrate the sector level ("static") parameters of technologies and preferences such that the 1980 JSNA and OECD STAN sectoral data replicate an equilibrium of the model; 1980 is the "base" year. In the base year, all value-added prices are set equal to one. The numeraire–which I assume, in the model economy, is the aggregate investment good at date *t*, X_t–for prices in the simulations is therefore 1980 Yen. That is, the price of one unit of the investment good at any date equals one 1980 Yen. I also normalize all 1980 equilibrium allocations relative to 1980 (nominal and real) GDP in Japan, which I set equal to 100.
2. I input actual measured time-series of sectoral TFP growth rates (derived from the sectoral growth accounting in appendix 2 and used in section 3), working population growth rates (taken from the United Nations Population dataset used in sections 2 and 3), government consumption as a fraction of GDP, and net exports by sector.
3. I take from the extant literature independent estimates for aggregate parameters where possible, and elasticities.

Parameter values and their sources and/or targets are presented in table 13.

5.1 Production and technology

5.1.1 Industry Classification

I use OECD STAN and JSNA data to calibrate the model and measure TFP by sector. I follow the OECD classification of the three major sectors of economic activity, also utilized in the empirical analysis, in calibrating the model. I describe this classification in the data appendix.

5.1.2 Capital income shares, initial capital stocks, and capital depreciation rate

I compute the capital income share for sector *j* in Japan as follows. First, as in my empirical analysis, I assume Hayashi and Prescott's estimate of Japan's aggregate capital income share, $\alpha = 0.362.$ I then multiply the implied aggregate labor income share, $1-\alpha$, by the 1980 JSNA national accounts data value of nominal GDP to calculate an adjusted estimate of aggregate compensation of employees in the 1980 Japanese economy. I then compute the 1980 share of aggregate compensation of employees that each of the three industries in the model accounts for using OECD STAN sectoral compensation data. I multiply each sector's share of total compensation calculated from the STAN data by the adjusted aggregate compensation measure to produce GDP and aggregate capital income share consistent sectoral labor compensation values for 1980. I compute 1980 capital payments of sector *j* in a similar manner, as sector *j*'s share of αGDP_{1980}. Specifically, I compute sector *j*'s share of aggregate capital payments as sector *j* value added (specifically, the GDP-consistent, adjusted values that I calculated for the empirical analysis) less the sector *j* GDP-consistent measure of the compensation of employees computed above. Finally, each sector's labor income share is just its adjusted employee compensation value divided by the sum of its adjusted employee compensation value and adjusted capital payments.

To estimate the 1980 capital stock, I use the 1980 capital-output ratio from the data employed in section 2 and multiply it by 100 (1980 GDP). The depreciation rate is then calibrated as the ratio of 1980 capital consumption expenditure from the JNSA to the 1980 capital stock. The 1981 capital stock–which is an initial condition for the simulations starting in 1981– is estimated as the undepreciated portion of the 1980 capital stock, using the calibrated value of the depreciation rate, plus the value of 1980 investment expenditure net of inventory accumulation from JNSA.

5.1.3 Initial TFP levels and value-added scaling parameters by sector

I take initial TFP levels for each sector *j*, $A_{j,1980,}$ directly from the sectoral growth accounting data in appendix A2. They are extrapolated to subsequent years using the actual growth rates computed in the same growth accounting exercises. I then calculate the value-added production function scaling parameters for each sector *j*, $\Delta_{v,j}$, as the ratio of 1980 value added of sector *j*, adjusted so that the sum over sectors equals 1980 GDP as I describe in section 3), to the product of 1980 TFP and the 1980 capital-labor bundle for sector *j*, $\Delta_{v,j}= \frac{v_{j,1980}}{\left(A_{j,1980}k_{j,1980}^{\alpha_j}n_{j,1980}^{1-\alpha_j}\right)}$. Sector *j* capital income shares are as described in 5.1.2. Sector *j* capital services are calculated as sector *j* capital payments, and sector *j* labor services as sector *j* labor compensation, as all 1980 prices are set equal to one. Similarly, 1980 value added by sector is just taken as the (adjusted) nominal value in the data. Capital payments and labor compensation by sector are adjusted as described in 5.1.2, so that the sum over sectors of each equals the appropriate share of 1980 GDP given by the calibrated aggregate capital income share parameter

0.362. Value added, capital payments, and labor compensation of sector *j* are all normalized by 1980 GDP. Note that this implies that calibrated 1980 value added by sector is just the 1980 value added percentage of that sector.

5.1.4 TFP by sector

TFP by sector, $A_{j,t}, \forall\, j, t,$ for the years 1980 through 2018 is an exogenous input to the calibrated model. A sector's TFP is the Laspeyres chained real value added of the sector, with reference year 1980 (note that 1980 nominal, constant price, and chained value added are all equal in the calibrated model), from the OECD STAN database, divided by that sector's capital-hours bundle computed using the same income shares described in 5.1.2. The TFP of each sector and its annual growth rate is calculated in the sectoral growth accounting exercises of appendix A.2 for the period 1980 through 2018. Beyond 2018, I assume that the growth rate of each sector's TFP converges gradually such that its TFP factor grows at the sample average aggregate TFP growth rate by 2080. The sample average aggregate TFP growth rate, drawn from section 2, is 1.20 percent. (It makes little difference quantitatively, and none qualitatively, to my 1981-2018 simulation results if I let the model economy converge to a balanced growth path with a different (reasonable) long-run growth rate).

5.2 Household preference parameters

5.2.1 The discount factor

The household's discount factor, $\beta,$ is calibrated so that on a balanced growth path, with TFP factors in each sector growing at 1.2 percent, the real interest rate equals its long-run average. The World Bank estimates this average real interest rate for Japan, over a time-period which includes all years in my sample, as 2.28 percent.

5.2.2 Consumption and leisure weights, working population, and $\bar{c}_j$

The weights on consumption and leisure in the period utility function are calibrated so that in 1980 the household spends one-third of its total time endowment working. Specifically, I calibrate these parameters so that the static first order conditions represented by (36) hold at 1980 values of the aggregate consumption composite, $P_{C,1980}C_{1980}$, working population, N_{1980}, hours worked, n_{1980}, and wage rate $w_{1980} = 1$, where $N_{1980} = 3n_{1980} = 3\sum_{j=a,m,s} n_{j,1980}$.

Recall that from 5.1.3, employment by sector in 1980, $n_{j,1980}$, is calibrated as that sector's share of the aggregate compensation value of labor and normalized by 1980 GDP. The 1980 working population $N_{1980} = 3n_{1980}$ is thus also normalized by 1980 GDP and then extrapolated to all other years from 1981 to 2018 using the growth rates of the actual working age population taken from the

United Nations population estimates as in section 2. I assume that the growth rate of population and the working population is zero on the balanced growth path; from 2019 onwards, I assume the growth rate of the working population in the model economy gradually converges to zero by 2080.

There is one complicating issue for the use of (36) to calibrate ϕ; namely that the consumption composite appears in (36) and this does not equal aggregate consumption expenditure when $\bar{c}_j \neq 0$. From the first order conditions for optimal consumption allocations across sectoral value added,

$$\sum_{j=a,m,s} p_{j,t}(c_{j,t} - \overline{c_j}) = P_{c,t}C_t.$$

Then to obtain an estimate of $P_{c,1980}C_{1980}$ requires subtracting the 1980 value of $\overline{c_j}$ for all *j* from aggregate consumption expenditure in 1980, $\sum_{j=a,m,s} p_{j,1980}c_{j,1980}$ (a value which is drawn directly from the JSNA and normalized by 1980 GDP).

I calibrate the values of the non-homothetic terms $\overline{c_j}$ using estimates in Herrendorf et al. (2013). They provide estimates for $\overline{c_a}/c_{a,t}$ and $\overline{c_s}/c_{s,t}$ for 2010 and 1947. They assume, as do most in the literature, that $\overline{c_m} = 0$. I take their values for $\frac{\overline{c_j}}{c_{j,t}}, j = a, s$ for 2010 and 1947, interpolate linearly between them to find values for 1980, and multiply the 1980 estimated values by 1980 normalized (divided by 1980 GDP), value added consumption of agriculture and services calculated from the JSNA input-output tables (I describe the computation of value added consumption of each type of good below). This calculation yields estimates of $\overline{c_a}$ and $\overline{c_s}$. I then use these estimates in first order condition (36) to calculate the weights on consumption and leisure in the period utility function.

It is well known that balanced growth is inconsistent with arbitrary values of the non-homothetic utility parameters $\overline{c_a}$ and $\overline{c_s}$. Following Kehoe et al. (2018), I therefore let the values of these parameters gradually converge to zero after 2018, assuming they attain zero values by 2080.

5.3 Weights in consumption, investment, and government composites

I calibrate the weights in the household consumption and household/firm investment composites from JSNA 1980 "use table" data in the input-output section of the dataset. Because the entire value of a sector's output is value added in the model, which ignores intermediate inputs for simplicity, I follow the method proposed by Herrendorf et al. (2013) for reallocating final expenditure on the output of each sector–private and government consumption expenditure, investment, and net exports–to reflect agents' expenditure on the value added produced by that sector. Once this reallocation is accomplished, I calibrate the weights in each composite such that the demand functions, equations (28), (29), and (30), are satisfied at the estimated values of 1980 consumption, government consumption, and investment on the value added of each sector, and at 1980 prices equal to one.

Details of the value-added expenditure calculations are provided in the data appendix. To summarize, I first transform Japan's supply and use tables for 1980 by aggregating them into the three sectors consistent with the industry classifications described in 5.1.1. I then transform the supply and use tables using standard methods into a symmetric, industry-by-industry input-output table. I rake and scale the elements of the input-output table to be consistent with Japan's 1980 JSNA aggregate data on value added (GDP), household and NGO consumption expenditure, investment expenditure, government consumption expenditure and net exports. I then normalize all elements of the table by setting 1980 GDP equal to 100. Finally, I use the algorithm proposed by Herrendorf et al to compute the reallocation across sectors of each category of final expenditure– consumption, investment, etc.– to isolate spending on the value added of each sector in that expenditure category. The resulting 1980 expenditure on value added by sector and expenditure category are then used as inputs to equations (28), (29), and (30) to compute the consumption, government consumption, and investment weights on the value added of sectors in the associated CES composites. It is worth noting that the value-added expenditures algorithm preserves the value of total expenditure in each final expenditure category, and the total value added produced by each sector in 1980.

5.4 Government policies and net exports

I use total government expenditure as a fraction of GDP–computed using the nominal series in JSNA-to measure $\bar{g}_t$ at every date from 1980 through 2018. From 2019 onwards, I let the value of this fraction of GDP equal its 2018 value at every date, as the economy converges to its balanced growth path by 2080. Government spending as a fraction of GDP generally exhibits an upward trend over the sample period so the 2018 value is preferred as a balanced growth path value, rather than–for example–the much lower sample average. Notice that all government spending is "expensed" in the model; there is no government investment by assumption. The capital income tax rate, τ_k, is set equal to the 1980 value in Imrohoroglu et al. (2006).

I have already described the calibration of net exports of value added by sector for 1980, and 1980 aggregate net exports of value added which is simply equal to its 1980 final expenditure value. Both are then normalized by 1980 GDP. I estimate net exports of value added by sector for 1981 through 2018 as follows. I a) multiply the 1980 proportion that the value added exports of a sector represents of total 1980 exports by total nominal exports for each year in the sample 1981-2018; b) multiply the 1980 proportion that the value added imports of a sector represents of total 1980 imports by total nominal imports for each year in the sample from 1981-2018; c) divide the estimated nominal value added exports of each sector, and the estimated nominal imports of each sector, by a chained GDP price deflator for Japan with reference year 1980; d) scale the estimated real value of exports and imports for each sector for 1981-2018 by 1980 GDP to be consistent with model units; e) compute the value of real, scaled net exports of value added for each sector as the difference between real, scaled exports and real scaled imports. This method preserves total net exports from JSNA measured in 1980 Yen, and scaled by 1980 GDP, as the sum of estimated 1980 Yen, scaled net exports of value added across sectors.

5.5 Elasticity parameters

I set the intertemporal elasticity of substitution equal to 1. In this, I follow Herrendorf, Rogerson, and Valentinyi (2014), and not that it is consistent with the meta-analysis of Havranek et al. (2015) which shows that the mean value of the elasticity of intertemporal substitution for Japan across 109 estimates in empirical work is 0.893, with a standard deviation of 0.243. I take the household's elasticity of substitution between the value added of alternative sectors in consumption from Herrendorf, Rogerson, and Valentinyi (2013), setting it equal to 0. I assume, since there is no relative price substitution in household consumption between the value added of alternative very broad sectors of economic activity, that this is also the case for household investment and–in the absence of alternative value-added based estimates–for government consumption. That is, my benchmark model's specification of preferences follows equation (19b), with (35c) governing household consumption $C_t = \frac{c_{j,t} - \bar{c}_j}{\omega_{c,j}}, \forall j,$and $X_t = \frac{x_{j,t}}{\omega_{x,j}}, G_t = \frac{g_{j,t}}{\omega_{g,j}}$.

6. Results

6.1 Benchmark model

In the benchmark calibration of the model, where parameter values follow table 13, the exogenous sources of variation and growth are: i) The aggregate working age population, which is total hours available to the household for work and leisure; ii) sectoral TFP; iii) government spending as a share of GDP; and iv) sectoral and aggregate net exports. Here, I evaluate this model's performance in replicating Japan's economic performance from 1981 through 2018. Specifically, I evaluate the multi-sector model's performance in replicating aggregate and sectoral allocations, aggregate growth accounting facts, and sectoral contributions to aggregate TFP factor growth.

6.1.1 Aggregate and sectoral allocations

I compute aggregate value added by summing value-added price weighted output across sectors. I compute real GDP by calculating a Laspeyres chain index using the model's predicted value-added prices and outputs by sector. Output per working age person is real GDP divided by the level of the working age population calibrated as described in section 5. To compute aggregate capital and hours factors, no price-weighting is necessary in aggregating sectoral capital inputs and sectoral hours worked in the numerator, however, output in the denominator of the capital factor is calculated as the value-added price weighted sum of value added across sectors. The aggregate TFP factor is the ratio of model-implied GDP per working age person to the model-implied values of the aggregate capital and labor factors.

In the panels of figure 12, I show the benchmark model's predictions and data for i) the level and growth rate of GDP per working age person; ii) the level and growth rate of GDP per hour worked; iii) the level and growth rate of the capital factor; iv) the level and growth rate of the hours factor; and v) the aggregate TFP factor and TFP factor growth. In each figure featuring the level of a variable, I normalize the level in both model and data to equal 100 in 1980. Figure 13 shows how the model's sectoral allocation of hours compares to that in the data.

Figures 12a and 12b show that the model's ability to match the level of GDP per working age person is very good, however, it predicts somewhat too much growth in the second half of the 1990s, and too little growth in the mid-2000s and after the great recession. Figures 12c and 12d show that the model's match to the level and growth rate of GDP per hour is even closer, although it predicts excessively rapid growth in the early 1990s and at the end of the sample period. Figure 12e shows that the model predicts systematically somewhat too high a level of the capital-factor due to a counterfactually high growth rate of the capital factor in the first half of the 1980s and the early 1990s, and a capital factor that is counterfactually volatile throughout the sample period. Figures 12g and 12h show that the model predicts a level of the hours factor that is on average very close to that in the data until just prior to the great recession and the following years; the model implies that hours worked per working age person should have fallen by much more prior to and during the great recession, and in the aftermath of the 2011 earthquake than was observed in Japan. Overall, the growth rate of the hours factor implied by the model is too low in the last decade of the sample. Finally, figures 12i and 12j show that model's match to the level and growth rate of the TFP factor is close, although it grows a little too quickly in the first couple of years in the sample, and too slowly during the great recession, and a little too quickly in the last few years of the sample. Since actual sectoral TFP growth rates are inputs to the model, deviations of model implied aggregate TFP from measured aggregate TFP in the data are attributable to an inaccuracy of the model's match to sectoral shares of value added, capital, and hours, and to value added prices of sectors relative to the implicit deflator for aggregate GDP. The net impact of these deviations is evidently small on average, as the growth rate of the model's TFP factor is very close to that observed in the data.

Figure 13 confirms that the model's match to hours worked shares of sectors is quite close– very close for all three sectors through the mid-1990s, and very close throughout the sample period for agriculture. From the mid-1990s onwards, the model modestly but systematically underpredicts the observed share of hours worked in services and overpredicts that in industry. Given the role of household intertemporal allocations for sectoral shares of economic activity and resources, this implies that the model systematically overpredicts household investment demand (savings) and underpredicts household consumption demand from the mid-1990s onwards. This is corroborated by the counterfactually high capital factor predicted by the model. The "excess savings" generated in the model are likely the result of intertemporal substitution; during the mid-late 1990s the model predicts counterfactually high growth of GDP per household member and during the 2000s counterfactually low growth in GDP per household member.

6.1.2 Aggregate growth accounting

In Table 14, I show the model's implied decennial aggregate growth accounting for the Japanese economy in terms of the capital, labor, and TFP factors and compare its performance to the empirical growth accounting data in table 2, which are reproduced in parentheses. Looking first at the final row of numbers which present average growth rates for the entire sample period, the benchmark model's predictions for GDP per working age person and the TFP factor are close to the data. On average, and as seen in figure 12, the model predicts somewhat too little growth in the hours factor (after the mid-1990s) and too much growth in the capital factor throughout the sample period.

The decennial accounting shows that the model's decade-by-decade predictions for the TFP factor, in the second column of numbers, are close. It predicts somewhat too little TFP growth on average in the 1980s and somewhat too much TFP growth in the 2010s. The third column of numbers show that, quantitatively, the model's predictions for average capital-factor growth in each decade are not very far from but systematically higher than the data in all but the final eight years of the sample. The final column of numbers shows that the model's predictions for average hours factor growth in the 1980s and 1990s are not too far from the data (and very close in the 1980s), but that in the 2000s and 2010s the model substantially underpredicts average hours factor growth. Overall, as a result, the first column of numbers in the table shows that the model's predicted average growth of GDP per working age person is very close to the data in the 1980s, too high relative to the data in the 1990s due to counterfactually rapid capital and hours factor growth, and too low in the 2000s and 2010s due to insufficiently rapid hours factor growth.

In terms of decade-by-decade *changes* in average growth rates, notice that the model produces a significant decline in average hours factor growth in the 1990s relative to the 1980s, as seen in the data which features a mandated reduction in the length of the working week not incorporated in the model. The model's predicted decline is not quite large enough, however. Similarly, the model successfully predicts a large decline in TFP factor growth in the 1990s relative to the 1980s, but this decline is not as large as in the data. The model predicts excessively rapid capital-factor growth in the 1990s relative to the 1980s, but the magnitude of this "miss" is not great. The model's "miss" of the decline in average hours factor growth in the 2000s relative to the 1990s is large, however, the model almost perfectly matches the magnitude of increase in average hours factor growth in the 2010s relative to the 2000s. This is surprising since multiple labor market policies were in place in Japan during the 2010s (Abe's "Womenomics", for example) designed to stimulate labor supply which are not incorporated in the model. Nonetheless, the model cannot replicate the size of growth in the hours factor during either the 2000s or 2010s. Finally, the model significantly overpredicts the increase in TFP factor growth in the 2010s relative to the 2000s.

Table 15 shows that the benchmark model matches extraordinarily well the growth accounting for GDP per hour worked. This should not be surprising given that the model's greatest weakness in matching data for GDP per working age person is in failing to capture changes in the growth rate of hours per working age person. The model's prediction for average GDP per hour worked by decade, and over the entire sample, seen in the first column of numbers of table 15 is quantitatively close to the data although, because average TFP growth in the 1990s does not decline as much relative to the 1980s as in the data, the model overpredicts labor productivity growth in the 1990s. However, overall, because the model's implied TFP factor and capital factor average growth rates by decade reasonably approximate those in the data, its accounting for GDP per hour is good.

6.1.3 Sectoral accounting for GDP per working age person and growth factors

The model's performance in replicating the contributions of sectors to GDP per working age person growth, growth in the capital and hours factors, and growth in aggregate TFP is represented by figures 14a through 17b and tables 16 through 19 respectively. I measure these contributions in an exactly analogous manner as in the data. I document the model's performance in matching an empirical sectoral decomposition of GDP per hour worked in appendix A.5.

Figures 14a and 14b show that the model's accounting for the time-series of sectoral contributions to GDP per working age person growth is similar to the data although positive co-movement of different sectors' contributions in the model is closer than that observed in the data. Table 16 presents a sectoral accounting for decennial average growth rates of GDP per working age person with the empirical values shown in parentheses. The last row of numbers in the table shows that over the entire sample period, the model accurately replicates agriculture's contribution to average GDP per working age person growth, assigns a modestly greater contribution to industry, and a somewhat smaller contribution to services. The model's predictions for the contributions of all three sectors in the 1980s are remarkably accurate. The second row of numbers shows that the model over-predicts growth in GDP per working age person in the 1990s largely because it over-predicts the contribution to that growth of the industrial sector; the model fails to capture the magnitude of decline in the industrial sector's growth contribution in the 1990s relative to the 1980s. The model does a good job of matching quantitatively the (smaller) decline in services' contribution. By contrast, the model predicts too little growth in the 2000s largely because it substantially under-predicts the service sector's contribution, and the magnitude of decline in services' contribution in the 2000s relative to the 1990s. Although the model only modestly underpredicts the industrial sector's contribution to growth during the 2000s, a bigger problem is that it predicts a large decline in industry's contribution in the 2000s relative to the 1990s whereas in the data there is actually a small increase (a consequence of the model underpredicting industry's growth contribution decline in the 1990s relative to the 1980s). The model also underpredicts growth in the 2010s, largely because it understates services' contribution with a much smaller understatement of the contributions of agriculture and industry. In this case, however, the direction (positive) and magnitude of change in industry's sectoral contribution in the 2010s relative to the 2000s is proximately correct, while the model somewhat overstates the increase in services' contribution.

Figures 15a and 15b show that excess volatility of the aggregate capital factor in the model relative to the data largely reflects excess volatility of the service sector's contribution to growth in the factor. The last row of numbers in table 17 shows that the model accurately replicates the contribution of agriculture to average capital factor growth over the entire sample period but over-predicts the contributions of industry (a little) and, especially, services. In fact, the contribution of services to aggregate capital factor growth is significantly over-estimated by the model in every decade except the 2010s. By contrast, the model's predicted contribution of agriculture is quite close to the data in every decade and that of industry is close to the data in every decade except the 1990s, when the model significantly over-predicts industry's role in capital deepening. Almost all directional changes in sectoral contributions to capital deepening across decades are correct; there is a small increase in industry's contribution in the 2000s relative to the 1990s but, because industry's contribution increase in the 1990s relative to the 1980s is overstated, the model predicts a decline in industry's contribution in the 2000s. Overall, the fact that the model overstates the level of the capital factor relative to the data is largely a consequence of its counterfactually large prediction for services' contribution.

Figures 16a and 16b show that the model predicts an excessively large role for both services and the industrial sector in producing excessively volatile hours factor growth during the great recession. The last row of numbers in table 18 shows that, over the entire sample period, agriculture's contribution to the aggregate positive average hours factor growth is accurately predicted, industry's contribution a little too small, while the service sector's contribution is much too small thereby producing the model's significant under-prediction of *average* aggregate hours factor growth. In addition, the first row of numbers shows that the model's predicted sectoral contributions to average hours factor growth are quite close to those in the data for the 1980s. The model fails to match quantitatively the decline in industry's contribution to aggregate hours growth in the 1990s relative to the 1980s, although it matches quite closely the decline in the contribution of services and the small increase in the contribution of agriculture. The model's largest failure in matching sectoral contributions to within-decade aggregate hours factor growth is seen in the 2000s and 2010s when it dramatically underpredicts the contribution of services to the (relatively) large positive hours factor growth observed in both decades and, in addition, understates the magnitude of the increase in services' contribution in the 2000s relative to the 1990s and in the 2010s relative to the 2000s. Notably, the model also fails to predict an increase in industry's contribution to aggregate hours growth in the 2000s relative to the 1990s, although successfully predicts that industry's contributions are negative in the 1990s and 2000s but positive in the 2010s. Overall, the model fails to match quantitatively the observed low and declining hours growth in the 1990s due to an underprediction of the decline in industry's contribution, and the rapid aggregate hours growth in the 2000s and 2010s due largely to underprediction of services' contribution.

Figures 17a and 17b and table 19a show that the model reproduces total sectoral contributions to aggregate TFP growth remarkably well. Recall that the model's successful replication of aggregate TFP growth conditional on actual sectoral TFP growth inputs requires that its predictions for sectoral allocations and relative prices be accurate. While figures 17a and 17b show that the model's total sectoral contributions to aggregate TFP growth are excessively volatile during the great recession, this is the only period when they are noticeably so. The last row of numbers in table 19a shows that the model almost perfectly matches sectoral contributions to average aggregate TFP growth over the entire sample period. In the 1980s, the model assigns too little aggregate TFP growth contributions to all three sectors, resulting in a moderate underprediction of aggregate TFP factor growth; in the 1990s and 2000s, it assigns modestly too large of a TFP growth contribution to industry, and modestly too little to services; in the 2010s, the model assigns too little of a TFP growth contribution to industry and significantly too great of a contribution to services leading to a significant overprediction of aggregate TFP factor growth in the 2010s. Notably, the model fails to quantitatively match the decline in industry's contribution in the 1990s relative to the 1980s, capturing only about half of this.

Overall, the model's biggest "misses" of sectoral contributions to growth factors, relative to the data, are: i) overprediction of industry's contribution to aggregate hours growth in the 1990s and, specifically, underprediction of the *decline* in industry's contribution in the 1990s relative to the 1980s; ii) underprediction of the magnitude of the service sector's contribution to aggregate hours factor growth in the 2000s and 2010s and, specifically, of the increase in services' contribution in the 2000s relative to the 1990s and (to a lesser extent) in the 2010s relative to the 2000s; iii) underprediction of the decline in industry's TFP growth contribution in the 1990s; and iv) overprediction of the service sector's contribution to aggregate TFP factor growth in the 2010s. The first three factors are largely responsible for the model's overprediction of GDP per working age person growth in the 1990s and underprediction of growth in the 2000s and 2010s.

6.1.4 Decomposition of sectoral contributions to TFP growth

Figures 17c through 17n compare the model's predictions for the decomposition of aggregate TFP TFP factor growth into weighted sectoral (within) TFP factor and residual contributions, as well as the decomposition of residual contributions into those due to relative price, capital income share, and value-added reallocation sources. Tables 19b through 19d present a decennial sectoral accounting for i) aggregate TFP factor growth into total weighted TFP factor and residual contributions of sectors, ii) aggregate TFP factor growth into sectoral weighted TFP factor and residual contributions, and iii) the aggregate residual into sectoral contributions to its three sources, respectively. In each decomposition analysis I reproduce the empirical results, sometimes reformatting figures to ensure comparability with the benchmark model's predictions.

Figures 17c and 17d show that the model matches remarkably well time-series movements in the decomposition of aggregate TFP into the total weighted TFP factor and residual contributions of sectors; the former is the quantitatively dominant determinant and the latter much smaller although not trivial, especially in the 1990s. Table 19b clarifies that the model matches quite closely the total weighted TFP factor contribution of sectors to average aggregate TFP factor growth by decade. However, the model underpredicts the residual contribution of sectors in the 1980s and somewhat overpredicts this contribution in the 1990s and 2010s. Nonetheless, the last row of numbers in the table shows that the model matches well the full-sample average contributions, marginally underestimating the weighted TFP factor contribution and marginally overpredicting the residual contribution.

Figures 17e and 17f show that the model also matches the time series of weighted TFP factor contributions by sector quite well, while figures 17g and 17h show that there are several periods over which the model significantly "misses" the time-series of residual contributions by sector. Table 19c clarifies these observations. Looking first at the last row of numbers in the table, on average over the entire sample period the model matches remarkably well the decomposition into weighted TFP and residual contributions of industry. It is less accurate in matching the decomposition for agriculture and services, modestly underestimating the weighted TFP and overestimating the residual contribution of agriculture, and conversely for services. For agriculture, the decomposition is most accurate in the 1990s and 2000s. For industry, the decomposition relatively accurately measures the weighted TFP contribution in all decades, and relatively inaccurately measures industry's residual contribution, underestimating it in the 1980s and 2010s and overestimating it in the 1990s and 2000s. For services, the decomposition is most accurate in the 1990s and more accurately measures the weighted TFP than the residual contribution in all decades except the 1990s. The underprediction of services' residual contribution in the 1980s and 2000s and overprediction in the 2010s are notable. The combination of the model's underprediction of industrial and service sector residual contributions is primarily responsible for its underprediction of aggregate TFP factor growth in the 1980s. Services' residual contribution in the 2010s is a more important source of the model's overprediction of services' 2010s' total contribution to TFP factor growth than is services weighted TFP contribution, and results in the model's overprediction of 2010s aggregate TFP factor growth. Overall, residual "misses" by the model are the source of inaccuracies in the model's aggregate TFP factor growth performance.

The tendency of the model to generate relatively inaccurate predictions for the residual contributions of sectors, although these contributions are generally small, reflects in figures 17i through 17n which show the breakdown by sector of the three sources of the residual; relative price effects (which impact aggregate TFP factor growth through sectoral contributions to GDP per working age person); capital income share adjustments (which impact TFP factor growth through sectoral contributions to capital deepening); and value added reallocation effects (which also impact residual sectoral contributions to aggregate TFP factor growth through sectors' capital deepening contributions). Table 19d quantifies the decennial average growth rate impact for the aggregate residual of each residual source by sector.

Figures 17i and 17j show that time-series relative price contributions in the model are larger for industry and services than in the data and not always consistent with the direction of relative price contributions of sectors in the data. Figures 17k and 17l show that the model correctly predicts that agriculture has the largest capital income share time-series residual contribution although the contribution appears modestly overpredicted and not always accurately reflects directional movements observed in the data. Figures 17m and 17n suggest that time-series sectoral reallocation contributions in the model are too small for industry and services, and too large for agriculture.

The last four rows of numbers in table 19d summarize the model's full sample performance in predicting behavior of residual contributions to aggregate TFP factor growth. The first column of numbers in the last set of rows shows the aggregate effect for TFP factor growth of the residual predicted by the model, with the empirical contributions in parentheses. While, as we have seen, the model quite accurately predicts the total size of residual contributions to average aggregate TFP factor growth, it does not do a great job of allocating residual contributions among the three sources; relative price effects are under-predicted, while capital income share and value-added reallocation effects are over-predicted. The next three columns of numbers in the last set of rows of the table show the full-sample sectoral contributions to the residual. In the first of these three columns, it is evident that the model's overprediction of agriculture's residual contribution is largely due to a counterfactually large positive capital income share contribution, although there is also a small overestimate of agriculture's value-added reallocation contribution. Agriculture's counterfactually large capital income share contribution is solely responsible for the model's overprediction of the total capital-income share effect. The model's overprediction of agriculture's value-added reallocation contribution is smaller than its overprediction of services' value-added reallocation contribution, but together these account for the model's overprediction of total value-added reallocation effects. The model's underprediction of relative price effects is almost entirely due to a significant underprediction of services' contribution.

The remaining rows in the table break down total residual effects by source (first column of numbers) and sectoral contributions to the residual y source (second through fourth columns of numbers) by decade. The first column of numbers shows that the model significantly underpredicts relative price effects in the 1980s and 2000s, and overpredicts them in the 1990s. The underprediction in the 1980s and 2000s are essentially due to substantial underprediction of services' contributions, and the overprediction in the 1990s is due to a substantial overprediction of industry's contribution. While the model gets the total relative price effect roughly right in the 2010s, this is the consequence of an overprediction of services' and underprediction of industry's contributions. Agriculture plays a trivial role. The capital income share effect over-prediction of the model occurs in all but the 1990s, when the model is roughly accurate. Overprediction of the capital income share effect in the 1980s, 2000s, and 2010s is almost exclusively due to a counterfactually large contribution of agriculture. Agriculture's capital income share contribution is also over-predicted in the 1990s but offset by a roughly equal underprediction of that of the service sector. The model predicts a counterfactually large positive value-added reallocation effect in every decade. In the 1980s, this is primarily due to a counterfactually large contribution of agriculture; in the 1990s and 2000s, it is due to a counterfactually large (if nonetheless negative) contribution of services; in the 2010s, agriculture's excessively large positive contribution is responsible.

Overall, the model's performance in matching aggregate TFP factor growth and its weighted TFP factor and total residual sources is very good, as is its performance in matching weighted TFP contributions to aggregate TFP growth of individual sectors. However, it fails to quantitatively and sometimes qualitatively match annual time-series movements in (and hence average growth rates of) sectoral relative prices, sectoral capital-output ratios, and sectoral shares of value added. As a result, it does not do a good job of decomposing residual effect growth in aggregate TFP among sources by sector.

6.2 Sensitivity analysis

6.2.1 Elasticities

Since the model fails to capture the magnitude of decline in industry's hours per working age person in the 1990s, and the magnitude of industry and service sector hours per working age person growth in the 2010s, I evaluate the effects of assuming higher values of the elasticity of intertemporal substitution and the (Frisch) elasticity of labor supply. I consider the consequences of doubling each elasticity from a value of 1 to 2. A doubling of the Frisch elasticity increases the responsiveness of labor supply growth to wage rate growth and the interest rate (inversely). A doubling of the intertemporal elasticity of substitution increases the responsiveness of labor supply growth to wage rate growth (but by less than does a doubling of the Frisch elasticity), the interest rate (exactly equal to the impact of a doubling of the Frisch elasticity), and results in a positive response of labor supply growth to growth in the cost of the consumption index. The five panels of figure 18, and tables 20a to 20e show the main results of doubling these elasticities individually. The complete set of results, including decomposition of sectoral TFP contributions into residual sources, is available upon request.

The figures show that the model's predictions for levels of the aggregate growth accounting variables for GDP per working age person are very similar to those of the benchmark specification. The correlations of the aggregate accounting growth factors across alternative calibrations are very high because the same exogenous inputs are driving optimal responses in the model. Both a higher intertemporal elasticity and a higher labor supply elasticity increase modestly the variability of the hours and capital factors over the sample period, with a higher intertemporal elasticity having marginally greater impact than a higher Frisch elasticity. However, note that the aggregate TFP factor is almost identical; unless alternative parameter values in a simulation significantly affect sectoral allocations, the aggregate TFP factor predicted by the model will be essentially unchanged since within-sector TFP factors are the identical across simulations. Indeed, figure 18e shows that the higher elasticities only marginally affect the model's predicted sectoral shares of hours. Services exhibit a slightly higher share and agriculture slightly lower share in the 1980s relative to the benchmark specification, and services a slightly lower share and industry a slightly higher share in the aftermath of the great recession. In both periods, the high elasticity variants perform marginally better than the benchmark model.

Table 22 shows there are some small, quantitative effects of higher elasticities for the model's estimated aggregate growth accounting. The model predicts faster GDP per working age person growth under both high elasticity specifications in the 1980s, with both variants more closely matching the empirical growth rate than the benchmark specification. The high intertemporal elasticity model variant generates significantly *higher* 1980s growth than observed in the data. Average TFP factor growth in the 1980s is essentially unchanged across specifications. The increased 1980s average growth rate in both high elasticity variants is mainly attributable to *counterfactually* high hours factor growth; high elasticities move the model farther from observed hours factor growth than does the benchmark specification. The high intertemporal elasticity variant also predicts higher capital factor growth than in the benchmark model in the 1980s which also moves the model's capital factor growth farther from the data. Thus, although the high elasticity variants improve the model's ability to match quantitatively average growth in the 1980s, they do not accomplish this through the increase in TFP factor growth which would improve the model's aggregate growth accounting but through counterfactually high growth in production inputs.

The magnitude of *decline* in growth of GDP per working age person and in the hours factor in the 1990s relative to the 2000s is much closer to the data in high elasticity variants, however. In fact, the high intertemporal elasticity model marginally overpredicts hours growth decline. Neither TFP factor nor capital factor growth is much changed in the model's predictions for the 1990s in either high elasticity variants, so the greater hours factor growth decline generates the greater decline in GDP per working age person growth in the 1990s relative to the 1980s, improving the performance of the model.

However, the high elasticity variants also predict a *greater* decline in the hours factor during the great recession. This aggravates the benchmark model's underprediction of GDP per working age person growth in the 2000s and of the decline in GDP per working age person growth in the 2000s relative to the 1990s. Again, TFP and capital factor growth are not much altered relative to the benchmark specification. There is a significantly larger increase in hours per working age person growth in the 2010s predicted by the high elasticity variants, bringing hours factor growth within the last decade closer to that in the data relative to the benchmark. However, the model now *overpredicts* the increase in hours growth in the 2010s relative to the 2000s. Faster predicted hours factor growth in the 2010s is somewhat offset in its impact for predicted GDP per working age person growth by more negative growth in the capital factor in the high elasticity variants.

Finally, the last four rows of the table show that there is little to choose between the predictions of the three specifications over the entire sample period.

Overall, the higher elasticity variants somewhat improve the model's fit to the aggregate growth accounting data in the 1990s (high intertemporal elasticity is best) and 2010s (high Frisch elasticity is best) but worsen its performance in the 1980s (high intertemporal elasticity is worst) and 2000s (high Frisch elasticity is worst). Higher elasticity variants improve the model's performance in matching the magnitude of decrease in hours factor growth in the 1990s relative to the 1980s. They make little difference to the model's failure to match the increase in hours factor growth in the 2000s relative to the 1990s; both high elasticity variants, like the benchmark, predict *decreases* and of roughly the same size. The high elasticity variants also deteriorate the models' performance in matching the magnitude of increase in hours factor growth in the 2010s relative to the 2000s, *overpredicting* the increase relative to the benchmark. It is difficult to unambiguously state that either high elasticity variant is a significantly better match to the data than the benchmark.

Tables 23a through 23e provide an assessment of the model's performance vs. the benchmark specification in matching sectoral contributions to growth in GDP per working age person, the capital, hours, and TFP factors, and to weighted/within-sector TFP effects.

The second column of numbers in table 23a shows that the high elasticity variants do not significantly alter agriculture's predicted contribution to GDP per working age person growth relative to the benchmark in any decade. In the 1980s, the two high elasticity variants predict an identical increase in services' contribution relative to the benchmark which does not improve the fit of the model. In the 1980s, the high intertemporal elasticity variant predicts a larger increase in industry's contribution to GDP per working age person growth relative to the benchmark than does the high Frisch elasticity variant, and both are closer to the data than the benchmark. In the 1990s, the high Frisch elasticity variant leaves industry and service sector contributions to GDP per working age person growth essentially unchanged relative to the benchmark, however, the high intertemporal elasticity variant reduces the contributions of both industry (closer to the data) and services (farther from the data). In the 2000s, the high elasticity variants predict smaller contributions to GDP per working age person growth of both industry and services relative to the benchmark, with the high intertemporal elasticity generating a larger decline; both variants are farther from the data than the benchmark. In the 2010s, the high Frisch elasticity variant performs best, significantly raising the contributions of both industry (more than the high intertemporal elasticity variant does) and services (a high intertemporal elasticity reduces this contribution).

Table 23b shows that the high elasticity variants leave agriculture's contributions to capital deepening unchanged in all decades. Quantitatively, the high Frisch elasticity variant marginally alters the capital factor growth contributions of industry and services within each decade relative to the benchmark, and always changes the contributions of these two sectors in the same direction. It also slightly increases the decennial changes across decades of both industry and service sector capital deepening contributions relative to the benchmark. The high intertemporal elasticity variant has a bigger impact on the capital factor growth contribution of industry within each decade than does the high Frisch elasticity variant. It has a smaller impact on service-sector contributions, except in the 2010s, which is the only decade in which the high intertemporal elasticity does not shift the contributions of industry and services in opposite directions relative to the benchmark. Overall, however, all effects of higher elasticities for capital deepening contributions are small. The effects of high elasticities for sectoral contributions to TFP factor growth seen in table 23d are trivial. Only the numbers in table 23c, which show the hours factor growth contributions of sectors under alternative elasticities, account for the quantitatively significant changes seen in the sectoral contributions to GDP per working age person growth in table 23a and the aggregate growth accounting in table 22.

The second column of numbers in table 23c show that the high elasticity variants have trivial consequences for the model's contributions of agriculture to hours factor growth. All the action is in industry, in the third column of numbers. There are relatively small effects of high elasticities for service sector contributions in the fourth column. In the 1980s, the rapid increase in the aggregate hours factor growth relative to the benchmark and data seen in table 22 and generated by both high elasticity variants is disproportionately reflected in a higher contribution of industry relative to services, and more so for the high intertemporal elasticity variant. In the 1990s, the negative industrial sector hours contribution predicted by the high intertemporal elasticity variant is much closer to the data than either the high Frisch elasticity or benchmark model and brings the *reduction* in industry's contribution to hours factor growth in the 1990s relative to the 1980s very close to the data. By contrast, in the 2000s industry's negative contribution to hours growth is larger in the high elasticity variants than in the benchmark, moving the model farther from the data. In the 2010s industry's positive contributions are larger in both high elasticity variants than in the benchmark moving the model farther from industry's contribution in the data. However, the service sector's positive contributions to hours factor growth are also larger in the high elasticity variants, moving the model closer to services' contribution in the data. The combination of excessively large negative industry contributions in the 2000s and excessively large positive industry contributions in the 2010s means that the high elasticity variants predict a counterfactually large increase in industry's hours factor growth contributions in the 2010s relative to the 2000s than observed in the data or the benchmark model. By contrast, the smaller service sector contributions in the 2000s and larger contributions in the 2010s predicted by the high elasticity variants imply a closer match to the observed increase in services' hours factor growth contributions in the 2010s relative to the 2000s–especially for the high Frisch elasticity model.

Within-decades, the high elasticity variants deteriorate the model's performance in matching industry's contributions in the 1980s (high intertemporal elasticity is worst) but improve its performance in matching services contributions in the 1980s (high Frisch elasticity is best). The high elasticity variants deteriorate the model's performance in matching services' contributions in the 1990s (high intertemporal elasticity is worst) but improve its performance in matching industry's contributions in the 1990s (high intertemporal elasticity is best). The high elasticity variants deteriorate the model's performance in matching both industry's contributions in the 2000s (high intertemporal elasticity is worst) and services' contributions in the 2000s (high Frisch elasticity is worst). Finally, the high elasticity variants deteriorate the model's performance in matching industry's contributions in the 2010s (high intertemporal elasticity is worst) but improve the model's performance in matching services' contribution (high Frisch elasticity is best). High elasticity variants improve the model's ability to match industry's decline in hours factor growth contributions in the 1990s relative to the 1980s, and the increase in services' hours factor growth contributions in the 2010s relative to the 2000s.

High elasticity variants, by increasing the sensitivity of endogenous variables to sectoral TFP changes, tend to worsen the model's ability to match within-decade average growth and sectoral contributions but improve its performance in matching large cross-decade changes in aggregate growth and sectoral contributions to aggregate growth. Neither high elasticity variant unambiguously improves the fit of the model to both aggregate growth accounting and sectoral contribution data.

6.2.3 Aggregate labor supply wedge

I now explore the performance of a model featuring an aggregate labor wedge in the intra-temporal labor-leisure optimality condition. The wedge effectively represents a time-varying tax on the wage rate. It is derived by measuring the value in the data of the right-hand side of the intra-temporal optimality condition given by,

$$(1-\tau_{w,t}) \equiv \left(\frac{1-\psi}{\psi}\right)\left(\frac{P_{c,t}C_t/N_t}{w_t}\right)/(1-\frac{n_t}{N_t}).$$

I divide aggregate labor income by aggregate employment to measure the economy-wide (nominal) wage at each date, the difference between the working population and employment to measure leisure and employ OECD aggregate (nominal) household consumption expenditure data. The five panels of figure 19 and tables 22 through 23d display the results.

Figure 19a shows the measured labor wedge which measures the distortion to optimal labor supply due to labor market policies, practices, and institutions. This is the portion of the wage that is effectively received by households, net of the proportional tax rate implied by such policies. A value of one implies no tax or friction. A value less than one implies labor supply taxation, and greater than one labor supply subsidy. The figure shows that the reduction in the length of the workweek instituted in the late 1980s and early 1990s effectively taxed labor supply, reducing the opportunity cost of leisure. The effect of this policy for labor supply gradually diminished over the following decade, the effective labor supply tax rate declined, and the wedge converged back to a value of one. Policies designed to raise labor force participation after the great recession resulted in an effective subsidy to labor supply, increasing the opportunity cost of leisure. However, the largest subsidy was quite short-lived. By the end of the sample period, there is essentially no net subsidy. Figure 19b shows that the labor wedge slows growth in GDP per working age person too early relative to the data, starting in the late 1980s, and by too large a magnitude in the late 1980s and early 1990s. From the mid-1990s onwards, however, the labor wedge facilitates faster growth in the model relative to the benchmark, and it tracks the data more closely than the benchmark variant from about 1996 until the great recession. It also does a slightly better job of tracking relatively rapid GDP per working age person in the 2010s. Figure 19c shows that the labor wedge has little impact relative to the benchmark specification for predicted capital factor movements, and figure 19e shows it has essentially zero impact relative to the benchmark specification for tracking the TFP factor. Figure 19d shows that, not surprisingly, almost all the difference in the GDP per working age person performance of the labor wedge variant relative to the benchmark model derives from a different prediction for the evolution of hours per working age person. The hours factor declines too much in the late 1980s and early 1990s but moves more closely with the data than the benchmark after the mid-1990s except during the great recession. Figure 19a shows that the great recession of 2008-2009 is associated with a decline in the wedge or a higher effective tax rate on labor supply.

Table 22 shows the growth accounting for the labor wedge model and compares it to that of the benchmark and the data. As the figures suggest, the labor wedge model produces too little growth on average in the 1980s because it predicts slightly negative, rather than positive, growth in hours per working age person. It performs somewhat better than the benchmark in matching the slow growth of output per working age person in the 1990s but, again, not because it better matches hours per working age person but because it is closer to the data in its prediction for capital deepening. However, in the 2000s, unlike the benchmark, the labor wedge variant produces the observed positive, rather than negative, growth in hours per working age person and generates significantly faster growth in the hours factor in the 2010s. Its growth rate predictions for the last twenty years are thus closer to the data than those of the benchmark model. Its capital factor predictions are also closer to the data in the 2000s and 2010s.

Table 23a shows that its ability to match the GDP per working age person growth rate in the 2000s and 2010s better than the benchmark model is due to more accurate, larger growth contributions of all three major sectors. Roughly the opposite is true of its predicted contributions in the 1980s and 1990s; they are less accurate and too small relative to the data except for the implied contribution of industry in the 1990s which is marginally closer to the data than the benchmark model. Table 23b shows there is a mixed bag of results for the labor wedge relative to the benchmark variant in matching sectoral contributions to the average growth of the capital factor in each decade. Although most differences are small, the labor wedge variant's predictions for industry and service sector contributions in the 1980s are significantly worse and its predictions for the two sectors' contributions in the 1990s significantly better than those of the benchmark. Table 23d shows its predictions for sectoral contributions to TFP factor growth are almost identical to those of the benchmark. This is because predicted sectoral hours shares (not shown here for brevity but available upon request) are essentially identical in simulations of the two models. Finally, table 23c shows that the labor wedge variant's growth rate and growth accounting "misses" relative to the benchmark in the 1980s and 1990s are largely due to its failure to replicate the industrial sector's positive contribution to hours factor growth in the 1980s, and the decline in industry's contribution in the 1990s. The service sector's contribution to hours factor growth also counterfactually rises in the 1990s, although its 1990s value is significantly closer to the data than in the benchmark model. By contrast, the labor wedge model produces a more significant increase in the hours growth contribution of services in the 2000s, relative to the benchmark, and a much smaller decline in the hours growth contribution of industry relative to the benchmark. In the 2010s, the labor wedge more significantly overpredicts industry's contribution to hours growth relative to the benchmark but comes closer to the data in its prediction for services' contribution. Nonetheless, the predicted increase in industry's contribution to hours factor growth in the 2010s relative to the 2000s is smaller than that of the benchmark model and closer to the data, while that of services is smaller and farther from the data.

The intra-temporal labor wedge model overall does a better job of capturing hours factor contributions to GDP per working age person growth, and sectoral contributions to hours factor growth in, especially, the 2010s. However, the match to hours factor growth in the 2010s is far from quantitatively close. There is a larger failure of the model to match hours factor growth and growth rate changes in the 1980s and first half of the 1990s. The labor tax that exactly replicates the intra-temporal labor-leisure optimality condition is "too high" early in the sample, and insufficiently low late in the sample, relative to the hours per working age person supplied in the data. This could suggest that Japan's labor market or other interventions and institutions distorted the household's inter-temporal margin, as well as the intra-temporal margin.

Combining the intra-temporal and inter-temporal optimality conditions of the household yields the inter-temporal condition for optimal labor supply. I define the intertemporal wedge, $\tau_{c,t}$, by the value of the inter-temporal optimality condition,

$$1-\tau_{c,t}=\left(\frac{w_{t+1}(l_{t+1}/N_{t+1})}{w_t(l_t/N_t)}\right)\left(\frac{1-\tau_{w,t+1}}{1-\tau_{w,t}}\right)\left(\frac{P_{x,t}}{\beta\left((1-\delta(1-\tau_{rk}))P_{x,t+1}+r_{t+1}(1-\tau_k)\right)}\right).$$

Here, the first two terms in brackets are simply equal to consumption expenditure per working age person growth. An intertemporal wedge–which could represent a time-varying consumption expenditure tax or tax on the gross return to capital–reduces consumption expenditure growth relative to its optimal rate, conditional on the return to capital. Exogenous TFP growth largely drives growth in wages in the first term, and the level of TFP also is a key exogenous determinant of the return to capital in the third term. In the 1980s, wages would have been rising quite rapidly with TFP growth. In the benchmark model, absent either a labor wedge or intertemporal wedge, rapidly growing wages were associated with declining leisure per working age to satisfy the intertemporal optimality condition during the 1980s, and hence rising hours worked per working age person. The model is close to the data in its hours factor growth prediction. In the labor wedge model, the labor tax was increasing over the 1980s, $\left(\frac{1-\tau_{w,t+1}}{1-\tau_{w,t}}\right)<1$, thereby reducing the impact of TFP growth for wage growth. In the absence of an intertemporal wedge, $\tau_{c,t}=0$, leisure per working age person could fall or rise to satisfy the intertemporal optimality condition depending on the relative size of wage growth and growth in the labor wedge. In the labor wedge model, leisure per working age person counterfactually rose over time on average in the 1980s and hours worked per working age person counterfactually declined. A positive intertemporal tax rate, $\tau_{c,t}>0$, by suppressing growth in leisure and promoting growth in hours, could reconcile the labor wedge model with 1980s hours factor data. Similarly, in the 2000s and 2010s, wage growth is much slower due to slower TFP growth. In the benchmark model *absent* wedges, this–conditional on the return to capital–is associated with slowly rising leisure and falling hours in the 2000s, and slowly declining leisure and rising hours per working age person in the 2010s. Hours in the 2010s do not rise sufficiently rapidly relative to the data. In the labor wedge model, the wedge is rising in the 2000s (the tax is falling), $\left(\frac{1-\tau_{w,t+1}}{1-\tau_{w,t}}\right)>1$, and this allows for slowly falling leisure and rising hours per working age person, but the latter do not rise fast enough. In both variants of the model, to replicate observed growth in hours in the 2000s would require a large tax on consumption growth, $\tau_{c,t}>0$. In the 2010s, the labor tax is temporarily negative, $\tau_{w,t+1}<0$, (there is a subsidy) and initially increasing in size, so that $\left(\frac{1-\tau_{w,t+1}}{1-\tau_{w,t}}\right)>1$, although this ratio stabilizes at roughly one and becomes smaller than one before the end of the sample. Then, given (slow) wage growth and the return to capital, leisure should be falling, and hours worked rising, relative to the benchmark model on average – at least in the first few years of the 2010s. The model successfully predicts a larger rise in hours per working age person than in the benchmark during the 2010s, but the rise in labor supply is nonetheless insufficiently large relative to the data. Again, a positive tax $\tau_{c,t} > 0$ which suppresses consumption and leisure growth conditional on wage growth and the return to capital could reconcile model and data.

If measuring the return to capital in the data accurately were straightforward, incorporating an intertemporal wedge in the model and directly quantifying its importance would make sense. I do not attempt that here. It is worth mentioning, however, that the model's prediction for capital deepening is typically off by a small factor so that its predicted return to capital is inaccurate.

7. Conclusion

My results imply that the most important modification to a competitive equilibrium multi-sector growth model that could improve its fit to Japan's growth experience is careful specification of several labor market policies and practices implemented between the late 1980s and the present date. The model's greatest weakness lies in its inability to match growth rates of hours per working age person and changes in growth rates of hours per working age person across decades based solely on efficient intertemporal and intra-temporal allocations of labor supply. Specifically, a benchmark model cannot account for the large decline in hours per working age person growth in the 1990s or its 1990s growth rate, nor can it produce the positive growth rate of hours per working age person in the 2000s, nor can in match quantitatively the rapid growth rate of hours per working age person in the 2010s. A variant allowing for either a much higher elasticity of labor supply or of intertemporal substitution improves the model's ability to match the large decline in hours growth in the 1990s and the growth rate in the 2010s, but deteriorates the model's ability to match the increase in hours in the 2000s, within-decade hours growth in the 1980s and 2000s, and the increase in hours growth in the 2010s. A variant incorporating a labor supply wedge does better in matching hours per working age person growth within the 2000s (marginally) and 2010s (substantively), although is not capable of replicating quantitatively the within-decade growth rates. However, it performs much worse in matching hours growth in the 1980s. I show that only the addition of an intertemporal distortion could reconcile a model with a labor supply friction with hours growth data over the entire sample period.

Overall, the results call for an exploration of how labor market policies in the 1980s, 1990s, and 2010s affected household intra-temporal and intertemporal labor-leisure allocations. Given the joint observation of persistent TFP slowing and evidently important role of labor market policies, practices, and institutions in dictating observed GDP and hours per working age person growth, a potential avenue for future inquiry would also investigate any role of Japan's labor market policies for incentives to innovate and improve efficiency–contributing to sectoral and aggregate TFP growth slowing.

Other natural extensions of the work described here include 1) incorporating sectoral input-output linkages, 2) refining and increasing the set of sub-sectors of economic activity to account for sectoral differences in R&D and other measures of innovation intensity, and 3) opening the economy. It is possible that input-output linkages among sectors significantly tightens the model's predictions for structural change. Conditioning on measured TFP growth for sectoral value added, this could increase the model's accuracy in predicting weighted TFP and, especially, residual contributions of sectors and may improve model-based estimates of value-added reallocation and relative price effects. Including sub-sectors differentiated by the intensity of measured innovation or "tech" could shed light on underlying reasons for slowing industrial sector TFP growth in the 1990s and slowing service sector TFP growth in the 2000s and beyond. Opening the economy would allow analysis of how the evolution of Japan's international competitiveness implicated her structural change, and hence measured aggregate productivity. The emergence of China as a manufacturing giant during the sample period is of particular interest, as discussed by Coleman (2005).

These extensions are beyond the scope of the present paper and left for future work.

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Figure 1a. Real GDP per working age person, chained 1980 Yen (1980=100)

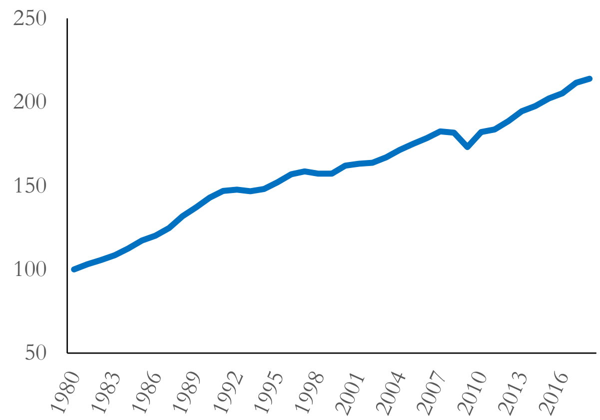


Figure 1b. Real GDP per hour worked, chained 1980 Yen (1980=100)

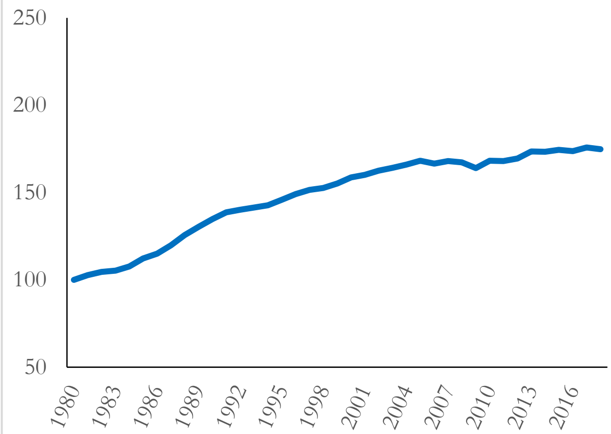


Figure 2a. Real GDP per working age person growth (percent)

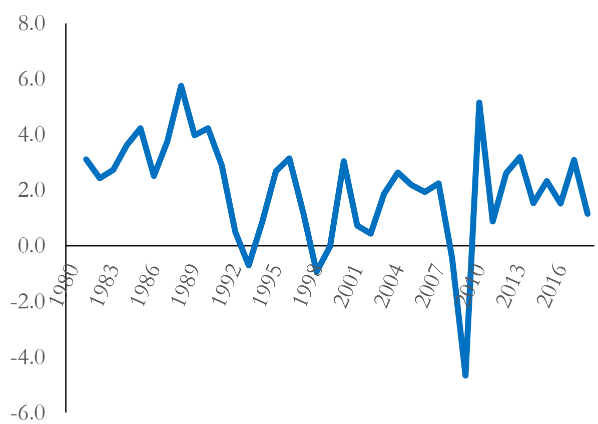


Figure 2b. Real GDP per hour worked growth (percent)

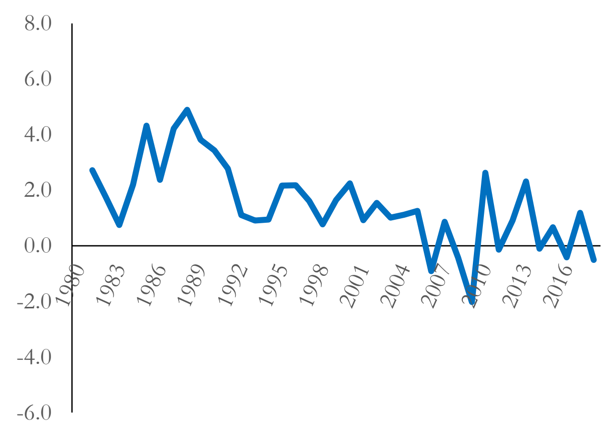


Figure 3a. Accounting for output per working age person (1980=100)

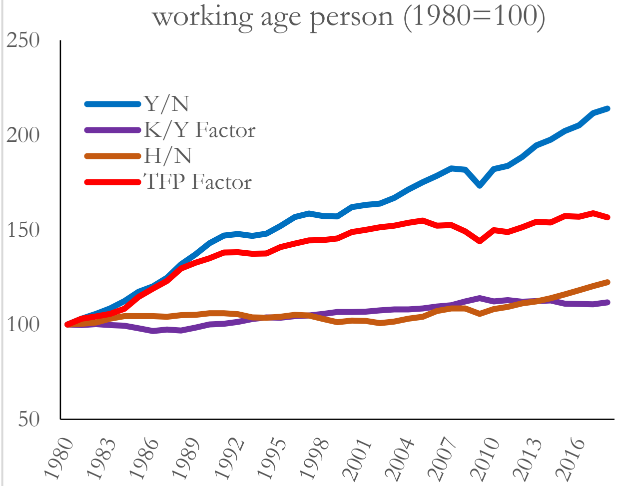
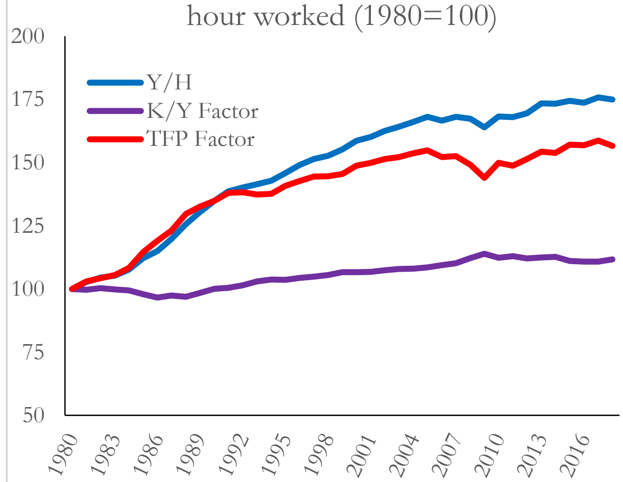


Figure 3b. Accounting for output per hour worked (1980=100)



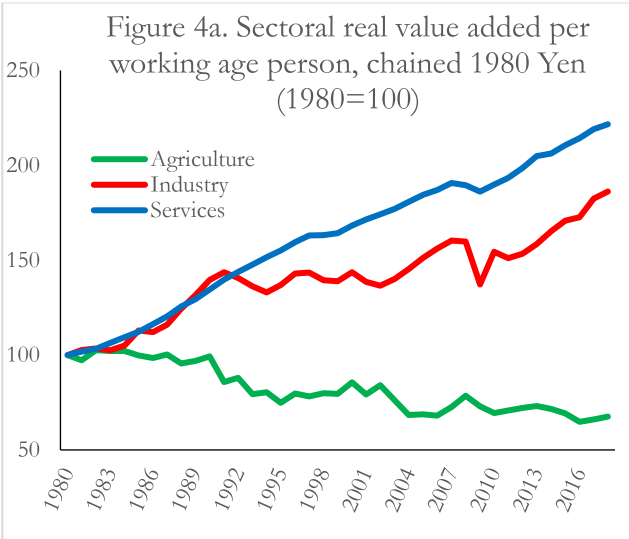


Figure 4a. Sectoral real value added per working age person, chained 1980 Yen (1980=100)

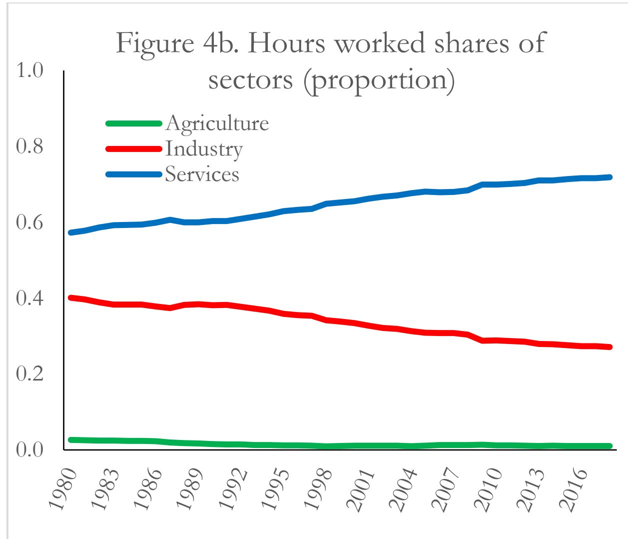


Figure 4b. Hours worked shares of sectors (proportion)

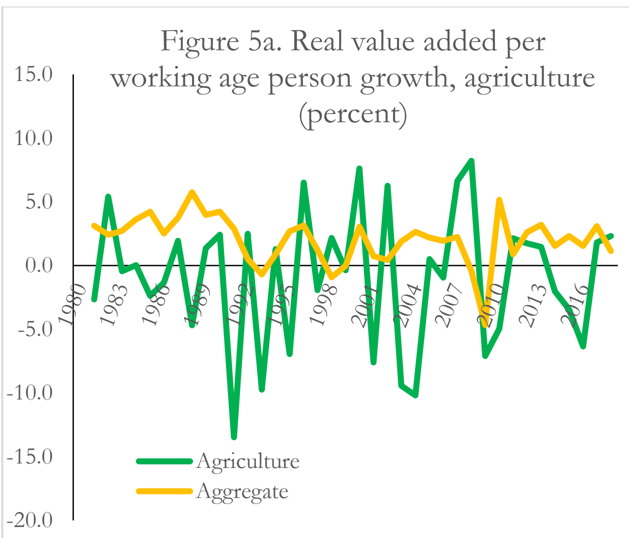


Figure 5a. Real value added per working age person growth, agriculture (percent)

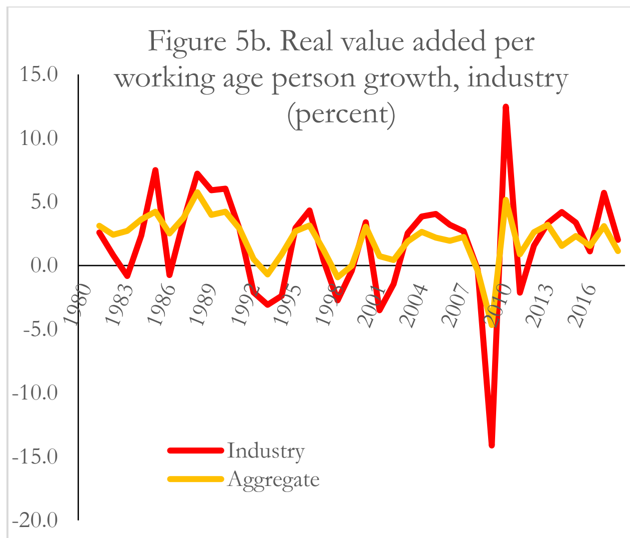


Figure 5b. Real value added per working age person growth, industry (percent)

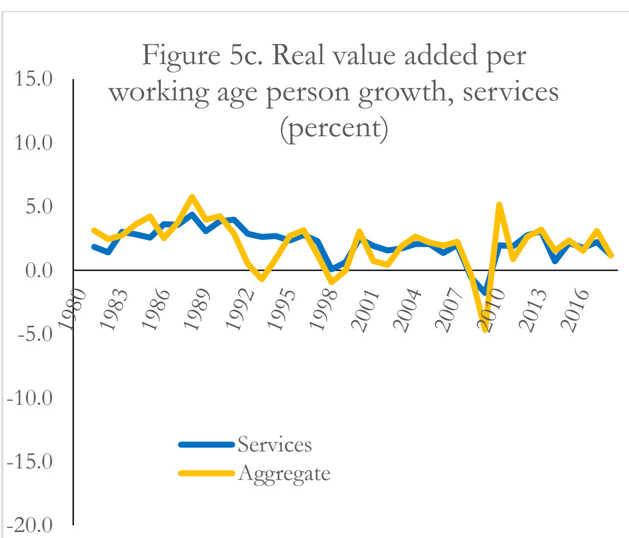


Figure 5c. Real value added per working age person growth, services (percent)

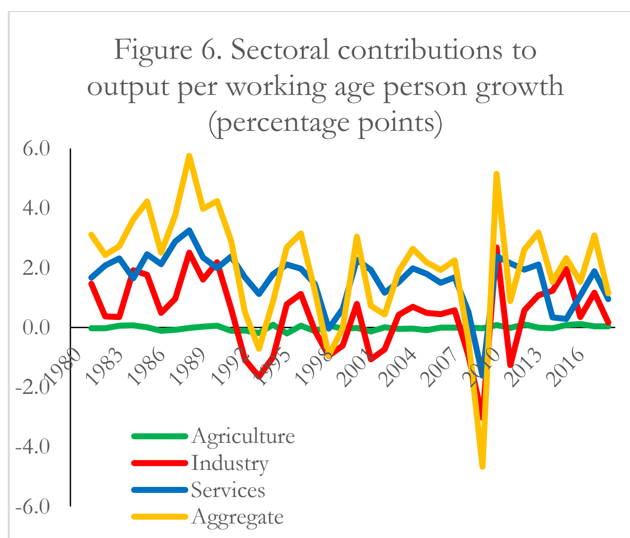


Figure 6. Sectoral contributions to output per working age person growth (percentage points)

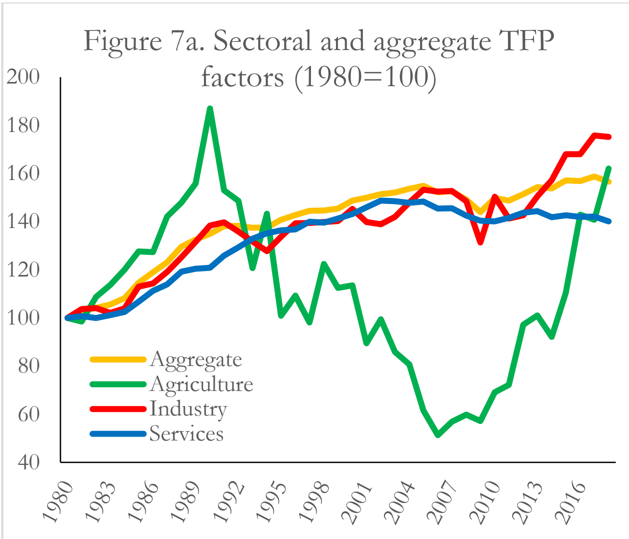


Figure 7a. Sectoral and aggregate TFP factors (1980=100)

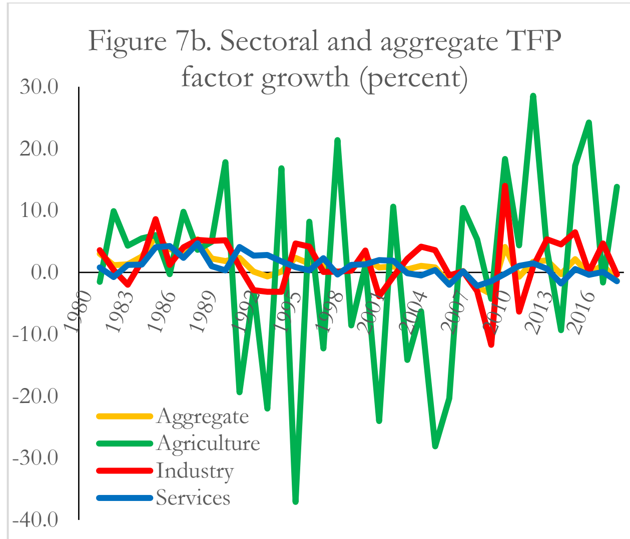


Figure 7b. Sectoral and aggregate TFP factor growth (percent)

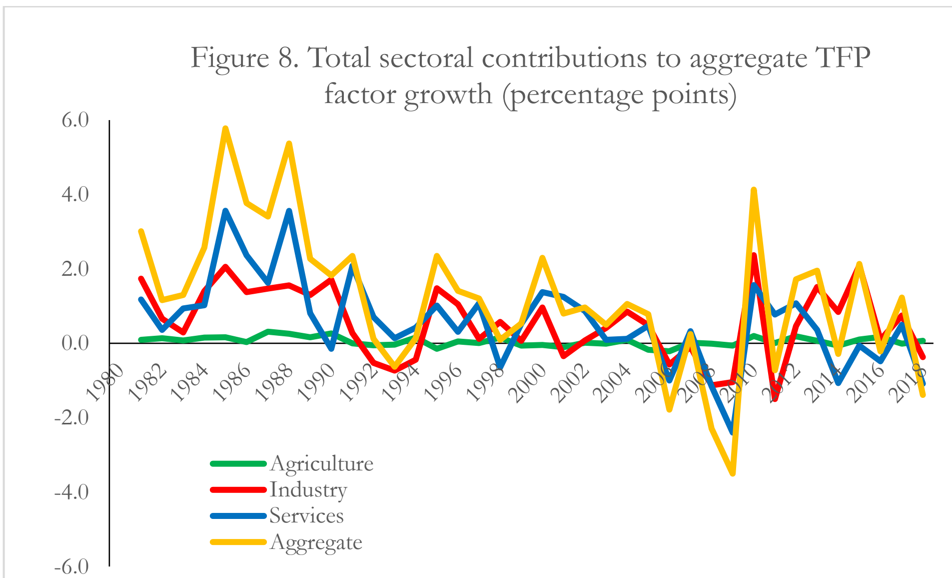


Figure 8. Total sectoral contributions to aggregate TFP factor growth (percentage points)

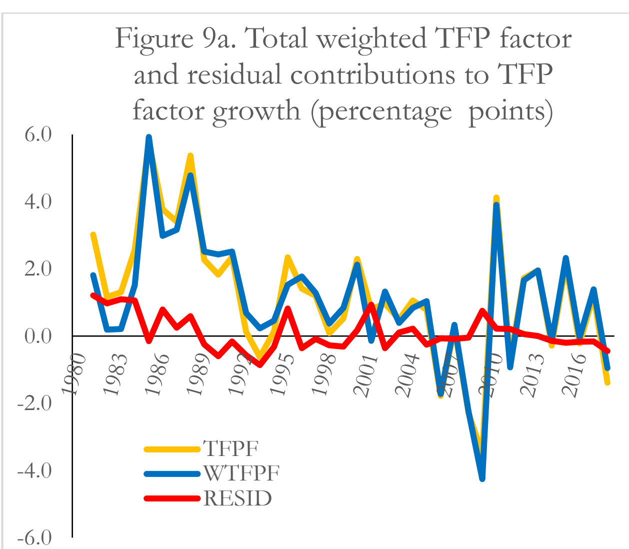


Figure 9a. Total weighted TFP factor and residual contributions to TFP factor growth (percentage points)

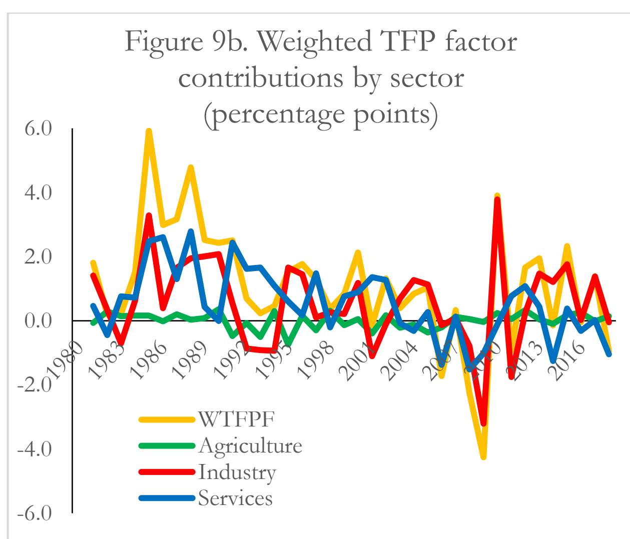


Figure 9b. Weighted TFP factor contributions by sector (percentage points)

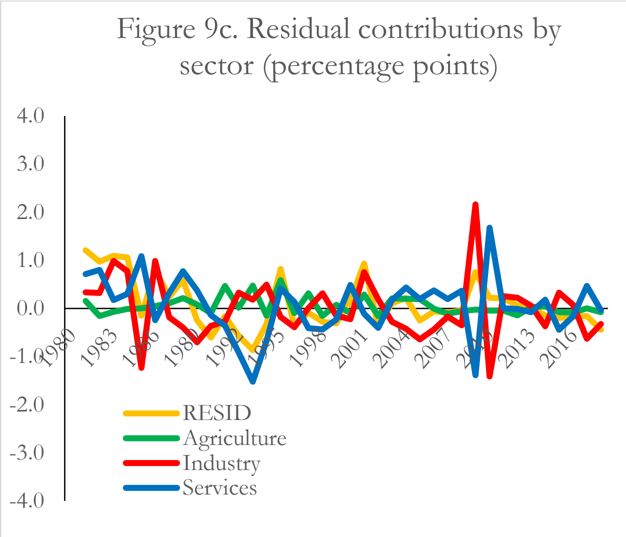


Figure 9c. Residual contributions by sector (percentage points)
4.0
3.0
2.0
1.0
0.0
-1.0
-2.0
-3.0
-4.0
1980
1983
1986
1989
1992
1995
1998
2001
2004
2007
2010
2013
2016
RESID
Agriculture
Industry
Services

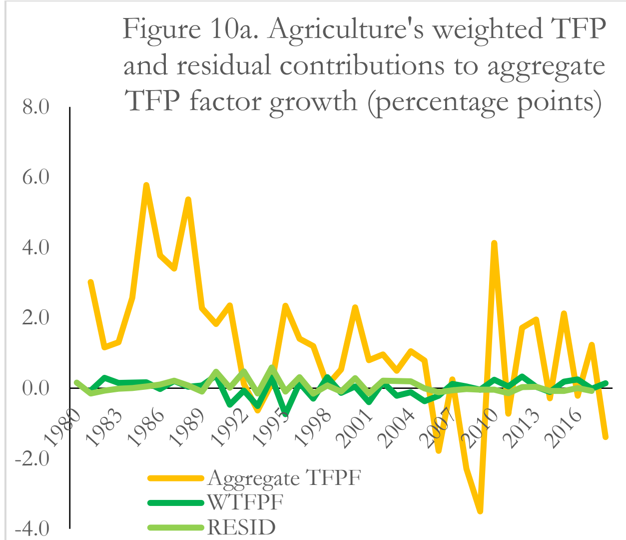


Figure 10a. Agriculture's weighted TFP and residual contributions to aggregate TFP factor growth (percentage points)
8.0
6.0
4.0
2.0
0.0
-2.0
-4.0
1980
1983
1986
1989
1992
1995
1998
2001
2004
2007
2010
2013
2016
Aggregate TFPF
WTFPF
RESID

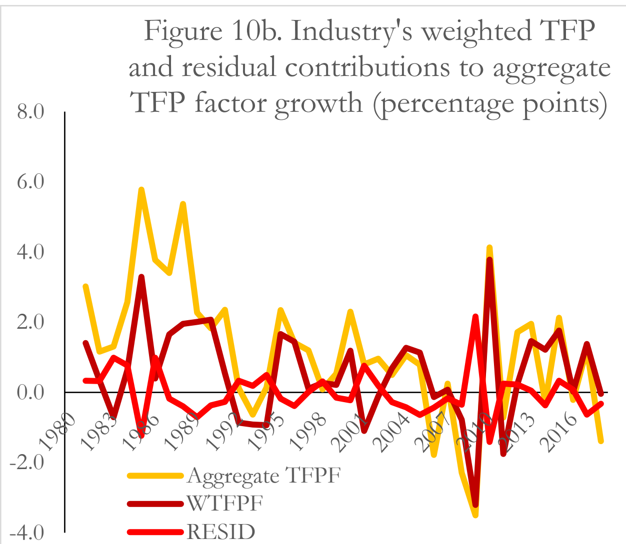


Figure 10b. Industry's weighted TFP and residual contributions to aggregate TFP factor growth (percentage points)
8.0
6.0
4.0
2.0
0.0
-2.0
-4.0
1980
1983
1986
1989
1992
1995
1998
2001
2004
2007
2010
2013
2016
Aggregate TFPF
WTFPF
RESID

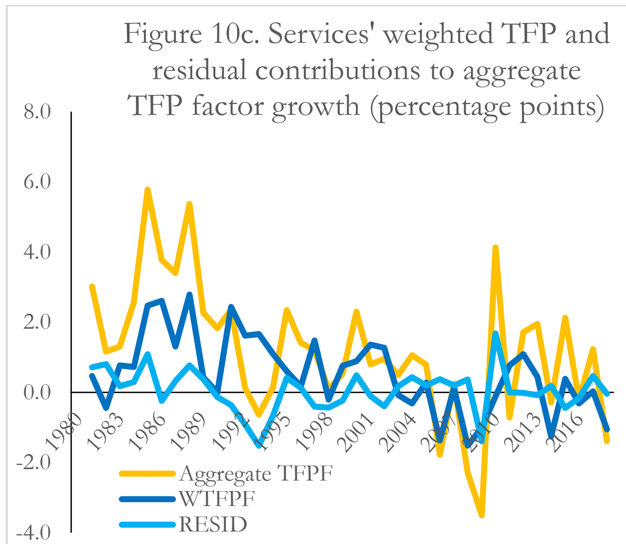


Figure 10c. Services' weighted TFP and residual contributions to aggregate TFP factor growth (percentage points)
8.0
6.0
4.0
2.0
0.0
-2.0
-4.0
1980
1983
1986
1989
1992
1995
1998
2001
2004
2007
2010
2013
2016
Aggregate TFPF
WTFPF
RESID

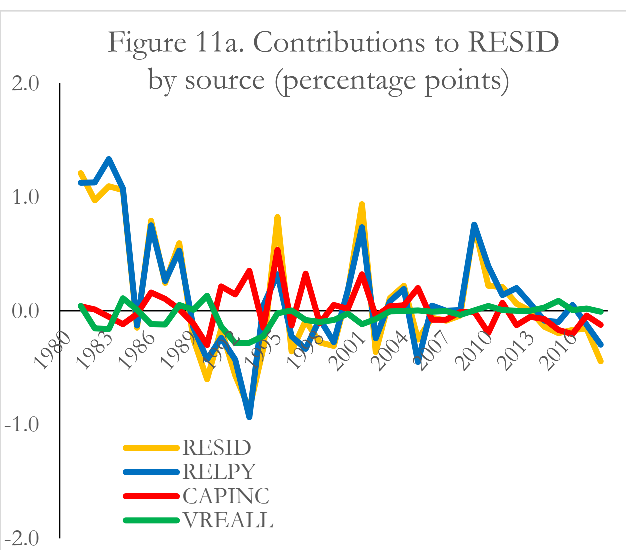


Figure 11a. Contributions to RESID by source (percentage points)
2.0
1.0
0.0
-1.0
-2.0
1980
1983
1986
1989
1992
1995
1998
2001
2004
2007
2010
2013
2016
RESID
RELPY
CAPINC
VREALL

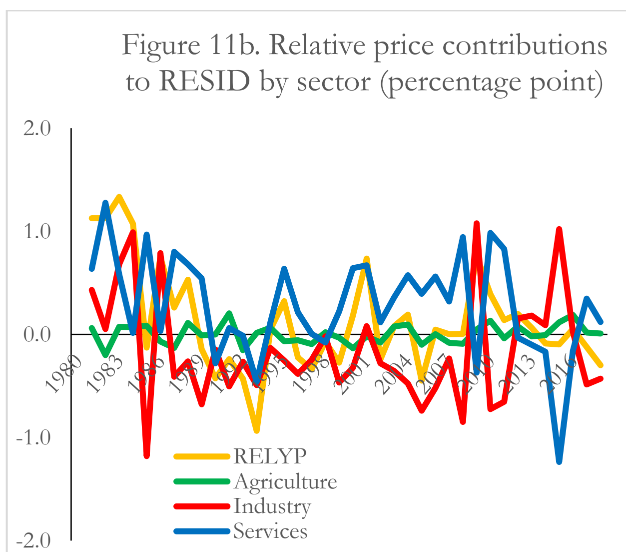


Figure 11b. Relative price contributions to RESID by sector (percentage point)
2.0
1.0
0.0
-1.0
-2.0
1980
1983
1986
1989
1992
1995
1998
2001
2004
2007
2010
2013
2016
RELYP
Agriculture
Industry
Services

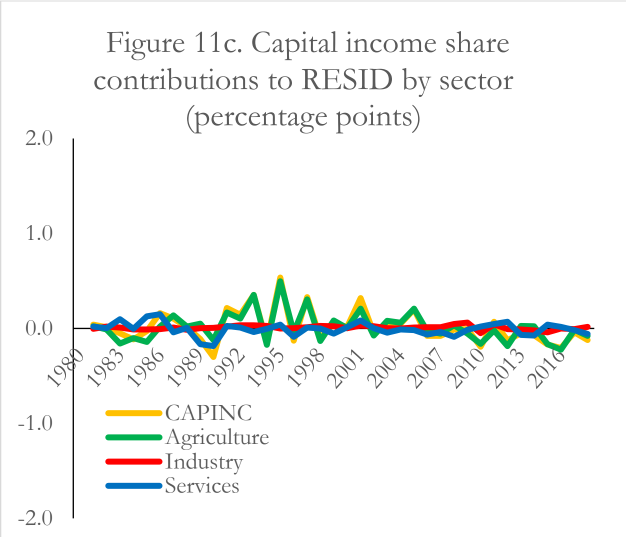


Figure 11c. Capital income share contributions to RESID by sector (percentage points)
2.0
1.0
0.0
-1.0
-2.0
1980
1983
1986
1989
1992
1995
1998
2001
2004
2007
2010
2013
2016
CAPINC
Agriculture
Industry
Services

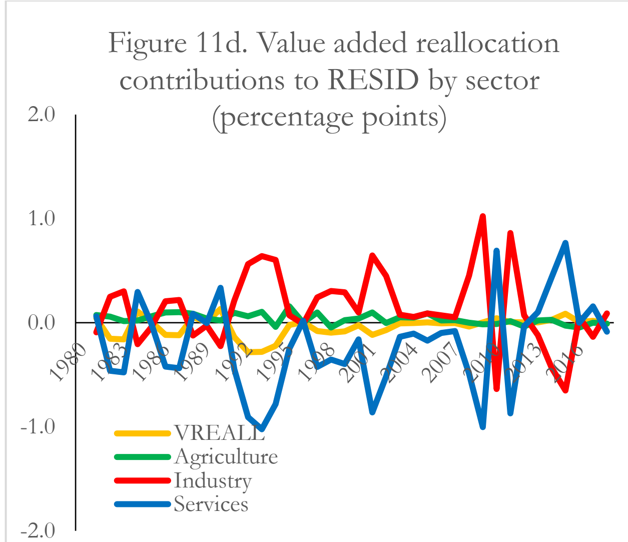


Figure 11d. Value added reallocation contributions to RESID by sector (percentage points)
2.0
1.0
0.0
-1.0
-2.0
VREALL
Agriculture
Industry
Services

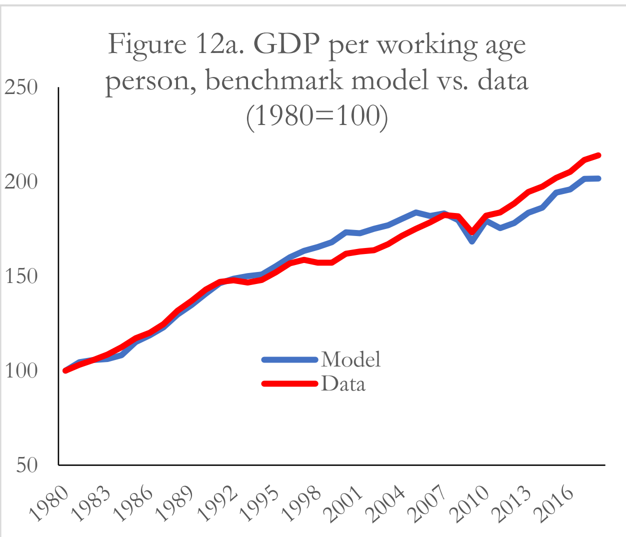


Figure 12a. GDP per working age person, benchmark model vs. data (1980=100)
250
200
150
100
50
1980
1983
1986
1989
1992
1995
1998
2001
2004
2007
2010
2013
2016
Model
Data

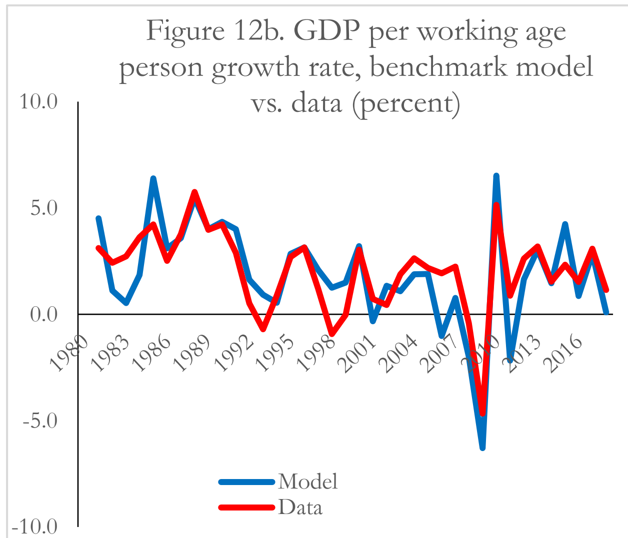


Figure 12b. GDP per working age person growth rate, benchmark model vs. data (percent)
10.0
5.0
0.0
-5.0
-10.0
1980
1983
1986
1989
1992
1995
1998
2001
2004
2007
2013
2016
Model
Data

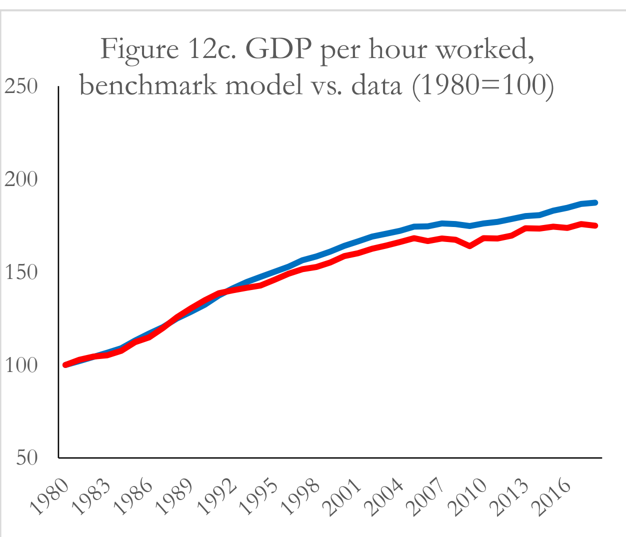


Figure 12c. GDP per hour worked, benchmark model vs. data (1980=100)
250
200
150
100
50
1980
1983
1986
1989
1992
1995
1998
2001
2004
2007
2010
2013
2016

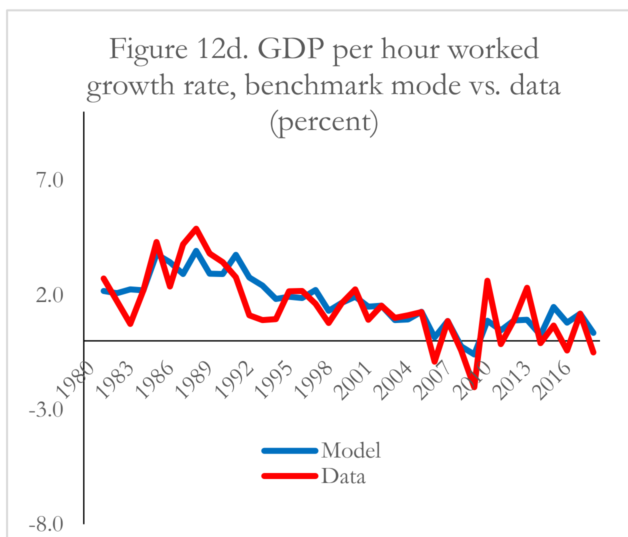


Figure 12d. GDP per hour worked growth rate, benchmark mode vs. data (percent)
7.0
2.0
-3.0
-8.0
1980
1983
1986
1989
1992
1995
1998
2001
2004
2007
2010
2013
2016
Model
Data

Figure 12e. Capital factor, benchmark model vs. data (1980=100)

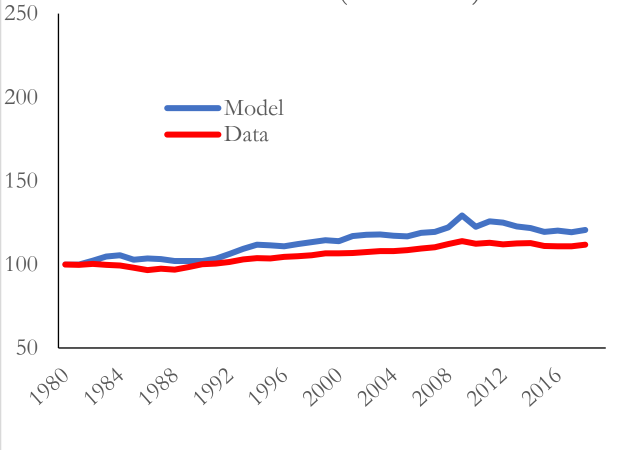


Figure 12f. Capital factor growth rate, benchmark model vs. data (percent)

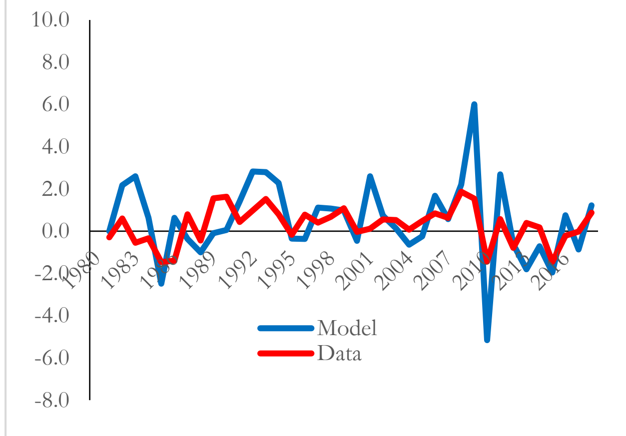


Figure 12g. Hours factor, benchmark model vs. data (1980=100)

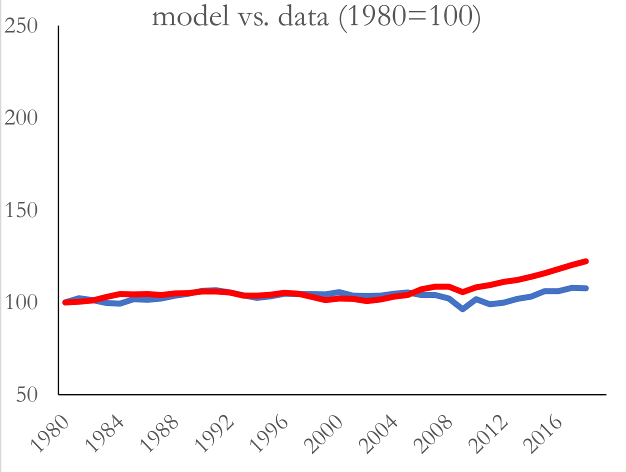


Figure 12h. Hours factor growth rate, benchmark model vs. data (percent)

Figure 12i. TFP factor, benchmark model vs. data (1980=100)

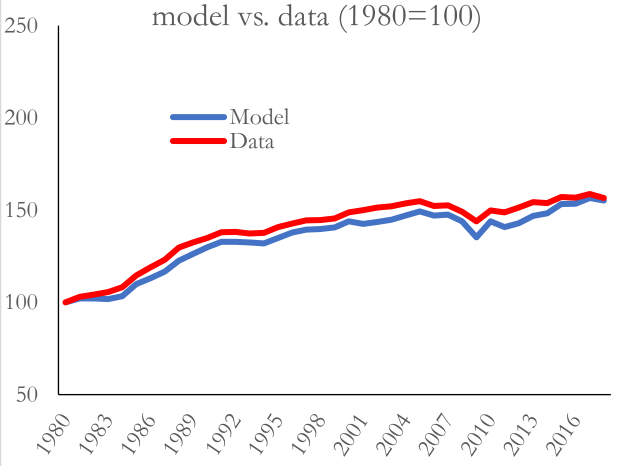
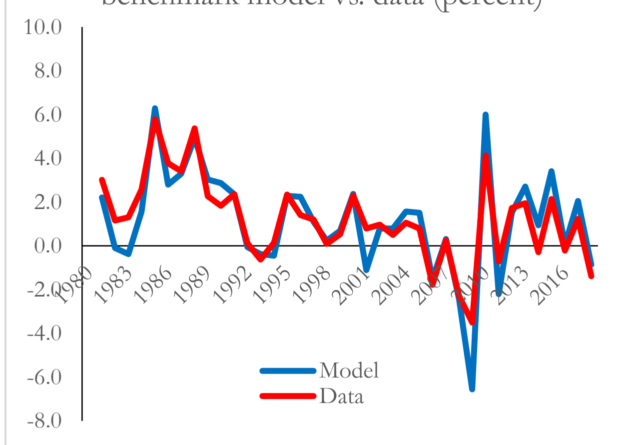


Figure 12j. TFP factor growth, benchmark model vs. data (percent)



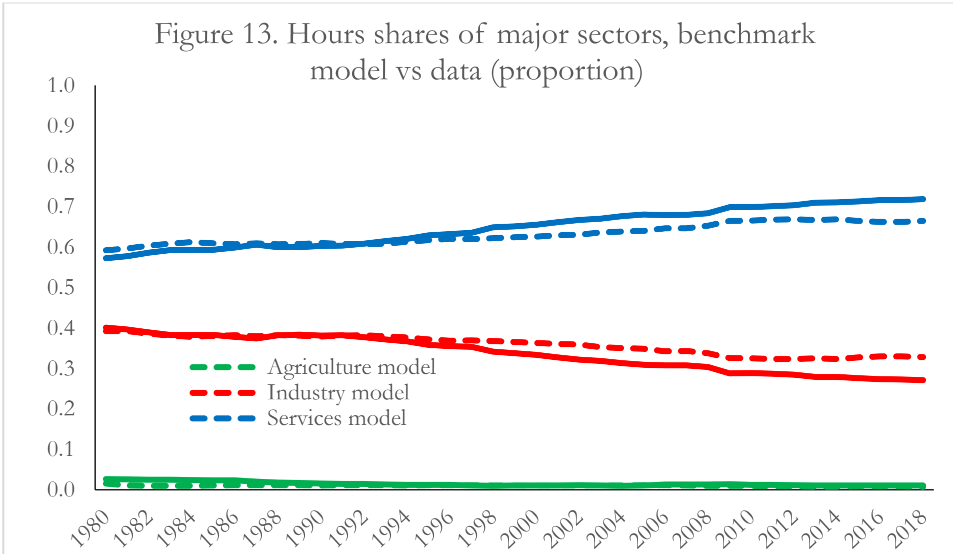


Figure 13. Hours shares of major sectors, benchmark model vs data (proportion)

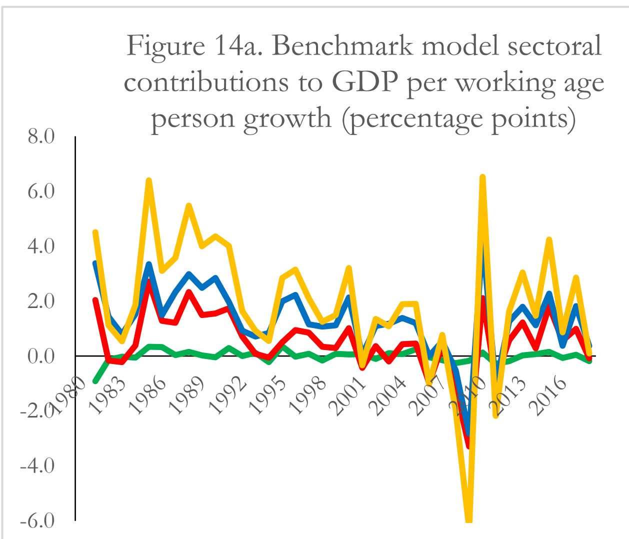


Figure 14a. Benchmark model sectoral contributions to GDP per working age person growth (percentage points)

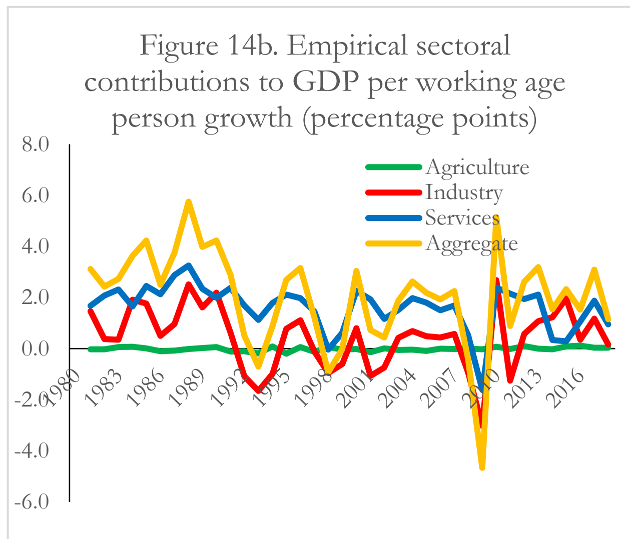


Figure 14b. Empirical sectoral contributions to GDP per working age person growth (percentage points)

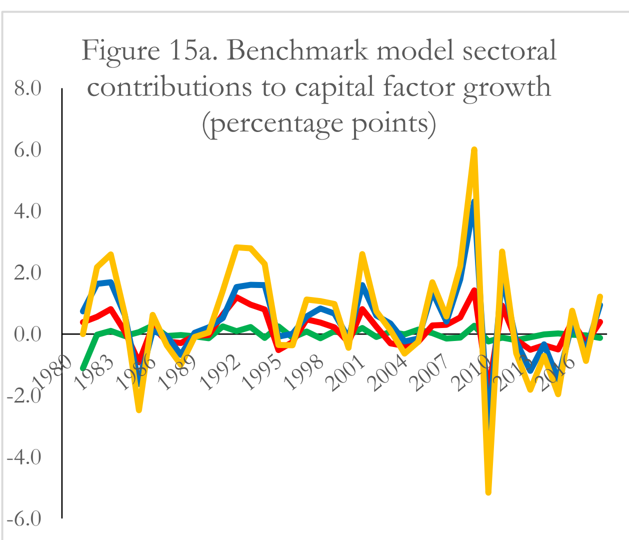


Figure 15a. Benchmark model sectoral contributions to capital factor growth (percentage points)

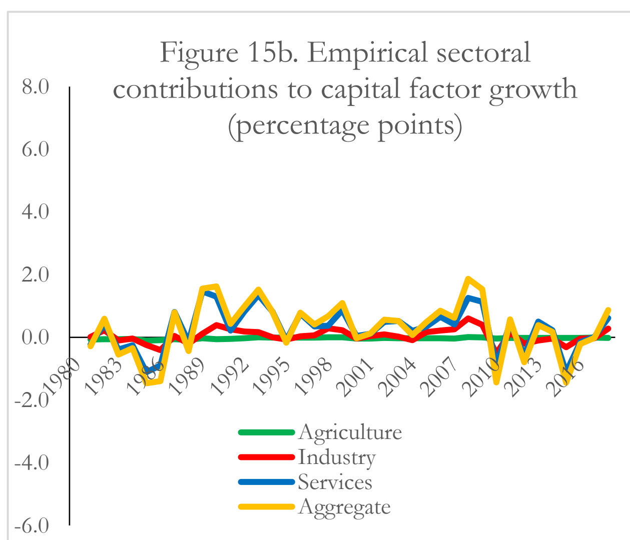


Figure 15b. Empirical sectoral contributions to capital factor growth (percentage points)

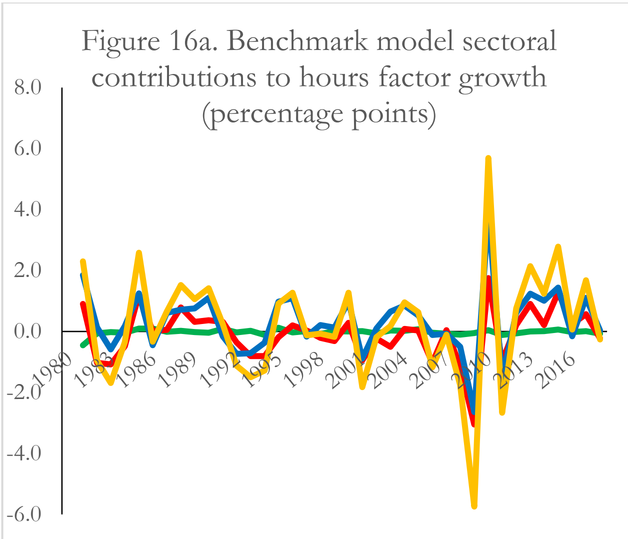


Figure 16a. Benchmark model sectoral contributions to hours factor growth (percentage points)

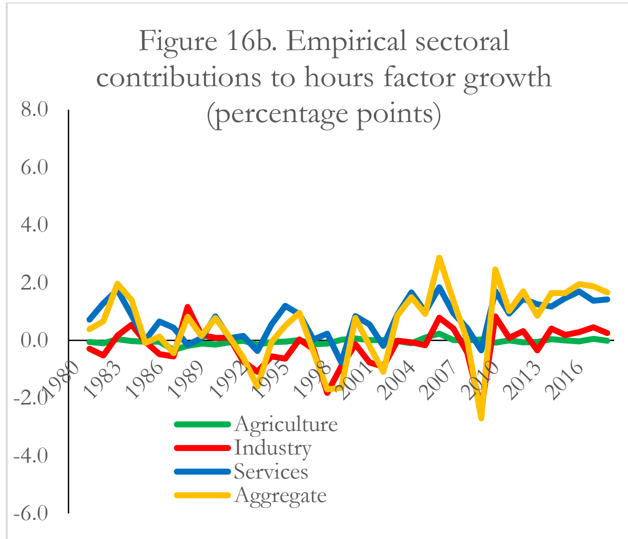


Figure 16b. Empirical sectoral contributions to hours factor growth (percentage points)

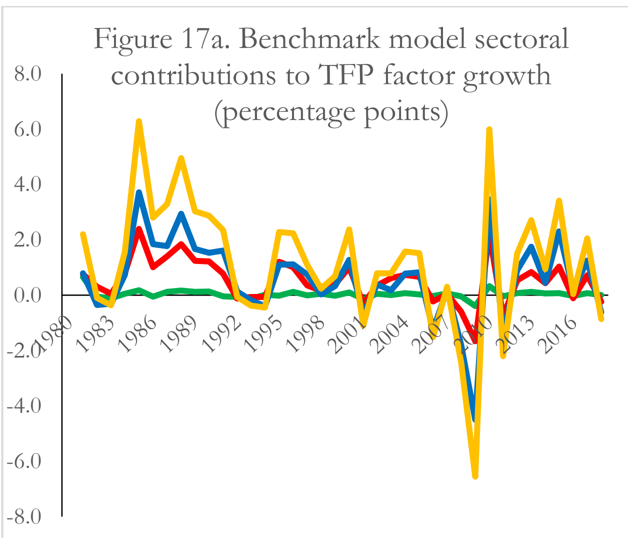


Figure 17a. Benchmark model sectoral contributions to TFP factor growth (percentage points)

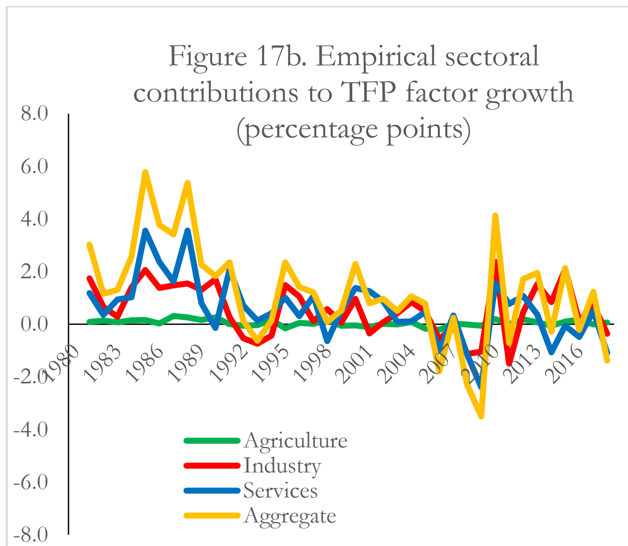


Figure 17b. Empirical sectoral contributions to TFP factor growth (percentage points)

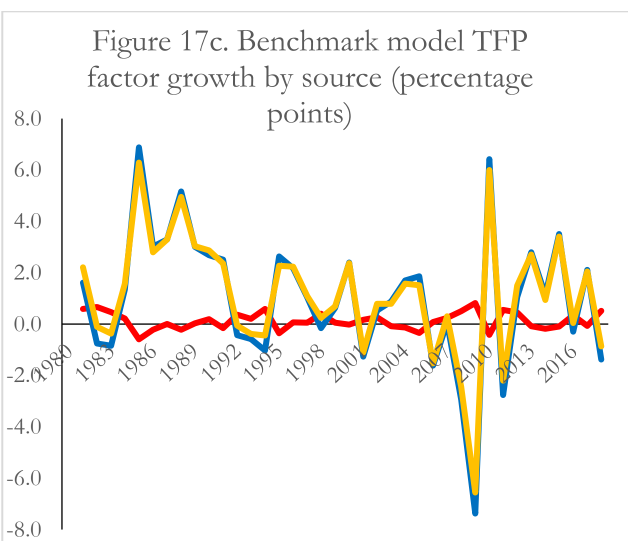


Figure 17c. Benchmark model TFP factor growth by source (percentage points)

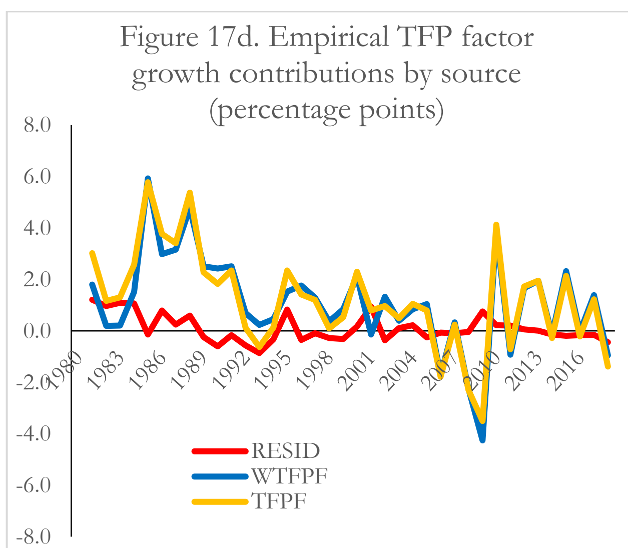


Figure 17d. Empirical TFP factor growth contributions by source (percentage points)

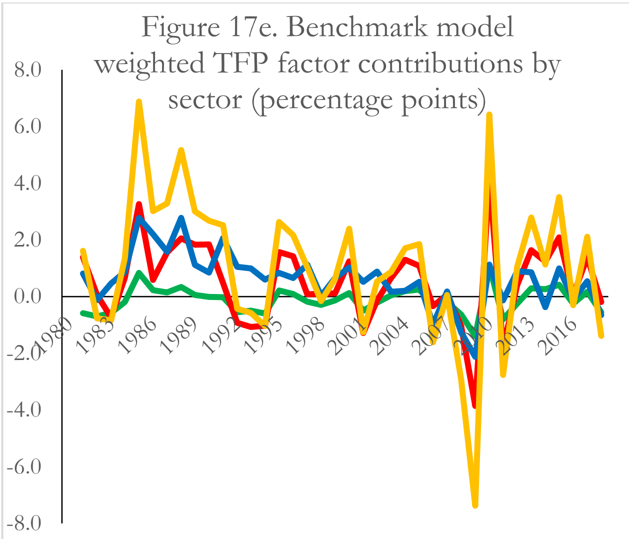


Figure 17e. Benchmark model weighted TFP factor contributions by sector (percentage points)
8.0
6.0
4.0
2.0
0.0
-2.0
-4.0
-6.0
-8.0

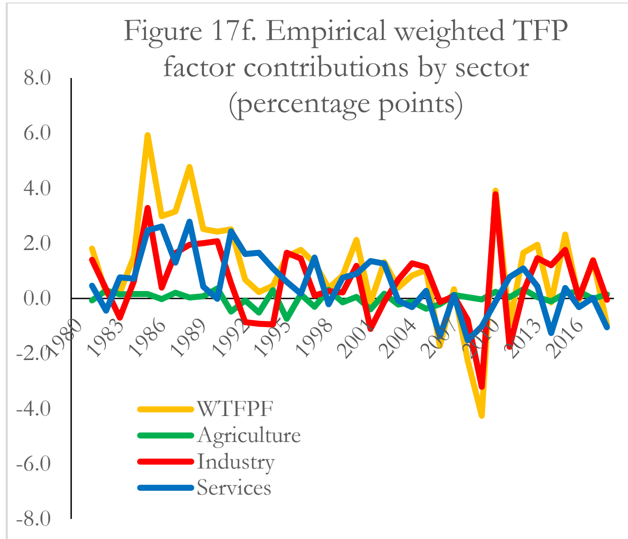


Figure 17f. Empirical weighted TFP factor contributions by sector (percentage points)
8.0
6.0
4.0
2.0
0.0
-2.0
-4.0
-6.0
-8.0
WTFPF
Agriculture
Industry
Services

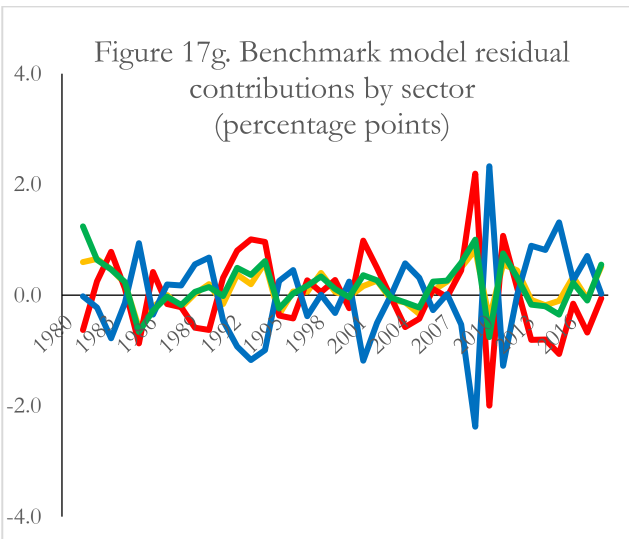


Figure 17g. Benchmark model residual contributions by sector (percentage points)
4.0
2.0
0.0
-2.0
-4.0

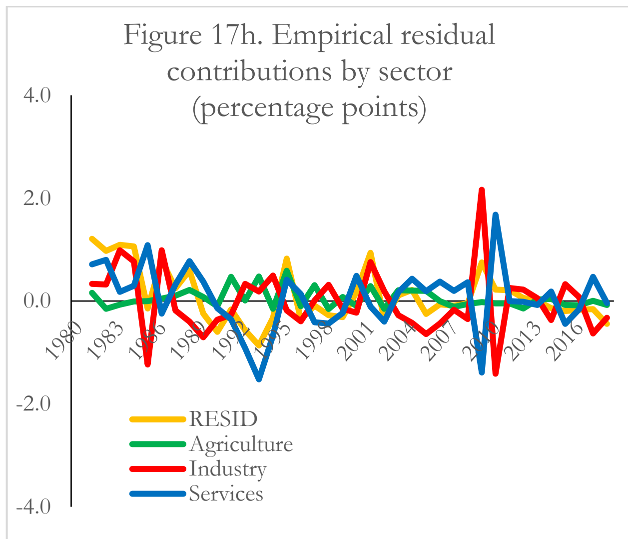


Figure 17h. Empirical residual contributions by sector (percentage points)
4.0
2.0
0.0
-2.0
-4.0
RESID
Agriculture
Industry
Services

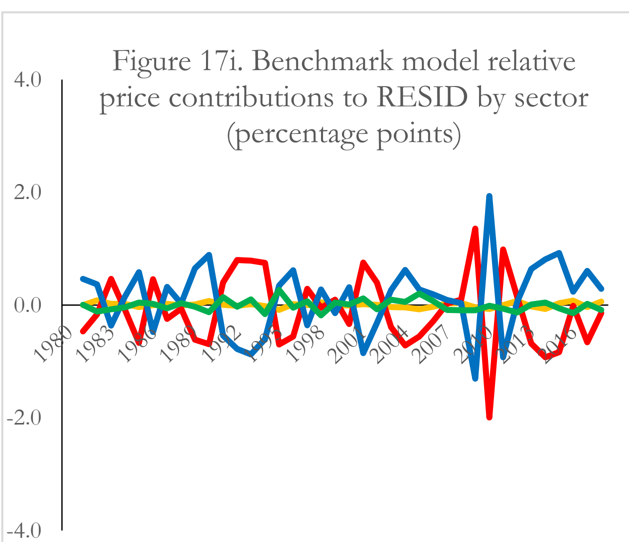


Figure 17i. Benchmark model relative price contributions to RESID by sector (percentage points)
4.0
2.0
0.0
-2.0
-4.0

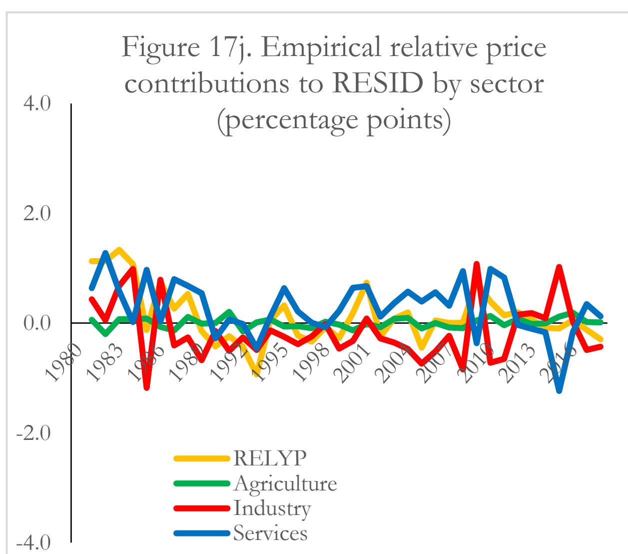


Figure 17j. Empirical relative price contributions to RESID by sector (percentage points)
4.0
2.0
0.0
-2.0
-4.0
RELYP
Agriculture
Industry
Services

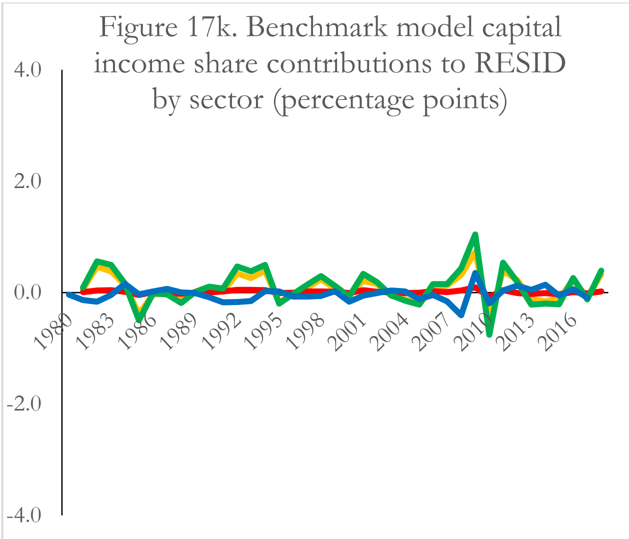


Figure 17k. Benchmark model capital income share contributions to RESID by sector (percentage points)

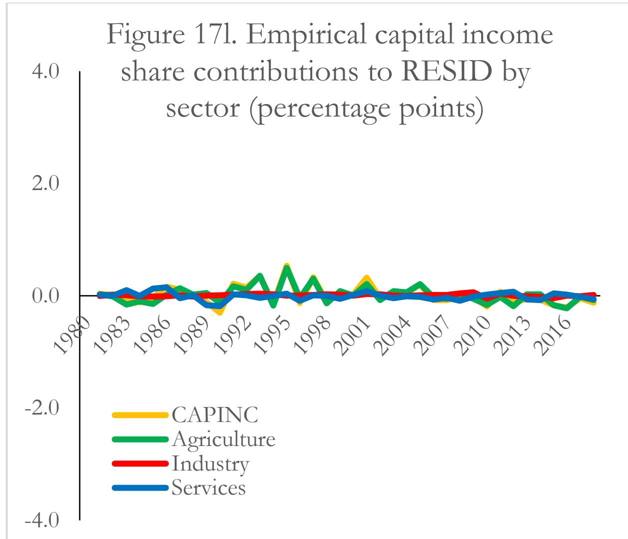


Figure 17l. Empirical capital income share contributions to RESID by sector (percentage points)

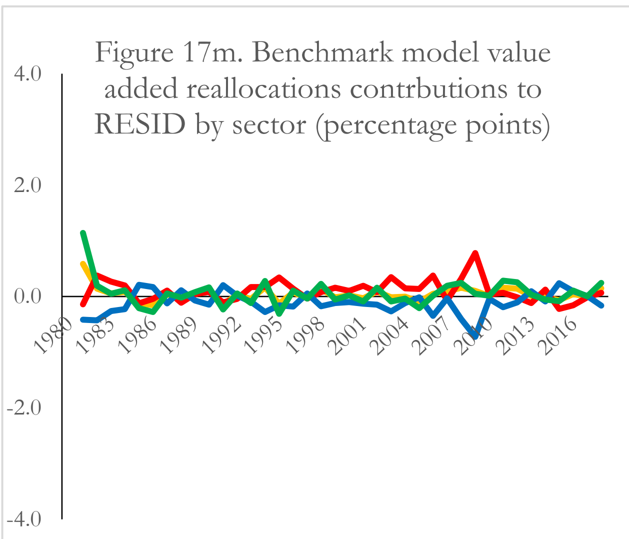


Figure 17m. Benchmark model value added reallocations contrbutions to RESID by sector (percentage points)

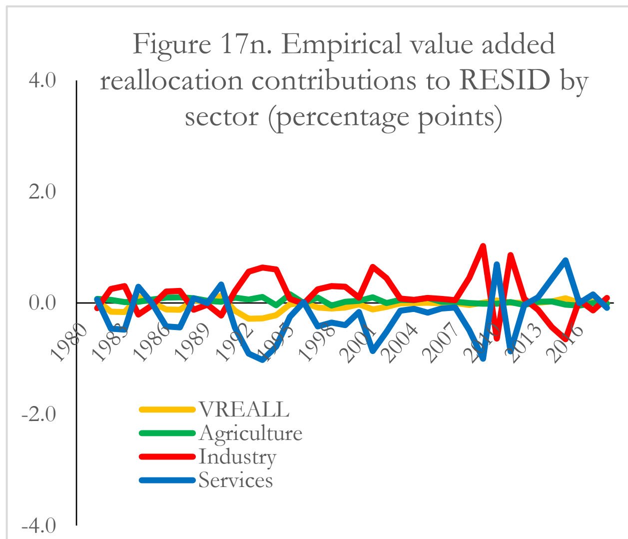


Figure 17n. Empirical value added reallocation contributions to RESID by sector (percentage points)

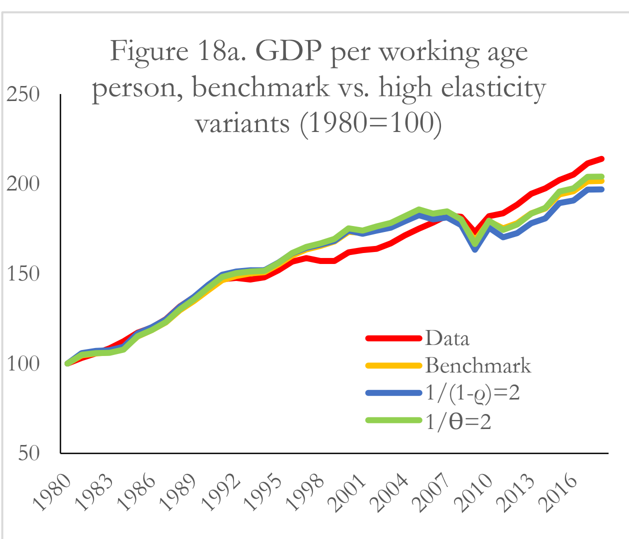


Figure 18a. GDP per working age person, benchmark vs. high elasticity variants (1980=100)

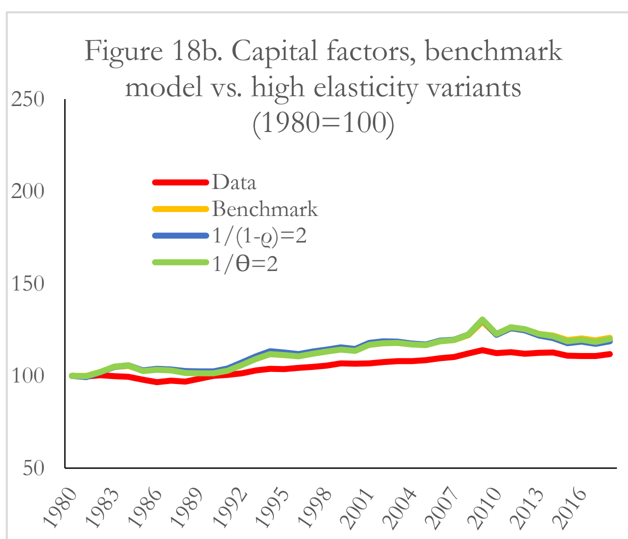


Figure 18b. Capital factors, benchmark model vs. high elasticity variants (1980=100)

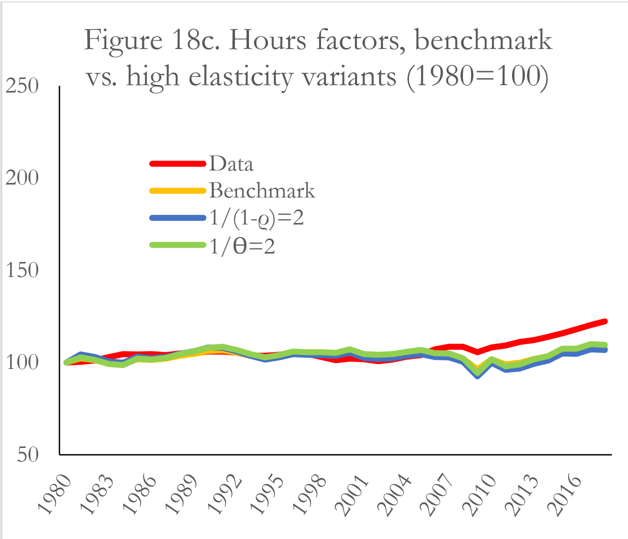


Figure 18c. Hours factors, benchmark vs. high elasticity variants (1980=100)
250
200
150
100
50
Data
Benchmark
1/(1-ϱ)=2
1/θ=2
1980
1983
1986
1989
1992
1995
1998
2001
2004
2007
2010
2013
2016

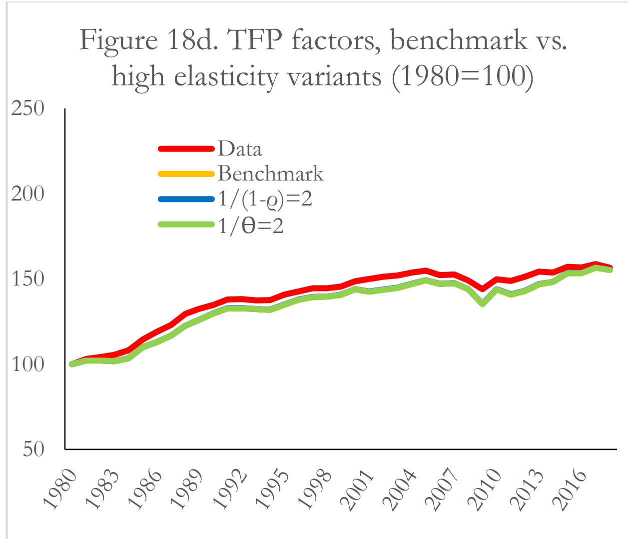


Figure 18d. TFP factors, benchmark vs. high elasticity variants (1980=100)
250
200
150
100
50
Data
Benchmark
1/(1-ϱ)=2
1/θ=2
1980
1983
1986
1989
1992
1995
1998
2001
2004
2007
2010
2013
2016

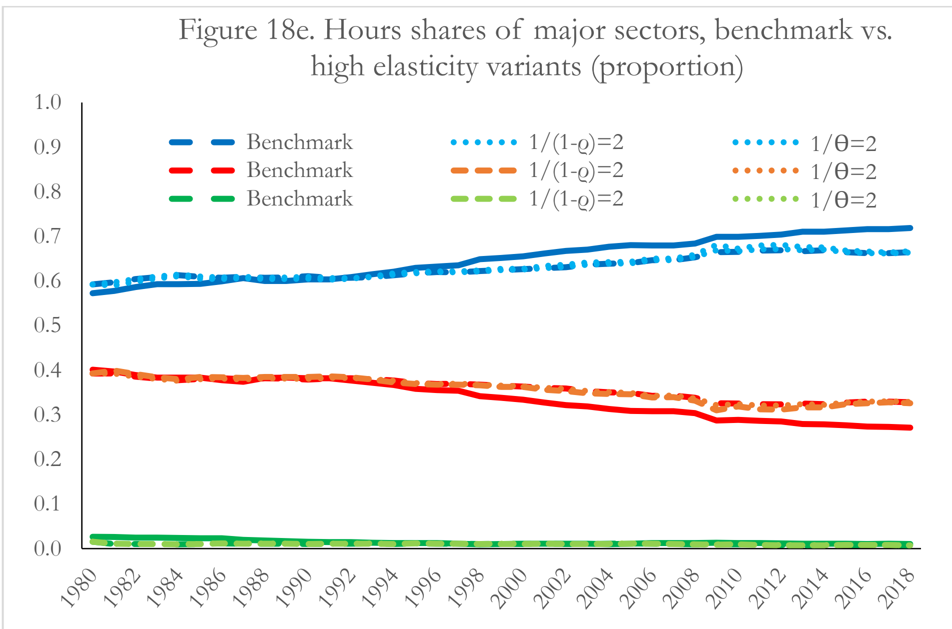


Figure 18e. Hours shares of major sectors, benchmark vs. high elasticity variants (proportion)
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
Benchmark
Benchmark
Benchmark
1/(1-ϱ)=2
1/(1-ϱ)=2
1/(1-ϱ)=2
1/θ=2
1/θ=2
1/θ=2
1980
1982
1984
1986
1988
1990
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
2014
2016
2018

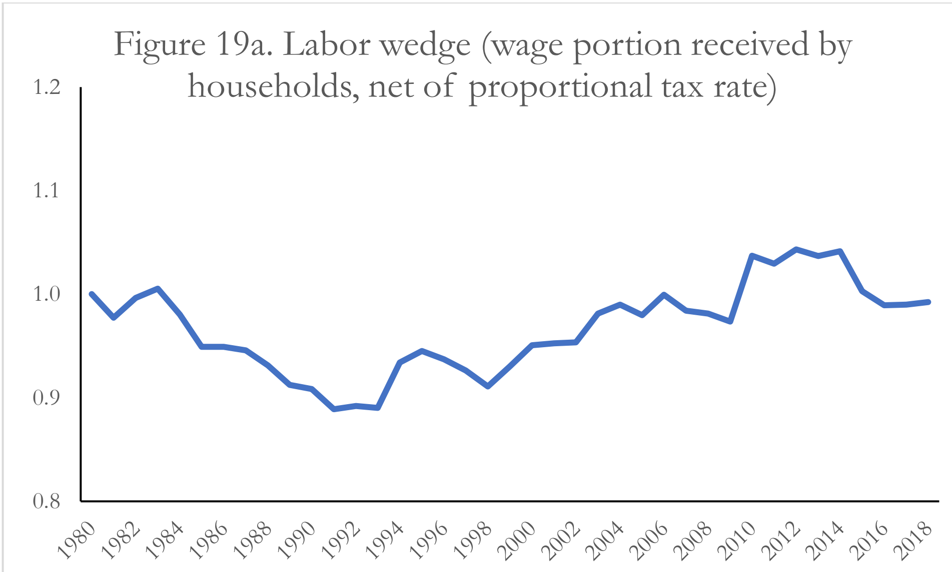


Figure 19a. Labor wedge (wage portion received by households, net of proportional tax rate)
1.2
1.1
1.0
0.9
0.8
1980
1982
1984
1986
1988
1990
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
2014
2016
2018

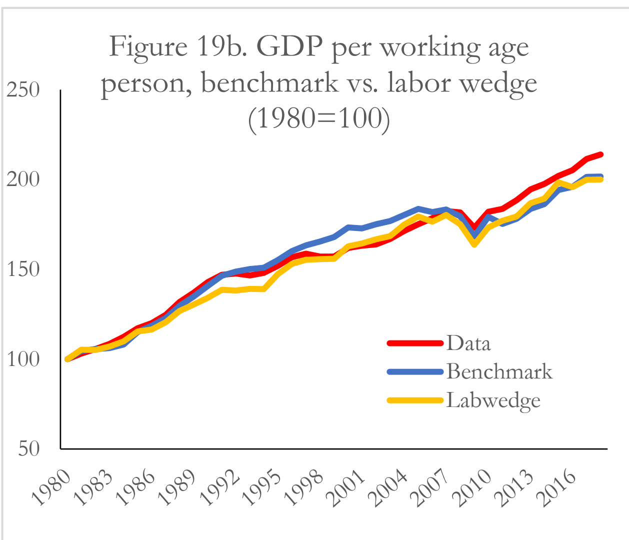
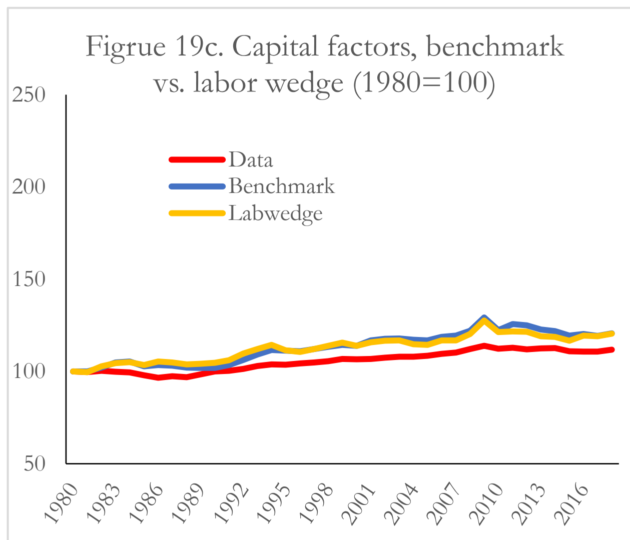


Figure 19b. GDP per working age person, benchmark vs. labor wedge (1980=100)
250
200
150
100
50
Data
Benchmark
Labwedge
1980
1983
1986
1989
1992
1995
1998
2001
2004
2007
2010
2013
2016


Figrue 19c. Capital factors, benchmark vs. labor wedge (1980=100)
250
200
150
100
50
Data
Benchmark
Labwedge
1980
1983
1986
1989
1992
1995
1998
2001
2004
2007
2010
2013
2016

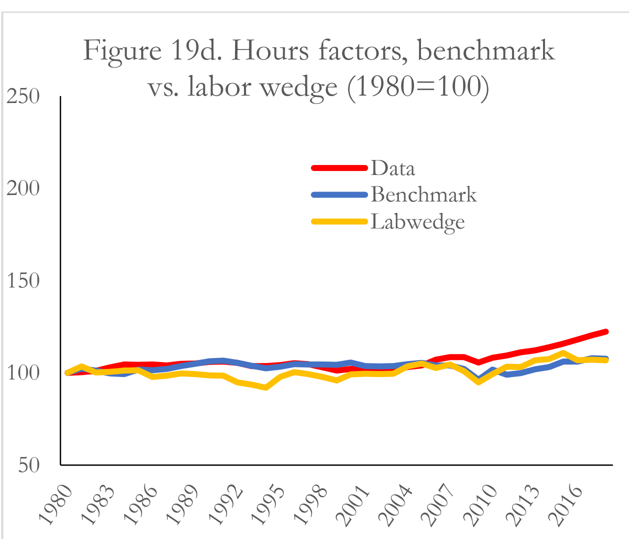


Figure 19d. Hours factors, benchmark vs. labor wedge (1980=100)
250
200
150
100
50
Data
Benchmark
Labwedge
1980
1983
1986
1989
1992
1995
1998
2001
2004
2007
2010
2013
2016

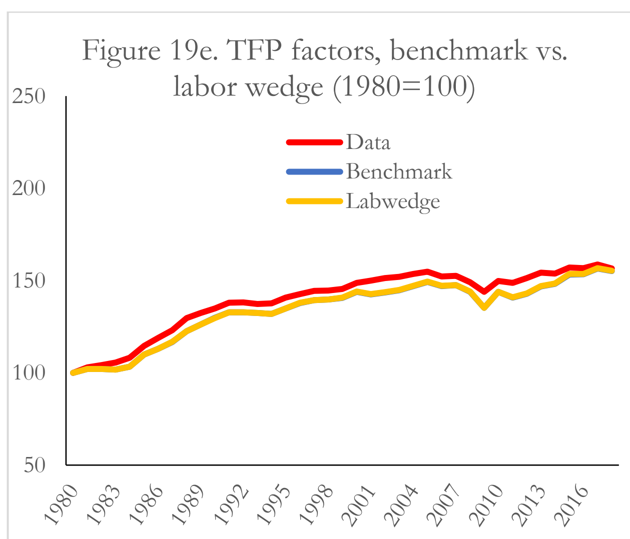


Figure 19e. TFP factors, benchmark vs. labor wedge (1980=100)
250
200
150
100
50
Data
Benchmark
Labwedge
1980
1983
1986
1989
1992
1995
1998
2001
2004
2007
2010
2013
2016

Table 1. Growth in output per working age person and output per hour worked, 1981-2018

Period	Y/N	Y/H
1981–1990	3.64	3.05
1991–2000	1.27	1.64
2001–2010	1.21	0.60
(2001-2007)	(1.72)	(0.83)
2011–2018	2.04	0.49
1981–2018	**2.04**	**1.49**

Table 2. Accounting for growth in output per working age person 1981–2018

Period	Y/N	$A^{\frac{1}{1-\alpha}}$	$(K/Y)^{\frac{\alpha}{1-\alpha}}$	H/N
1981–1990	**3.64**	3.05	0.01	0.58
1991–2000	**1.27**	0.98	0.65	-0.36
2001–2010	**1.21**	0.09	0.52	0.60
(2001-2007)	**(1.72)**	(0.37)	(0.46)	(0.89)
2011–2018	**2.04**	0.55	-0.06	1.54
1981-2018	**2.04**	**1.20**	**0.30**	**0.54**

Table 3. Accounting for growth in output per hour worked 1981-2018

Period	Y/H	$A^{\frac{1}{1-\alpha}}$	$(K/Y)^{\frac{\alpha}{1-\alpha}}$
1981–1990	**3.05**	3.05	0.01
1991–2000	**1.64**	0.98	0.65
2001–2010 **(2001-2007)**	**0.60** **(0.83)**	0.09 (0.37)	0.52 (0.46)
2011–2018	**0.49**	0.55	-0.06
1981-2018	**1.49**	**1.20**	**0.30**

Table 4. Sectoral value-added growth per working aged person 1981–2018

Period	Aggregate	Agriculture	Industry	Services
1981–1990	**3.64**	-0.04	3.44	3.01
1991–2000	**1.27**	-1.24	0.32	2.27
2001–2010	**1.21**	-1.86	0.94	1.22
2011–2018	**2.04**	-0.29	2.40	1.96
1981-2018	**2.04**	**-0.89**	**1.74**	**2.12**

Table 5. Sectoral contributions to GDP per working age person growth (percentage points)

Period	Aggregate	Agriculture	Industry	Services
1981–1990	**3.64**	-0.00	1.36	2.28
1991–2000	**1.27**	-0.06	-0.21	1.54
2001–2010	**1.21**	-0.03	-0.05	1.29
2011–2018	**2.04**	0.04	0.66	1.34
1981-2018	**2.04**	**-0.01**	**0.43**	**1.62**

Table 6. Sectoral contributions to aggregate capital factor growth (percentage points)

Period	Aggregate	Agriculture	Industry	Services
1981–1990	**0.01**	-0.07	-0.02	0.10
1991–2000	**0.65**	-0.01	0.11	0.55
2001–2010	**0.52**	-0.02	0.12	0.43
2011–2018	**-0.06**	-0.02	-0.04	-0.00
1981-2018	**0.30**	**-0.03**	**0.05**	**0.28**

Table 7. Sectoral contributions to hours per working age person growth (percentage points)

Period	Aggregate	Agriculture	Industry	Services
1981–1990	**0.58**	-0.10	0.03	0.65
1991–2000	**-0.36**	-0.05	-0.60	0.29
2001–2010	**0.60**	0.02	-0.27	0.85
2011–2018	**1.54**	-0.01	0.21	1.34
1981-2018	**0.54**	**-0.27**	**-0.23**	**0.46**

Table 8. Sectoral and aggregate TFP factor growth 1981–2018 (percent)

Period	Aggregate	Agriculture	Industry	Services
1981–1990	**3.05**	6.02	3.33	1.93
1991–2000	**0.98**	-5.47	0.47	1.72
2001–2010	**0.09**	-5.26	0.44	-0.20
2011–2018	**0.55**	10.12	1.92	0.02
1981-2018	**1.20**	**0.89**	**1.52**	**0.91**

Table 9. Sectoral contributions to aggregate TFP growth 1981–2018 (percentage points)

Period	Aggregate	Agriculture	Industry	Services
1981–1990	**3.05**	0.16	1.36	1.53
1991–2000	**0.98**	0.00	0.28	0.70
2001–2010	**0.09**	-0.03	0.10	0.01
2011–2018	**0.55**	0.07	0.49	0.00
1981-2018	**1.20**	**0.05**	**0.56**	**0.59**

Table 10. Weighted TFPF and RESID contributions to aggregate TFPF growth (percentage points)

Period	Aggregate TFPF	WTFPF	RESID
1981–1990	**3.05**	2.55	0.50
1991–2000	**0.98**	1.18	-0.20
2001–2010	**0.09**	-0.05	0.14
2011–2018	**0.55**	0.66	-0.10
1981-2018	**1.20**	**1.11**	**0.09**

Table 11. Sectoral WTFPF and RESID contributions to aggregate TFP factor growth (percentage points)

Period	Aggregate TFPF	Agriculture	Industry	Services
1981–1990	**3.05**	**0.16**	**1.36**	**1.53**
WTFPF	2.55	0.14	1.30	1.11
RESID	0.50	0.03	0.05	0.42
1991–2000	**0.98**	**0.00**	**0.28**	**0.70**
WTFPF	1.18	-0.14	0.27	1.05
RESID	-0.20	0.14	0.01	-0.35
2001–2010	**0.09**	**-0.03**	**0.10**	**0.01**
WTFPF	-0.05	-0.08	0.16	-0.14
RESID	0.14	0.05	-0.06	0.15
2011–2018	**0.55**	**0.07**	**0.49**	**0.00**
WTFPF	0.66	0.11	0.54	0.01
RESID	-0.10	-0.04	-0.05	-0.01
1981–2018	**1.20**	**0.05**	**0.56**	**0.59**
WTFPF	1.11	0.00	0.57	0.53
RESID	0.09	0.05	-0.01	0.06

Table 12. Sectoral contributions to aggregate RESID (percentage points)

Period	Aggregate RESID	Agriculture	Industry	Services
1981–1990	**0.50**	**0.03**	**0.05**	**0.42**
RELYP	**0.55**	-0.00	0.03	0.53
CAPINC	**-0.03**	-0.03	0.00	0.00
VREALL	**-0.02**	0.06	0.03	-0.10
1991–2000	**-0.20**	**0.14**	**0.01**	**-0.35**
RELYP	**-0.20**	-0.02	-0.31	0.13
CAPINC	**0.13**	0.12	0.02	-0.01
VREALL	**-0.12**	0.05	0.30	-0.47
2001–2010	**0.07**	**0.05**	**-0.06**	**0.15**
RELYP	**0.15**	-0.00	-0.30	0.46
CAPINC	**0.02**	0.02	-0.02	0.02
VREALL	**-0.02**	0.03	0.23	-0.28
2011–2018	**-0.10**	**-0.04**	**-0.05**	**-0.01**
RELYP	**-0.02**	0.04	-0.01	-0.05
CAPINC	**-0.09**	-0.08	-0.00	-0.01
VREALL	**0.02**	-0.01	-0.03	0.06
1981–2018	**0.10**	**0.05**	**-0.01**	**0.06**
RELYP	**0.13**	0.00	-0.16	0.28
CAPINC	**0.01**	0.01	0.01	-0.01
VREALL	**-0.04**	0.03	0.14	-0.21

Table 13. Calibrated parameters of benchmark model

Parameter	Value	Source/target
Technology		
α	0.362	Hayashi and Prescott (2002)
$\alpha_a, \alpha_m, \alpha_s$	0.708, 0.372, 0.335	OECD (STAN), JSNA (1980)
$A_{a,1980}, A_{m,1980}, A_{s,1980}$	5.376, 112.958, 132.063	OECD (STAN), JSNA (1980)
$\Delta_{a,v}, \Delta_{m,v}, \Delta_{s,v}$	0.082, 0.008, 0.007	JSNA sectoral value added (1980)
$\omega_{x,a}, \omega_{x,m}, \omega_{x,s}$	0.036, 0.666, 0.297	JSNA input-output (1980)
Δ_x	1.000	JSNA fixed investment (1980)
δ	0.062	JSNA capital consumption (1980)
k_0	271.940	JSNA capital-GDP ratio (1980)
γ	1.012	Sample average TFP growth rate
$\sigma_{A,a}, \sigma_{A,m}, \sigma_{A,s}$	0.012	Sample average TFP growth rate
Preferences		
β	0.989	WDI, long-run real interest rate
ϕ	0.327	JSNA, labor 1/3 total time, 1980
$\omega_{c,a}, \omega_{c,m}, \omega_{c,s}$	0.015, 0.250, 0.735	JSNA input-output (1980)
$\bar{c}_a, \bar{c}_s$	1.231, 10.934	Herrendorf et al. (2013), JSNA input-output (1980)
Δ_c	0.423	JSNA consumption spending (1980)
n	1.000	Sample average working population growth rate
Government		
τ_k	0.3598	Chen et al. (2006)
$\omega_{g,a}, \omega_{g,m}, \omega_{g,s}$	0.018, 0.129, 0.853	JSNA input-output (1980)
Δ_g	1.000	JSNA government spending (1980)
$\bar{g}$	0.198	JSNA government share of GDP (2018)
Elasticities		
$1/(1-\rho)$	1.000	Herrendorf et al. (2014)
ε	0.000	Herrendorf et al. (2013)
ϑ	0.000	Herrendorf et al. (2013)
$1/\theta$	1.000	Kehoe and Prescott (2002)

Table 14. Benchmark model's aggregate growth accounting for GDP per working age person, data in parentheses (percentage points)

Period	Y/N	$A^{\frac{1}{1-\alpha}}$	$(K/Y)^{\frac{\alpha}{1-\alpha}}$	H/N
1981–1990	**3.49** **(3.64)**	2.65 (3.05)	0.21 (0.01)	0.62 (0.58)
1991–2000	**2.11** **(1.27)**	1.04 (0.98)	1.13 (0.65)	-0.06 (-0.36)
2001–2010	**0.39** **(1.21)**	-0.07 (0.09)	0.79 (0.52)	-0.33 (0.60)
2011–2018	**1.50** **(2.04)**	0.95 (0.55)	-0.16 (-0.06)	0.72 (1.54)
1981-2018	**1.89** **(2.04)**	**1.15** **(1.20)**	**0.53** **(0.30)**	**0.21** **(0.54)**

Table 15. Benchmark model's aggregate growth accounting for GDP per hour worked, data in parentheses (percentage points)

Period	Y/H	$A^{\frac{1}{1-\alpha}}$	$(K/Y)^{\frac{\alpha}{1-\alpha}}$
1981–1990	**2.86** **(3.05)**	2.65 (3.05)	0.21 (0.01)
1991–2000	**2.17** **(1.64)**	1.04 (0.98)	1.13 (0.65)
2001–2010	**0.72** **(0.60)**	-0.07 (0.09)	0.79 (0.52)
2011–2018	**0.79** **(0.49)**	0.95 (0.55)	-0.16 (-0.06)
1981-2018	**1.68** **(1.49)**	**1.15** **(1.20)**	**0.53** **(0.30)**

Table 16. Benchmark model's sectoral contributions to GDP per working aged person growth, data in parentheses (percentage points)

Period	Aggregate/ sum	Agriculture	Industry	Services
1981–1990	**3.49** **(3.64)**	-0.03 (-0.00)	1.26 (1.36)	2.25 (2.28)
1991–2000	**2.11** **(1.27)**	0.06 (-0.06)	0.64 (-0.21)	1.41 (1.54)
2001–2010	**0.39** **(1.21)**	-0.01 (-0.03)	-0.24 (-0.05)	0.64 (1.29)
2011–2018	**1.50** **(2.04)**	-0.06 (0.04)	0.57 (0.66)	0.99 (1.34)
1981-2018	**1.89** **(2.04)**	**-0.01** **(-0.01)**	**0.56** **(0.43)**	**1.34** **(1.62)**

Table 17. Benchmark model's sectoral contributions to capital deepening, data in parentheses (percentage points)

Period	Aggregate/ Sum	Agriculture	Industry	Services
1981–1990	**0.22** **(0.01)**	-0.11 (-0.07)	0.05 (-0.02)	0.27 (0.10)
1991–2000	**1.13** **(0.65)**	0.06 (-0.01)	0.36 (0.11)	0.71 (0.55)
2001–2010	**0.79** **(0.52)**	0.01 (-0.02)	0.08 (0.12)	0.70 (0.43)
2011–2018	**-0.16** **(-0.06)**	-0.07 (-0.02)	-0.02 (-0.06)	-0.07 (-0.00)
1981-2018	**0.53** **(0.30)**	**-0.03** **(-0.03)**	**0.13** **(0.05)**	**0.43** **(0.28)**

Table 18. Benchmark model's sectoral contributions to hours factor growth, data in parentheses (percentage points)

Period	Aggregate/ sum	Agriculture	Industry	Services
1981–1990	**0.62** **(0.58)**	-0.04 (-0.10)	0.11 (0.03)	0.56 (0.65)
1991–2000	**-0.06** **(-0.36)**	0.00 (-0.05)	-0.19 (-0.60)	0.13 (0.29)
2001–2010	**-0.34** **(0.60)**	-0.01 (0.02)	-0.50 (-0.27)	0.18 (0.85)
2011–2018	**0.72** **(1.54)**	-0.02 (-0.01)	0.28 (0.21)	0.46 (1.34)
1981-2018	**0.21** **(0.54)**	**-0.02** **(-0.03)**	**-0.09** **(-0.18)**	**0.32** **(0.75)**

Table 19a. Benchmark model's sectoral contributions to TFP factor growth, data in parentheses (percentage points)

Period	Aggregate/ sum	Agriculture	Industry	Services
1981–1990	**2.65 (3.05)**	0.12 (0.16)	1.10 (1.36)	1.43 (1.53)
1991–2000	**1.04 (0.98)**	-0.00 (0.00)	0.46 (0.28)	0.58 (0.70)
2001–2010	**-0.07 (0.09)**	-0.01 (-0.03)	0.18 (0.10)	-0.24 (0.01)
2011–2018	**0.95 (0.55)**	0.04 (0.07)	0.31 (0.49)	0.60 (0.00)
1981-2018	**1.15 (1.20)**	**0.04 (0.05)**	**0.52 (0.56)**	**0.59 (0.59)**

Table 19b. Benchmark model's WTFPF and RESID contributions to aggregate TFP factor growth, data in parentheses (percentage points)

Period	Aggregate TFPF	WTFPF	RESID
1981–1990	**2.65** **(3.05)**	2.54 (2.55)	0.11 (0.50)
1991–2000	**1.02** **(0.98)**	0.92 (1.18)	0.12 (-0.20)
2001–2010	**-0.07** **(0.09)**	-0.18 (-0.05)	0.11 (0.14)
2011–2018	**0.95** **(0.55)**	0.77 (0.66)	0.18 (-0.10)
1981-2018	**1.15** **(1.20)**	**1.03** **(1.11)**	**0.13** **(0.09)**

Table 19c. Benchmark model's sectoral WTFPF and RESID contributions to aggregate TFPF growth, data in parentheses (percentage points)

Period	Aggregate TFPF	Agriculture	Industry	Services
1981–1990	**2.65** **(3.05)**	**0.12** **(0.16)**	**1.10** **(1.36)**	**1.43** **(1.53)**
WTFPF	2.54 (2.55)	-0.05 (0.14)	1.25 (1.30)	1.33 (1.11)
RESID	0.11 (0.50)	0.16 (0.03)	-0.15 (0.05)	0.10 (0.42)
1991–2000	**1.02** **(0.98)**	**-0.00** **0.00**	**0.46** **(0.28)**	**0.58** **(0.70)**
WTFPF	0.92 (1.18)	-0.18 (-0.14)	0.20 (0.27)	0.90 (1.05)
RESID	0.12 (-0.20)	0.18 (0.14)	0.27 (0.01)	-0.33 (-0.35)
2001–2010	**-0.07** **(0.09)**	**-0.01** **(-0.03)**	**0.18** **(0.10)**	**-0.24** **(0.01)**
WTFPF	-0.18 (-0.05)	-0.16 (-0.08)	0.06 (0.16)	-0.08 (-0.14)
RESID	0.11 (0.14)	0.16 (0.05)	0.12 (-0.06)	-0.16 (0.15)
2011–2018	**0.95** **(0.55)**	**0.04** **(0.07)**	**0.31** **(0.49)**	**0.60** **(0.00)**
WTFPF	0.77 (0.66)	-0.09 (0.11)	0.60 (0.54)	0.26 (0.01)
RESID	0.18 (-0.10)	0.13 (-0.04)	-0.29 (-0.05)	0.34 (-0.01)
1981–2018	**1.15** **(1.20)**	**0.04** **(0.05)**	**0.52** **(0.56)**	**0.59** **(0.59)**
WTFPF	1.03 (1.11)	-0.12 (0.00)	0.52 (0.57)	0.62 (0.53)
RESID	0.13 (0.09)	0.16 (0.05)	-0.00 (-0.01)	-0.03 (0.06)

Table 19d. Benchmark model's sectoral contributions to aggregate RESID, data in parentheses (percentage points)

Period	Aggregate RESID	Agriculture	Industry	Services
1981–1990	**0.11 (0.50)**	**-0.16 (0.03)**	**0.15 (0.05)**	**0.10 (0.42)**
RELYP	0.02 (0.55)	-0.03 (-0.00)	-0.21 (0.03)	0.26 (0.53)
CAPINC	0.06 (-0.03)	0.07 (-0.03)	0.00 (0.00)	-0.02 (0.00)
VREALL	0.07 (-0.02)	0.13 (0.06)	0.06 (0.03)	-0.12 (-0.10)
1991–2000	**0.12 (-0.20)**	**0.18 (0.14)**	**0.27 (0.01)**	**-0.33 (-0.35)**
RELYP	-0.00 (-0.20)	0.02 (-0.02)	0.15 (-0.31)	-0.17 (0.13)
CAPINC	0.12 (0.13)	0.17 (0.12)	0.02 (0.02)	-0.07 (-0.01)
VREALL	0.01 (-0.12)	-0.01 (0.05)	0.10 (0.30)	-0.08 (-0.47)
2001–2010	**0.11 (0.14)**	**0.16 (0.05)**	**0.12 (-0.06)**	**-0.16 (0.15)**
RELYP	-0.02 (0.15)	0.02 (-0.00)	-0.13 (-0.30)	0.09 (0.46)
CAPINC	0.07 (0.02)	0.11 (0.02)	0.01 (-0.02)	-0.05 (0.02)
VREALL	0.04 (-0.02)	0.02 (0.03)	0.23 (0.23)	-0.22 (-0.28)
2011–2018	**0.18 (-0.10)**	**0.13 (-0.04)**	**-0.29 (-0.05)**	**0.34 (-0.01)**
RELYP	0.01 (-0.02)	-0.05 (0.04)	0.27 (-0.01)	0.33 (-0.05)
CAPINC	0.09 (-0.09)	0.08 (-0.08)	-0.00 (-0.00)	0.01 (-0.01)
VREALL	0.05 (0.02)	0.10 (-0.01)	-0.03 (-0.03)	-0.01 (0.06)
1981–2018	**0.13 (0.10)**	**0.16 (0.05)**	**-0.00 (-0.01)**	**-0.03 (0.06)**
RELYP	0.00 (0.13)	-0.01 (0.00)	-0.11 (-0.16)	0.12 (0.28)
CAPINC	0.08 (0.01)	0.11 (0.01)	0.01 (0.01)	-0.04 (-0.01)
VREALL	0.04 (-0.04)	0.06 (0.03)	0.10 (0.14)	-0.11 (-0.21)

Table 20. Benchmark model vs. high elasticity variants aggregate growth accounting for GDP per working age person, data in parentheses (percentage points)

Period	Y/N	$A^{\frac{1}{1-\alpha}}$	$(K/Y)^{\frac{\alpha}{1-\alpha}}$	H/N
1981–1990				
High 1/(1-ϱ)	**3.72**	2.65	0.26	0.81
High 1/θ	**3.60**	2.65	0.16	0.80
Benchmark	**3.49**	2.65	0.21	0.62
Data	**(3.64)**	(3.05)	(0.01)	(0.58)
1991–2000				
High 1/(1-ϱ)	**1.93**	1.03	1.16	-0.25
High 1/θ	**2.12**	1.03	1.17	-0.08
Benchmark	**2.11**	1.04	1.13	-0.06
Data	**(1.27)**	(0.98)	(0.65)	(-0.36)
2001–2010				
High 1/(1-ϱ)	**0.17**	-0.10	0.73	-0.46
High 1/θ	**0.31**	-0.10	0.85	-0.45
Benchmark	**0.39**	-0.07	0.79	-0.33
Data	**(1.21)**	(0.09)	(0.52)	(0.60)
2011–2018				
High 1/(1-ϱ)	**1.46**	0.93	-0.32	0.85
High 1/θ	**1.64**	0.94	-0.25	0.95
Benchmark	**1.50**	0.95	-0.16	0.72
Data	**(2.04)**	(0.55)	(-0.06)	(1.54)
1981-2018				
High 1/(1-ϱ)	**1.84**	**1.14**	**0.50**	**0.21**
High 1/θ	**1.93**	**1.14**	**0.52**	**0.27**
Benchmark	**1.89**	**1.15**	**0.53**	**0.21**
Data	**(2.04)**	**(1.20)**	**(0.30)**	**(0.54)**

Table 21a. Benchmark model vs. high elasticity variants sectoral contributions to GDP per working aged person growth, data in parentheses (percentage points)

Period	Aggregate/ sum	Agriculture	Industry	Services
1981–1990				
High $1/(1-\varrho)$	**3.72**	-0.02	1.42	2.32
High $1/\theta$	**3.60**	-0.03	1.31	2.32
Benchmark	**3.49**	-0.03	1.26	2.25
Data	**(3.64)**	(-0.00)	(1.36)	(2.28)
1991–2000				
High $1/(1-\varrho)$	**1.93**	0.05	0.51	1.38
High $1/\theta$	**2.12**	0.06	0.64	1.42
Benchmark	**2.11**	0.06	0.64	1.41
Data	**(1.27)**	(-0.06)	(-0.21)	(1.54)
2001–2010				
High $1/(1-\varrho)$	**0.17**	-0.02	-0.36	0.55
High $1/\theta$	**0.31**	-0.01	-0.28	0.60
Benchmark	**0.39**	-0.01	-0.24	0.64
Data	**(1.21)**	(-0.03)	(-0.05)	(1.29)
2011–2018				
High $1/(1-\varrho)$	**1.46**	-0.05	0.60	0.91
High $1/\theta$	**1.64**	-0.05	0.63	1.05
Benchmark	**1.50**	-0.06	0.57	0.99
Data	**(2.04)**	(0.04)	(0.66)	(1.34)
1981-2018				
High $1/(1-\varrho)$	**1.84**	**-0.01**	**0.54**	**1.31**
High $1/\theta$	**1.93**	**-0.01**	**0.57**	**1.37**
Benchmark	**1.89**	**-0.01**	**0.56**	**1.34**
Data	**(2.04)**	**(-0.01)**	**(0.43)**	**(1.62)**

Table 21b. Benchmark model vs. high elasticity variants sectoral contributions to capital deepening, data in parentheses (percentage points)

Period	Aggregate/ sum	Agriculture	Industry	Services
1981–1990				
High $1/(1-\varrho)$	**0.26**	-0.10	0.10	0.26
High $1/\theta$	**0.16**	-0.12	0.03	0.23
Benchmark	**0.22**	-0.11	0.05	0.27
Data	**(0.01)**	(-0.07)	(-0.02)	(0.10)
1991–2000				
High $1/(1-\varrho)$	**1.16**	0.06	0.34	0.76
High $1/\theta$	**1.17**	0.06	0.38	0.73
Benchmark	**1.13**	0.06	0.36	0.71
Data	**(0.65)**	(-0.01)	(0.11)	(0.55)
2001–2010				
High $1/(1-\varrho)$	**0.63**	0.01	0.02	0.70
High $1/\theta$	**0.85**	0.01	0.09	0.75
Benchmark	**0.79**	0.01	0.08	0.70
Data	**(0.52)**	(-0.02)	(0.12)	(0.43)
2011–2018				
High $1/(1-\varrho)$	**-0.32**	-0.07	-0.04	-0.21
High $1/\theta$	**-0.25**	-0.07	-0.04	-0.14
Benchmark	**-0.16**	-0.07	-0.02	-0.07
Data	**(-0.06)**	(-0.02)	(-0.06)	(-0.00)
1981-2018				
High $1/(1-\varrho)$	**0.50**	**-0.03**	**0.11**	**0.41**
High $1/\theta$	**0.52**	**-0.03**	**0.12**	**0.42**
Benchmark	**0.53**	**-0.03**	**0.13**	**0.43**
Data	**(0.30)**	**(-0.03)**	**(0.05)**	**(0.28)**

Table 21c. Benchmark model vs. high elasticity variants sectoral contributions to hours factor growth, data in parentheses (percentage points)

Period	Aggregate/ sum	Agriculture	Industry	Services
1981–1990				
High $1/(1-\varrho)$	**0.81**	-0.04	0.24	0.61
High $1/\Theta$	**0.80**	-0.04	0.18	0.65
Benchmark	**0.62**	-0.04	0.11	0.56
Data	**(0.58)**	(-0.10)	(0.03)	(0.65)
1991–2000				
High $1/(1-\varrho)$	**-0.25**	-0.00	-0.32	0.08
High $1/\Theta$	**-0.08**	0.00	-0.20	0.12
Benchmark	**-0.06**	0.00	-0.19	0.13
Data	**(-0.36)**	(-0.05)	(-0.60)	(0.29)
2001–2010				
High $1/(1-\varrho)$	**-0.46**	-0.02	-0.59	0.14
High $1/\Theta$	**-0.45**	-0.02	-0.56	0.12
Benchmark	**-0.34**	-0.01	-0.50	0.18
Data	**(0.60)**	(0.02)	(-0.27)	(0.85)
2011–2018				
High $1/(1-\varrho)$	**0.85**	-0.02	0.37	0.50
High $1/\Theta$	**0.95**	-0.02	0.37	0.60
Benchmark	**0.72**	-0.02	0.28	0.46
Data	**(1.54)**	(-0.01)	(0.21)	(1.34)
1981-2018				
High $1/(1-\varrho)$	**0.21**	**-0.02**	**-0.10**	**0.32**
High $1/\Theta$	**0.27**	**-0.02**	**-0.07**	**0.36**
Benchmark	**0.21**	**-0.02**	**-0.09**	**0.32**
Data	**(0.54)**	**(-0.03)**	**(-0.18)**	**(0.75)**

Table 21d. Benchmark model vs. high elasticity variants sectoral contributions to TFP factor growth, data in parentheses (percentage points)

Period	Aggregate/ sum	Agriculture	Industry	Services
1981–1990				
High $1/(1-\varrho)$	**2.65**	0.12	1.08	1.45
High $1/\theta$	**2.65**	0.12	1.10	1.43
Benchmark	**2.65**	0.12	1.10	1.43
Data	**(3.05)**	(0.16)	(1.36)	(1.53)
1991–2000				
High $1/(1-\varrho)$	**1.03**	-0.00	0.49	0.54
High $1/\theta$	**1.03**	-0.00	0.46	0.57
Benchmark	**1.04**	-0.00	0.46	0.58
Data	**(0.98)**	(0.00)	(0.28)	(0.70)
2001–2010				
High $1/(1-\varrho)$	**-0.10**	-0.01	0.21	-0.30
High $1/\theta$	**-0.10**	-0.01	0.18	-0.27
Benchmark	**-0.07**	-0.01	0.18	-0.24
Data	**(0.09)**	(-0.03)	(0.10)	(0.01)
2011–2018				
High $1/(1-\varrho)$	**0.93**	0.04	0.27	0.62
High $1/\theta$	**0.94**	0.04	0.29	0.60
Benchmark	**0.95**	0.04	0.31	0.60
Data	**(0.55)**	(0.07)	(0.49)	(0.00)
1981–2018				
High $1/(1-\varrho)$	**1.14**	0.04	0.53	0.57
High $1/\theta$	**1.14**	0.04	0.52	0.58
Benchmark	**1.15**	0.04	0.52	0.59
Data	**(1.20)**	(0.05)	(0.56)	(0.59)

Table 22. Benchmark model vs. wedge variants aggregate growth accounting for GDP per working age person, data in parentheses (percentage points)

Period	Y/N	$A^{\frac{1}{1-\alpha}}$	$(K/Y)^{\frac{\alpha}{1-\alpha}}$	H/N
1981–1990				
Labor wedge	**2.99**	2.63	0.48	-0.12
Benchmark	**3.49**	2.65	0.21	0.62
Data	**(3.64)**	(3.05)	(0.01)	(0.58)
1991–2000				
Labor wedge	**1.99**	1.01	0.87	0.10
Benchmark	**2.11**	1.04	1.13	-0.06
Data	**(1.27)**	(0.98)	(0.65)	(-0.36)
2001–2010				
Labor wedge	**0.69**	-0.07	0.70	0.06
Benchmark	**0.39**	-0.07	0.79	-0.33
Data	**(1.21)**	(0.09)	(0.52)	(0.60)
2011–2018				
Labor wedge	**1.82**	0.94	-0.07	0.95
Benchmark	**1.50**	0.95	-0.16	0.72
Data	**(2.04)**	(0.55)	(-0.06)	(1.54)
1981-2018				
Labor wedge	**1.87**	**1.14**	**0.53**	**0.21**
Benchmark	**1.89**	**1.15**	**0.53**	**0.21**
Data	**(2.04)**	**(1.20)**	**(0.30)**	**(0.54)**

Table 23a. Benchmark model vs. wedge variants sectoral contributions to GDP per working aged person growth, data in parentheses (percentage points)

Period	Aggregate/ sum	Agriculture	Industry	Services
1981–1990				
Labor wedge	**2.99**	-0.05	1.04	2.00
Benchmark	**3.49**	-0.03	1.26	2.25
Data	**(3.64)**	(-0.00)	(1.36)	(2.28)
1991–2000				
Labor wedge	**1.99**	0.06	0.58	1.34
Benchmark	**2.11**	0.06	0.64	1.41
Data	**(1.27)**	(-0.06)	(-0.21)	(1.54)
2001–2010				
Labor wedge	**0.69**	-0.00	-0.11	0.80
Benchmark	**0.39**	-0.01	-0.24	0.64
Data	**(1.21)**	(-0.03)	(-0.05)	(1.29)
2011–2018				
Labor wedge	**1.82**	-0.05	0.70	1.17
Benchmark	**1.50**	-0.06	0.57	0.99
Data	**(2.04)**	(0.04)	(0.66)	(1.34)
1981-2018				
Labor wedge	**1.87**	**-0.01**	**0.55**	**1.33**
Benchmark	**1.89**	**-0.01**	**0.56**	**1.34**
Data	**(2.04)**	**(-0.01)**	**(0.43)**	**(1.62)**

Table 23b. Benchmark model vs. wedge variants sectoral contributions to capital deepening, data in parentheses (percentage points)

Period	Aggregate/ sum	Agriculture	Industry	Services
1981–1990				
Labor wedge	**0.48**	-0.10	0.14	0.44
Benchmark	**0.22**	-0.11	0.05	0.27
Data	**(0.01)**	(-0.07)	(-0.02)	(0.10)
1991–2000				
Labor wedge	**0.87**	0.05	0.25	0.57
Benchmark	**1.13**	0.06	0.36	0.71
Data	**(0.65)**	(-0.01)	(0.11)	(0.55)
2001–2010				
Labor wedge	**0.70**	0.01	0.06	0.64
Benchmark	**0.79**	0.01	0.08	0.70
Data	**(0.52)**	(-0.02)	(0.12)	(0.43)
2011–2018				
Labor wedge	**-0.07**	-0.07	0.03	-0.03
Benchmark	**-0.16**	-0.07	-0.02	-0.07
Data	**(-0.06)**	(-0.02)	(-0.06)	(-0.00)
1981-2018				
Labor wedge	**0.53**	**-0.03**	**0.12**	**0.43**
Benchmark	**0.53**	**-0.03**	**0.13**	**0.43**
Data	**(0.30)**	**(-0.03)**	**(0.05)**	**(0.28)**

Table 23c. Benchmark model vs. high elasticity variants sectoral contributions to hours factor growth, data in parentheses (percentage points)

Period	Aggregate/ sum	Agriculture	Industry	Services
1981–1990				
Labor wedge	**-0.12**	-0.05	-0.21	0.14
Benchmark	**0.62**	-0.04	0.11	0.56
Data	**(0.58)**	(-0.10)	(0.03)	(0.65)
1991–2000				
Labor wedge	**0.10**	0.01	-0.12	0.22
Benchmark	**-0.06**	0.00	-0.19	0.13
Data	**(-0.36)**	(-0.05)	(-0.60)	(0.29)
2001–2010				
Labor wedge	**0.06**	-0.01	-0.33	0.40
Benchmark	**-0.34**	-0.01	-0.50	0.18
Data	**(0.60)**	(0.02)	(-0.27)	(0.85)
2011–2018				
Labor wedge	**0.95**	-0.02	0.37	0.60
Benchmark	**0.72**	-0.02	0.28	0.46
Data	**(1.54)**	(-0.01)	(0.21)	(1.34)
1981-2018				
Labor wedge	**0.21**	**-0.02**	**-0.10**	**0.33**
Benchmark	**0.21**	**-0.02**	**-0.09**	**0.32**
Data	**(0.54)**	**(-0.03)**	**(-0.18)**	**(0.75)**

Table 23d. Benchmark model vs. labor wedge variants sectoral contributions to TFP factor growth, data in parentheses (percentage points)

Period	Aggregate/ sum	Agriculture	Industry	Services
1981–1990				
Labor wedge	**2.63**	0.10	1.10	1.42
Benchmark	**2.65**	0.12	1.10	1.43
Data	**(3.05)**	(0.16)	(1.36)	(1.53)
1991–2000				
Labor wedge	**1.01**	0.01	0.46	0.55
Benchmark	**1.04**	-0.00	0.46	0.58
Data	**(0.98)**	(0.00)	(0.28)	(0.70)
2001–2010				
Labor wedge	**-0.07**	0.00	0.17	-0.24
Benchmark	**-0.07**	-0.01	0.18	-0.24
Data	**(0.09)**	(-0.03)	(0.10)	(0.01)
2011–2018				
Labor wedge	**0.94**	0.04	0.30	0.60
Benchmark	**0.95**	0.04	0.31	0.60
Data	**(0.55)**	(0.07)	(0.49)	(0.00)
1981–2018				
Labor wedge	**1.14**	0.04	0.52	0.58
Benchmark	**1.15**	0.04	0.52	0.59
Data	**(1.20)**	(0.05)	(0.56)	(0.59)

Appendixes

Data Appendix

Section 2.1 Real output is measured by real GDP at producer prices in chained 1980 yen. I calculate this setting nominal GDP equal to real GDP in 1980, and extrapolating using the growth rate of real GDP measured in chained 2015 yen published by the OECD.

In figure 1a, I divide real GDP by the number of working age people, computed as the population sum of those aged 16 years to 65 years drawn from the United Nations Population Estimates database. In figure 1b, I divide real GDP by the number of hours worked by employees, which I calculate using JSNA data. I estimate hours worked by employees as the product of average hours worked by all employees and the total number of employees, both drawn from JSNA. While this is a relatively narrow estimate of total hours, as the number of employees is much smaller than the total number of employed persons, the descriptive statistics and accounting results presented here are similar quantitatively to those in Betts (2021), where a measure of hours worked by employed persons is used, published by the GDCC and Penn World Tables (PWT). Unfortunately, the GDCC/PWT estimates of employed persons and average hours of employed persons for Japan do not include sectoral breakdowns, and so I use the narrower measure which is broken down by sector in JSNA and the OECD.

Section 2.2 To compute the capital-output ratio, I divide the nominal value of the economy's total stock of fixed capital, published in the OECD STAN accounts and in the JSNA, by nominal GDP drawn directly from the OECD national accounts. This raises two measurement issues. First, the use of the fixed capital stock rather than gross capital inclusive of inventories is non-standard. The reason for this choice is the lack of available gross capital data at the industry level over the sample period. My sectoral decompositions of output and TFP growth into industry sources relies on having consistent measures of capital at the aggregate and industry level. Second, the use of the nominal ratio is not ideal. At the aggregate level, this could be resolved, as net (and gross) capital and GDP measured in fixed 1980 yen are available. However, at the industry level, the only available measures of real capital and output over the sample period are in chained yen, and capital-output ratios computed using chained data are not meaningful. Note that the aggregate and industry level nominal capital-output ratios that I use in this analysis reflect not only changes in the volume of capital relative to output but also in the relative price of capital in terms of output.

I measure the TFP factor by taking the ratio of real output per working age person to the product of the capital and hours factors, using Hayashi and Prescott's (2002) estimate of the capital income share in Japan in the 1980s, 0.362.

Section 3 In the sectoral analysis, "agriculture" comprises industries, D01T03; D01, agriculture and hunting; D02, forestry and logging; and D03, fishing and aquaculture. "Industry" consists of D05T09, mining and quarrying; D10T33, manufacturing; D35T39, "utilities", including gas, electricity, and water supply, sewerage, waste management, and remediation activities; and D41T43, construction. "Services" comprises all service industries in the set of industries D45T99. The compilation of the data – collected from individual countries' national accounts – uses recommendations of the 2008 System of National Accounts (SNA08). In addition, the classification of industries in the OECD STAN data follows the International Standard Industrial Classification of all economic activities, Revision 4 (ISIC Rev. 4). All the original OECD STAN data series are in current Yen, except where I otherwise note.

Section 3.1

I measure real value added by sector in chained 1980 yen at producer prices, as is aggregate GDP. To do so requires some calculations. Aggregate GDP from the OECD national accounts, which I use to measure aggregate output in section 2, is valued at producer prices. The OECD's sectoral value-added series are measured at factor cost. For consistency of measures and facilitate the sectoral decompositions, I adjust the nominal value added of each sector measured at factor cost in proportion to its relative value in the sum of factor-cost value added over sectors, such that the sum over the three sectors equals nominal GDP measured at producer prices at every date. I then extrapolate each sector's real value-added series forward from its adjusted nominal 1980 value using the growth rate of the OECD's factor cost chained 2015 Yen series to produce a chained 1980 Yen sectoral value-added series.

The nominal sectoral value-added adjustment assigns net production taxes and measurement error included in producer price GDP to the three major sectors of economic activity in proportion to the relative size of each sector's nominal value added at factor cost at every date. I (implicitly) assume that net production taxes and measurement error assigned to each sector have a negligible effect on the growth rate of real output in the sector. Obviously, the nominal value-added data at producer prices for the three sectors sum to the total nominal GDP series in section 2; however, because the real sectoral value-added series are derived from chained Laspeyres indexes, they do not sum to aggregate chained real GDP.

Sectoral hours data are drawn from JSNA. The sectoral employment numbers are adjusted proportionately to account for small rounding errors in the sum over sectors relative to aggregate employment numbers published by JSNA and the OECD STAN. Total hours of employees are also subject to a small proportionate adjustment to account for rounding errors.

Section 3.2 Nominal fixed capital stocks by sector are based on OECD STAN data. The nominal capital stock of each sector is subject to a small proportional adjustment to account for measurement /rounding error, such that the sum over sectors of nominal fixed capital is exactly equal to the aggregate nominal fixed capital stock.

The aggregate GDP price deflator is the ratio of nominal GDP from the OECD to real GDP measured in 1980 chained yen calculated as I describe above. Sectoral value added price deflators are the ratios of adjusted nominal sectoral value added at each data to the (adjusted) real value added of the sector measured in 1980 chained yen and calculated as I describe above.

A.1 Comparison of aggregate growth accounting to Hayashi and Prescott (2002)

Table A.1 presents a growth accounting using my data for two sub-periods also studied by Hayashi and Prescott (2002), which do not exactly overlap with my decades. Hayashi and Prescott's results are in parentheses. Note that here I decompose hours per working age person into the analogue of the two sources that they study, hours per employee, and the employment rate from the working population. Also note that we use different metrics of all the variables: Real output (I use real GDP vs. the GNP that Hayashi and Prescott analyze); working age populations (I use population members ages 15 to 65 vs. Hayashi and Prescott's ages 19 to 69); employment vs. the employed persons used by Hayashi and Prescott, and hence average hours worked (I use per employee vs. per employed person); and capital-output ratios (nominal vs. constant price, including government and excluding foreign vs. excluding government and including foreign).

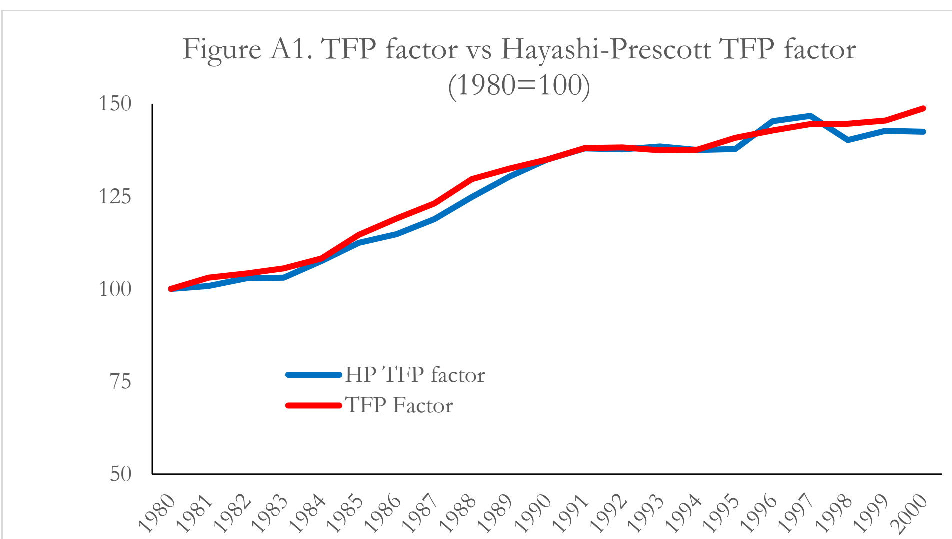
Difference in metrics do not substantially alter most of the average growth rates for the first sub-period, 1983-1991. Even the different capital-output ratio measures (nominal vs. constant price, including government and excluding foreign vs. excluding government and including foreign) do not produce quantitatively large differences in results. The first sub-period produces very similar results overall, except that the employment rate measured by employees that I use here grows more quickly than that measured by all employed persons in Hayashi and Prescott. The employment rate factor accounts for much more output per working age person growth in my accounting than in theirs, and the TFP factor a little less. In the second sub-period, the deviations in results are quantitatively larger for output, and the capital-output ratio, but smaller for TFP, average hours, and the employment rate. Qualitatively, the results for 1991-2000 relative to 1983-1991 are the same; TFP and output per working age person growth drop precipitously, capital-deepening increases, while employment rate growth and average hours decrease.

In figure A.1 I plot the time-series of my aggregate TFP series against that of Hayashi-Prescott. The latter series I draw directly from Hayashi's website. I normalize both metrics to equal 100 in 1980. Over the common sub-period 1981–2000, the two measures share very similar annual fluctuations; their sample correlation is 0.98. However, while this correlation is 0.99 over the period 1981-1990 it is only 0.70 over the period 1991-2000. My measure of the TFP factor is slightly less volatile (its relative standard deviation is 0.97) and it tends to be slightly higher.

Table A.1 Comparison to Hayashi-Prescott (2002)

Period	Y/N	$(K/Y)^{\frac{\alpha}{1-\alpha}}$	E/N	H/E	$A^{\frac{1}{1-\alpha}}$
1983–1991	3.75 (3.60)	0.03 (0.20)	1.10 (0.10)	-0.55 (-0.50)	3.18 (3.70)
1991–2000	1.27 (0.50)	0.67 (1.40)	0.48 (-0.40)	-0.89 (-0.90)	0.83 (0.30)

Figure A.1



A.2 Sectoral Growth Accounting

1. Agriculture

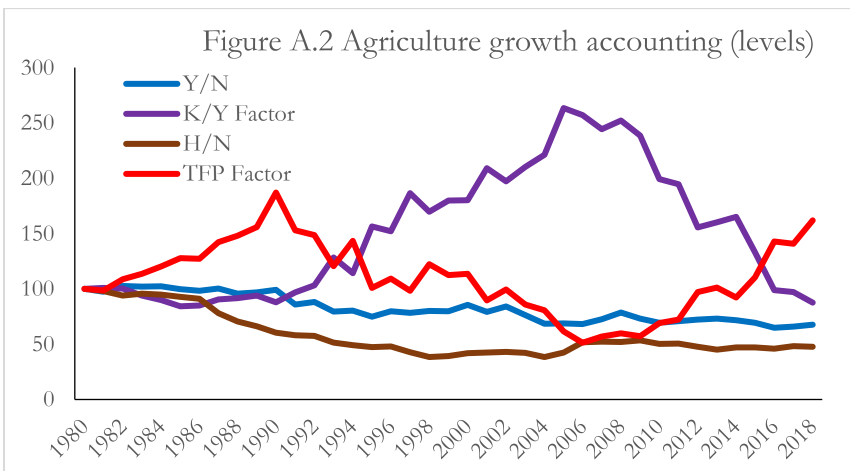
Data presented in section 3 showed that agriculture's level and share of economic activity shrank considerably from 1980 until the mid-2010s. Here I account for this contraction and develop estimates of the TFP factor in the sector (from which follows TFP, and the TFP growth rate used in the programs) employing growth accounting methods.

Figure A.2 shows a growth accounting of the level of output per working age person for agriculture, which assumes that the Cobb-Douglas function in section 3 of the text holds, shown in equations (4) and (5), with the capital share calibrated to match the benchmark 1980, Japanese agricultural capital income share. Namely, the growth accounting uses equation (A.1),

$$\left(\frac{Y_{a,t}}{N_t}\right) = A_{a,t}\left(\frac{K_{a,t}}{Y_{a,t}}\right)^{\frac{\alpha_a}{1-\alpha_a}}\left(\frac{H_{a,t}}{N_t}\right). \qquad (A.1)$$

In measuring the variables in equation (A.1), all variables (except the aggregate working age population, of course) are the sectoral analogues of those in the aggregate production function (1). I describe the sectoral data series and sources in detail in the text.

The figure illustrates that this sector's value added per working age person deviates



extraordinarily widely from the sectoral TFP factor over the sample period; this is not balanced growth path behavior (see the discussion of conditions for balanced growth at the aggregate level in terms of sectoral behavior in sections 3 and, especially, 4). Agriculture's value added and hours per working age person both gradually decline over the sample period although both exhibit a surprising increase in the mid-2000s, subsequently stabilizing. The capital factor is highly variable over the sample period, increasing dramatically from 1990 through the mid-2000s and declining equally dramatically thereafter.

Because these movements are so large relative to those in value added and hours per working age person, the "residual" TFP factor is highly negatively correlated with the capital factor.

One reason for the exaggerated behavior of agriculture's capital factor is that the calibrated (1980) share of capital income in the sector is extraordinarily high (see table 14), magnifying movements in the capital-output ratio of the sector. The direction of the movements in the capital factor are perfectly consistent with the implications of the multi-sector growth model, however. In a multi-sector growth model, the (net of tax) return to capital–and hence next period's marginal product of capital–in every sector must be equal. Because agriculture's capital income share is so large, the output-capital ratio can be lower in agriculture and the capital-output ratio higher than in other sectors for a given return. Through the Euler equation, each sector's return to capital is also positively associated with aggregate consumption per working age person growth, evaluated in numeraire units, which is driven by GDP per working age person growth. Thus, higher (perfectly anticipated) income and consumption tomorrow relative to today reduces the household's incentive to save and invest, raising the marginal product of capital. Hence each sector's $t+1$ capital-output ratio is *negatively* associated with income growth between t and $t+1$. This is true for agriculture, as figure A.2 illustrates; entering the 1990s with much slower GDP per working age person growth, the capital factor rises sharply and persistently. It declines significantly only after the great recession when GDP per working age person growth in Japan increased somewhat. The figure suggests that negative TFP growth from 1990 through the mid-2000s contributed to more negative value added per working age person growth during the early 1990s, as well as negative growth in the hours factor of the sector, while stabilization of both value added and hours per working age person in the sector after the great recession is associated with strong positive TFP growth and negative capital deepening.

Table A.2 presents a decennial growth rate accounting for the sector. The average growth rate of value added per working age person in agriculture was negative in every decade of the sample period, and over the full sample period. During the 1980s, slightly negative value-added growth coincided with rapid TFP factor growth, however, negative hours and capital factor growth offset the TFP increases. Negative value added per working age person growth in the 1990s and 2000s coincided with a large decline in, and negative, TFP factor growth, which was not offset by much higher, and positive, capital-factor growth. In the 1990s, negative TFP factor growth was exacerbated by negative hours factor growth; in the 2000s negative TFP factor growth was somewhat offset in its impact for value added growth by (surprisingly) positive hours growth. The relative stabilization of value added per working age person observed in the 2010s is associated with a large increase in TFP factor growth, a substantial decline in, and negative, capital factor growth, and negative hours factor growth. Thus, the largest decennial *changes* in the growth rate of value added per working age person in the 1990s (much more negative) and 2010s (much less negative) are primarily associated with big swings in the same direction of TFP factor growth. Over the entire sample period, modestly negative average value added per working age person growth was the result of significant, negative average hours factor growth offsetting modestly positive TFP factor growth, with very little average (negative) capital factor growth. Given the negative average growth in hours per working age person over the years 1980 through 2018, however, the agricultural sector does not exhibit balance growth behavior over the sample period.

Table A.2 Accounting for agricultural value added per working aged person 1980–2018

Period	**Y/N**	$\mathbf{(K/Y)^{\frac{\alpha}{1-\alpha}}}$	**H/N**	$\boldsymbol{A^{\frac{1}{1-\alpha}}}$
1981–1990	**-0.04**	-1.27	-4.79	6.02
1991–2000	**-1.24**	7.68	-3.45	-5.47
2001–2010	**-1.86**	1.23	2.17	-5.26
2011–2018	**-0.29**	-9.80	-0.61	10.12
1981-2018	**-0.89**	**-0.05**	**-1.73**	**0.89**

2. Industry

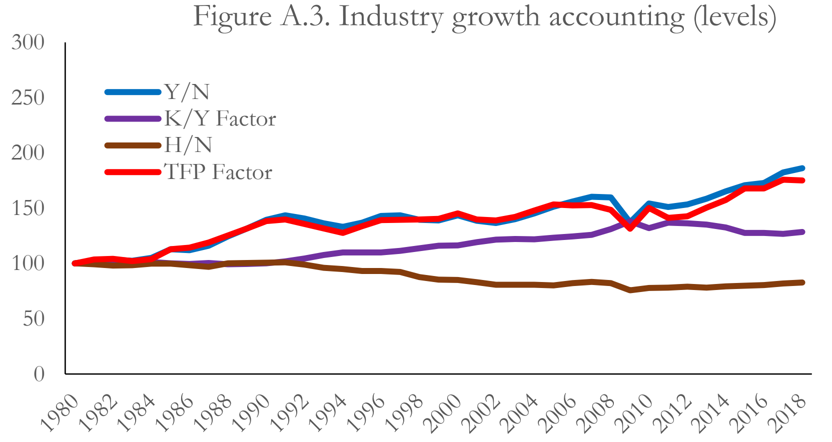
Industry's level but not its share of economic activity grew over the entire sample period as figures in section 3 illustrate.

Figure A.3 shows a growth accounting of the level of output per working age person for industry, assuming that output per working age person in the sector is described by

$$\left(\frac{Y_{m,t}}{N_t}\right) = A_{m,t}^{\frac{1}{1-\alpha_m}} \left(\frac{K_{m,t}}{Y_{m,t}}\right)^{\frac{\alpha_m}{1-\alpha_m}} \left(\frac{E_{m,t}}{N_t}\right) h_{m,t}, \qquad (A.2)$$

where the subscript "m" denotes manufacturing (although my classification of the sector includes energy and construction) and recall that the capital share is calibrated to match the 1980 industrial capital income share for Japan. The figure shows the long-run trend rise in value added per working age person in industry is closely associated with a trend increase in the TFP factor, and–to a lesser extent–capital factor, while the hours factor exhibits trend decline over the sample period. There is decline and stagnation in value added per working age person in the 1990s which correlates almost perfectly with a decline and stagnation in the TFP factor but is also coincident with a decline in the hours factor and occurs despite a rise in the capital factor. Similar statements can be made about the great recession. There is an increase in value added per working age person after the great recession which correlates closely with a rise in the TFP factor and, except in the last couple of years, and with steady growth in the hours factor of the sector. Table A.3 presents a formal decennial growth rate accounting for the sector.

Figure A.3. Industry growth accounting (levels)



The table shows that the growth rate of value added per working age person falls precipitously in the 1990s relative to the 1980s, recovers marginally in the 2000s, and improves to roughly long-run trend growth (2 percent) in the 2010s. During the 1980s, rapid output growth coincided almost exactly with rapid TFP factor growth, and the industrial sector exhibits behavior consistent with near-balanced growth. The decline in and negative average growth in output per working age person in the 1990s coincides with a large decline in average TFP factor growth, and smaller but significant decline in (and negative) hours factor growth. The growth slowdown would have been greater, had these sources of decline not been offset somewhat by positive capital-factor growth, consistent with the predictions of a neoclassical growth model. TFP factor growth is similar in the 2000s to the 1990s, while somewhat faster (although still negative) hours factor growth accounts for the small improvement in value added per working age person growth during the 2000s, offset a little by a reduction in capital factor growth. The faster growth observable in the 2010s is attributable to much faster TFP factor and positive hours factor growth and occurs despite negative capital-factor growth. On average over the entire sample, especially positive TFP factor, and capital factor, growth contribute to positive output per worker growth and are offset by negative growth in the sector's hours factor. Decennial changes in the growth rate of output per working age person in the sector are led by changes in TFP growth (in the 1990s and 2010s) and hours factor growth (in every decade).

3. Services

Services' level and share of economic activity experienced secular growth over the sample period, as agriculture's experienced secular decline. Figure A.4 shows a growth accounting of the level of value

Table A.3 Accounting for industrial value-added growth per working aged person 1980–2018

Period	**Y/N**	$(\mathbf{K/Y})^{\frac{\alpha}{1-\alpha}}$	**H/N**	$A^{\frac{1}{1-\alpha}}$
1981–1990	3.44	0.02	0.08	3.33
1991–2000	0.32	1.52	-1.67	0.47
2001–2010	0.94	1.32	-0.83	0.44
2011–2018	2.39	-0.28	0.75	1.92
1981-2018	**1.74**	**0.70**	**-0.48**	**1.52**

added per working age person for services, assuming that production of value added in the sector is described by

$$\left(\frac{Y_{s,t}}{N_t}\right) = A_{s,t}^{\frac{1}{1-\alpha_s}} \left(\frac{K_{s,t}}{Y_{s,t}}\right)^{\frac{\alpha_s}{1-\alpha_s}} \left(\frac{E_{s,t}}{N_t}\right) h_{s,t}. \tag{A.4}$$

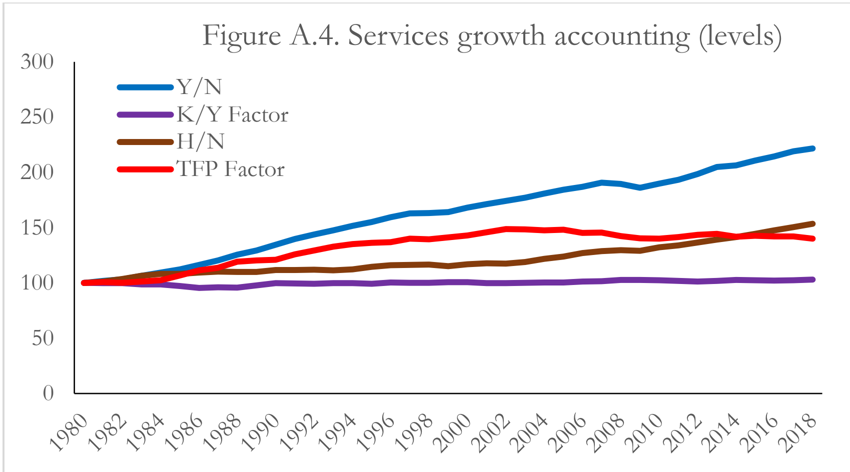


Figure A.4. Services growth accounting (levels)

The figure shows that the tremendous growth in value added per working age person over the sample period is driven by a combination of TFP factor and hours factor growth until roughly 1985, by TFP factor growth from the mid-1980s until roughly 2002, and by hours factor growth thereafter. The capital factor appears almost completely stable, with a notable decrease in the early 1980s and small increase in the late 1980s. The sector's growth after 2002 is associated with a declining TFP factor and increasing hours factor.

Table A.4 quantifies these observations in a decennial growth accounting. What is fascinating about this accounting is that decline in service sector value added per working age person growth in the 1990s predominantly comes not from TFP factor growth decline as it does in the industrial sector, although there is a modest fall, but from a decline in the growth of the hours factor. However, TFP factor growth collapses in the service sector in the 2000s through the 2010s, never recovering. This TFP growth collapse produces a second sharp decline in growth of value added per working age person in the 2000s, despite very healthy hours factor growth, while hours factor growth is the primary source of the partial recovery in service sector value added per person growth in the 2010s. Over the full sample, hours factor growth is the largest source of output growth in the sector!

Table A.4 Accounting for services value-added per working aged person growth 1980–2018

Period	**Y/N**	$\mathbf{(K/Y)^{\frac{\alpha}{1-\alpha}}}$	**H/N**	$\boldsymbol{A^{\frac{1}{1-\alpha}}}$
1981–1990	3.01	-0.01	1.10	1.93
1991–2000	2.27	0.10	0.45	1.72

2001–2010	1.22	0.18	1.24	-0.20
2011–2018	1.96	0.07	1.88	0.02
1981-2018	**2.12**	**0.08**	**1.13**	**0.91**

A.3 Sectoral decomposition of labor productivity growth

The growth rate of aggregate output per hour worked, labor productivity, measured in chained 1980 yen, has the following interpretation in terms of sectoral contributions, where I define a sector's share of hours worked at *t* as $s_{h,i,t} \equiv \left(\frac{H_{i,t}}{H_t}\right)$:

$$\frac{\left(\frac{Y_{t+1}}{H_{t+1}}\right) - \left(\frac{Y_t}{H_t}\right)}{\left(\frac{Y_t}{H_t}\right)} = \sum_{i=a,m,s} \left(\left(\frac{\frac{Y_{i,t+1}}{H_{i,t+1}}}{\frac{Y_{i,t}}{H_{i,t}}} \right) \left(\frac{\frac{P_{i,t+1}}{P_{t+1}}}{\frac{P_{i,t}}{P_t}} \right) \left(\frac{s_{h,i,t+1}}{s_{h,i,t}} \right) - 1 \right) s_{y,i,t}. \qquad (A.5)$$

The expression on the right-hand side of (A.5) shows that a sector's contribution of aggregate labor productivity growth depends on within-sector labor productivity growth, growth in the sector's relative output price, and growth in the sector's share of hours over time, in addition to its current share of value added. It is straightforward to show that the contributions of sectors to aggregate labor productivity growth can be approximated by the weighted sum of net growth rates in these components,

$$\frac{\left(\frac{Y_{t+1}}{H_{t+1}}\right) - \left(\frac{Y_t}{H_t}\right)}{\left(\frac{Y_t}{H_t}\right)} \cong \sum_{i=a,m,s} \left(\left(\frac{\frac{Y_{i,t+1}}{H_{i,t+1}} - \frac{Y_{i,t}}{H_{i,t}}}{\frac{Y_{i,t}}{H_{i,t}}} \right) + \left(\frac{\frac{P_{i,t+1}}{P_{t+1}} - \frac{P_{i,t}}{P_t}}{\frac{P_{i,t}}{P_t}} \right) + \left(\frac{s_{h,i,t+1} - s_{h,i,t}}{s_{h,i,t}} \right) \right) s_{y,i,t}. \, (A.6)$$

I illustrate the total contributions of each of the three major sectors of economic activity to the growth rate of aggregate output per hour worked in figure (A.5). The figure shows for each sector the total contribution represented by its element in the sum on the right-hand side of equation (A.5). The figure shows that agriculture plays a very small role, and almost all time-series variation in the aggregate growth rate is accounted for by industry and services. However, in contrast to GDP per working age person, a decline in industry's contribution heavily dominates the fall in aggregate productivity in the 1990s, while a decline in services' contribution drives continued aggregate productivity growth decline in the 2000s. The data in table A.5, which presents a decennial sectoral accounting of aggregate labor productivity growth in terms of total sectoral contributions to the average growth rate by decade, corroborate this. The service sector was the largest contributor to rapid aggregate labor productivity growth in the 1980s, although the industrial sector also contributed substantively. The industrial sector, however, was the dominant source of decline in aggregate labor productivity growth in the 1990s relative to the 1980s, and its contribution further declined in the 2000s. However, the service sector was largely responsible for the additional substantive decline in the aggregate productivity growth rate in the 2000s relative to the 1990s, and solely responsible for the further decline in the 2010s.

Figure A.5. Sectoral contributions to output per hour worked growth (percentage points)

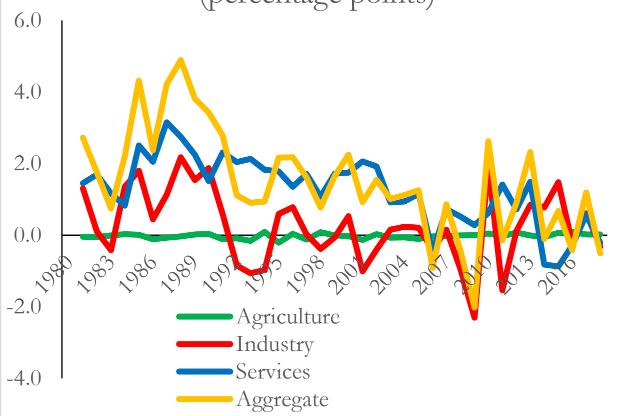


Figure A.6. Weighted labor productivity growth contributions to output per hour worked growth (percentage points)

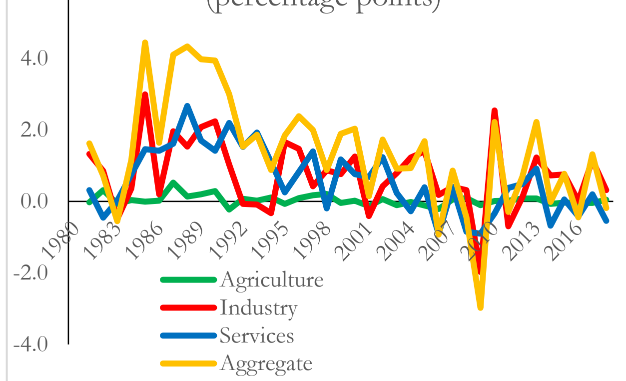


Figure A.7. Relative price contributions to output per hour worked growth (percentage points)

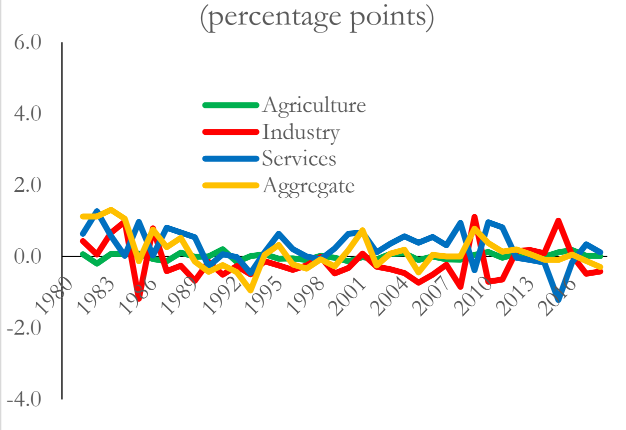
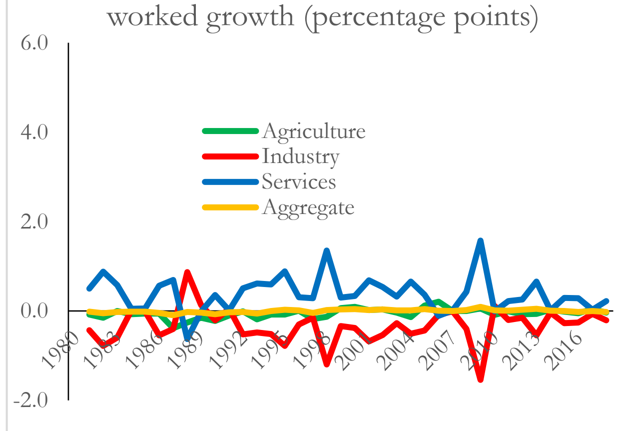


Figure A.8. Hours reallocation contributions to output per hour worked growth (percentage points)



I now decompose labor productivity growth further, using equation (A.5) (see equation (A.6) for an intuitive approximation) to decompose the labor productivity growth contribution of a sector into two sources: 1) Weighted (by its value-added share), within-sector, labor productivity growth, (denoted WLPG) and 2) a well-defined residual term, also weighted by a sector's value-added share. The residual term comprises two effects: 1) A relative output price effect of the sector, (denoted REPLYL), and 2) a sector's hours' worked reallocation effect (denoted HRSL). The derivation follows Diewert (2015) closely. Figures A.6, A,7, and A.8 and table A.6 display the results of the labor productivity decomposition. The figures and the table show that the large decline in industry's contribution to aggregate productivity growth in the 1990s relative to the 1980s was due not only to a substantial fall in its weighted labor productivity contribution, but also to a decline in its relative value-added price, and to a decline in its share of hours worked – in short, to a decline in its importance as a sector contributor to aggregate labor productivity growth.

Table A.5. Sectoral contributions to GDP per hour worked growth (percentage points)

Period	Aggregate	Agriculture	Industry	Services
1981–1990	**3.05**	-0.02	1.13	1.93
1991–2000	**1.64**	-0.05	-0.08	1.77
2001–2010	**0.60**	-0.04	-0.24	0.87
2011–2018	**0.49**	0.02	0.22	0.25
1981-2018	**1.49**	**-0.02**	**0.26**	**1.26**

By contrast, the service sector driven decline in aggregate labor productivity growth in the 2000s was almost entirely attributable to a decline in its within sector, weighted labor productivity contribution which was negative (service sector labor productivity fell). The relative value-added price of services rose more rapidly than in the 1990s, and the increase in its share of hours worked was only marginally smaller than in the previous decade. In the 2010s, however, the service-sector driven decline in labor productivity growth reflected not a decline in its within-sector labor productivity growth, but a decline in its relative output price and in growth of its share of hours worked. Nonetheless, hours worked continued to rise in services and decline in industry. In the 2010s although industry exhibited a much larger within-sector, weighted labor productivity growth contribution than services, the benefit of this for aggregate productivity growth was offset by persistent reallocation of hours worked from industry into services. Despite these observations, this evidence shows that labor productivity growth in all three sectors has fallen substantially and persistently since the 1980s contributing to the aggregate slowdown.

A.5 Benchmark model's sectoral accounting of GDP per hour worked

Figures A.9 and A.10 and table A.7 show benchmark model-predicted sectoral contributions to GDP per hour worked growth and compares them to the data analyzed in appendix A.4. Figure A.9 shows

Table A.6. Weighted labor productivity and residual contributions to aggregate labor productivity growth (percentage points)

Period	Aggregate Y/H	Agriculture	Industry	Services
1981–1990	**3.05**	**-0.02**	**1.13**	**1.93**
WLPG	2.54	0.14	1.31	1.09
RELPYL	0.55	-0.00	0.02	0.52
HRSR	-0.05	-0.16	-0.20	0.30
1991–2000	**1.64**	**-0.05**	**-0.08**	**1.77**
WLPG	1.83	0.04	0.70	1.10
RELPYL	-0.20	-0.02	-0.31	0.13
HRSR	-0.01	-0.06	-0.47	0.53
2001–2010	**0.60**	**-0.04**	**-0.24**	**0.87**
WLPG	0.41	-0.05	0.49	-0.03
RELPYL	0.15	-0.00	-0.29	0.45
HRSR	0.03	0.01	-0.43	0.45
2011–2018	**0.49**	**0.02**	**0.22**	**0.25**
WLPG	0.51	0.01	0.45	0.05
RELPYL	-0.02	0.04	-0.01	-0.05
HRSR	-0.00	-0.03	-0.22	0.25

1981–2018	**1.49**	**-0.02**	**0.26**	**1.26**
WLPG	1.37	0.04	0.75	0.58
RELPYL	0.13	0.00	-0.15	0.28
HRSR	-0.01	-0.06	-0.34	0.39

the model produces insufficiently volatile output per hour contributions throughout the sample relative to the empirical contributions shown in figure A.10. It does successfully capture negative trends over the sample period in the contributions of both industry and services to labor productivity growth, however. The last row of numbers in table A.7 reveal that the model accurately predicts the full sample contributions of agriculture and services to average labor productivity growth, but somewhat over-predicts that of industry. The model implies quite accurate sectoral contributions to average productivity growth in the 1980s but fails to match quantitatively the decline in industry's contribution in the 1990s relative to the 1980s. It generates fairly accurate sectoral contributions in the 2000s, both before and after the great recession, and modestly over-estimates the contributions of both industry and services in the 2010s. The model's biggest miss relative to the data by far, however, is in failing to match the decline in industry's contribution to labor productivity growth in the 1990s. The sectoral accounting results in section 6.1.3 show that this is attributable to a counterfactual increase in industry's contribution to capital deepening and a counterfactually small decline in industry's contribution to aggregate TFP factor growth in the 1990s relative to the 1980s.

Figures A.11 through A.16 decompose model-predicted sectoral contributions to labor productivity growth into their weighted labor productivity, relative price, and hours reallocation effects, and compare them to those in the data. Table A.8 presents a decennial accounting of labor productivity growth by source and sector.

Figures A.11 and A.12 show the model produces reasonable weighted labor productivity contributions of sectors in terms of trends, although possibly assigns a relatively small role to industry and agriculture and relatively large role to services. It also produces some counterfactual inverse correlations of the contributions of industry and services from the great recession onwards. Relative price contributions predicted by the model roughly match the volatility of those we see in the data except during the great recession, seen in figures A.13 and A.14, but the direction of some movements–especially in the last decade or so of the sample–are counterfactual. Figures A.15 and

A.16 show the model's hours reallocation contributions of sectors are insufficiently volatile relative to the data. Again, there are some counterfactual directional movements in the last decade of the sample.

The last four rows and first column of numbers in table A.8 show that over the entire sample period, the model overpredicts weighted labor productivity growth and underpredicts the relative price and hours reallocation effects of sectors. The second through fourth columns in the last four rows show that these "misses" are almost solely attributable to a full sample overprediction of service sector contributions to weighted labor productivity growth and underprediction of service sector contributions to relative price and hours reallocation effects. Again, the model under-predicts relative

Figure A.9 Benchmark model total sectoral contributions to labor productivity growth

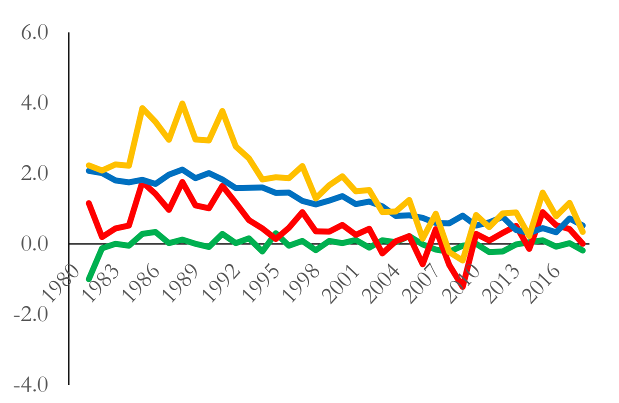


Figure A.10 Empirical total sectoral contributions to output per hour worked growth (percentage points)

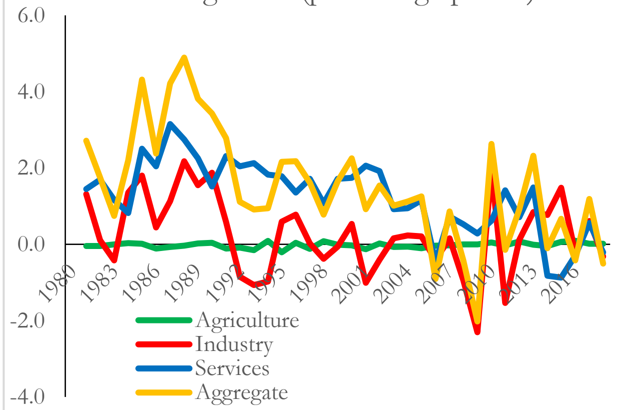


Figure A.11 Benchmark model weighted labor productivity growth contributions by sector (percentage points)

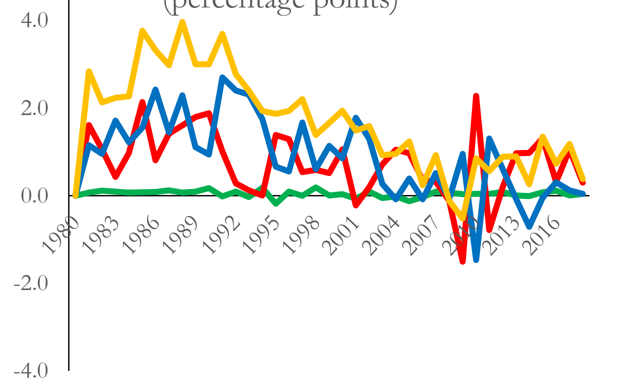


Figure A.12 Empirical weighted labor productivity growth contributions by scetor (percentage points)

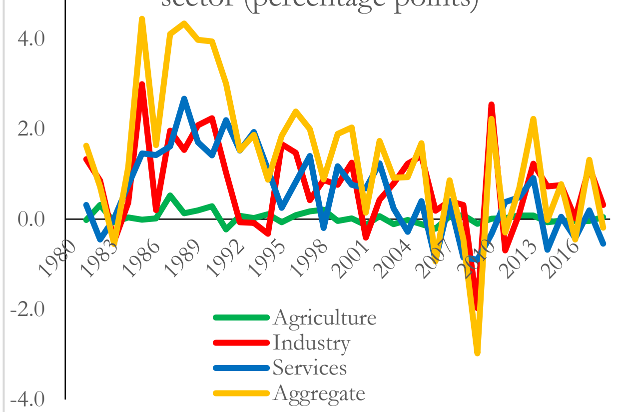


Figure A.13 Benchmark model relative price effects for labor productivity growth by sector (percentage points)

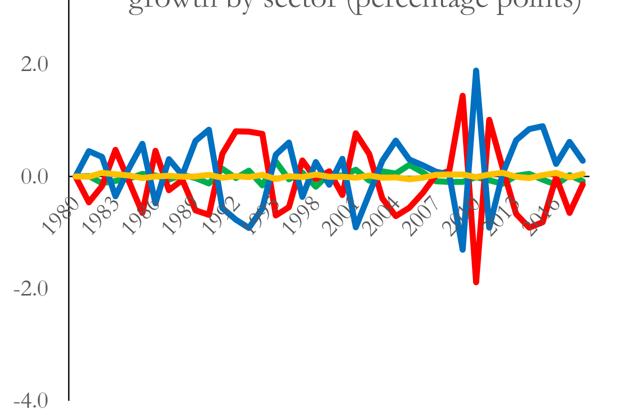
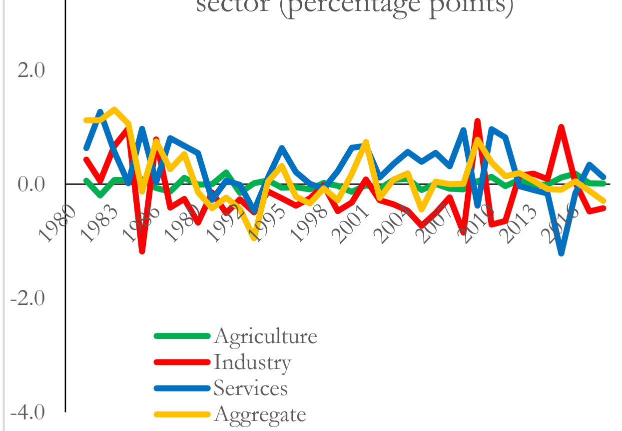


Figure A.14 Empirical relative price effects for labor productivity growth by sector (percentage points)



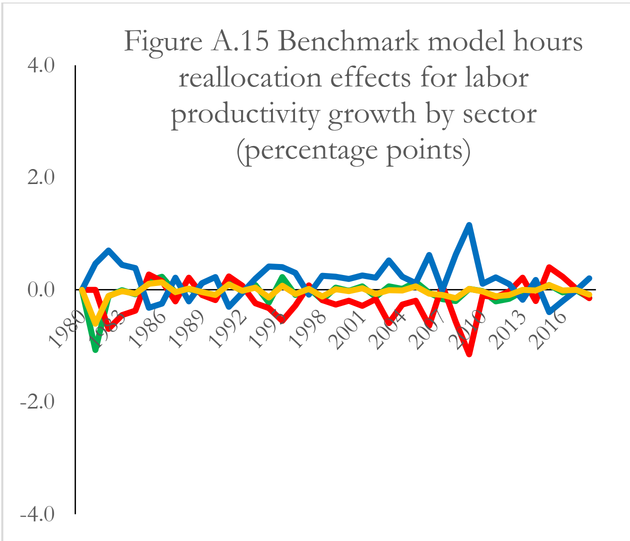


Figure A.15 Benchmark model hours reallocation effects for labor productivity growth by sector (percentage points)

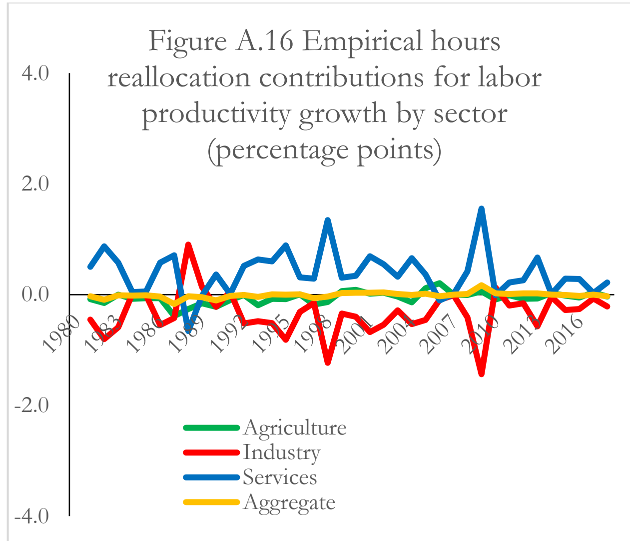


Figure A.16 Empirical hours reallocation contributions for labor productivity growth by sector (percentage points)

Table A.7 Benchmark model's sectoral contributions to GDP per hour worked growth, data in parentheses (percentage points)

Period	Aggregate/ sum	Agriculture	Industry	Services
1981–1990	**2.86** **(3.05)**	-0.05 (-0.02)	1.03 (1.13)	1.91 (1.93)
1991–2000	**2.17** **(1.64)**	0.05 (-0.05)	0.67 (-0.08)	1.44 (1.77)
2001–2010	**0.72** **(0.60)**	-0.01 (-0.03)	-0.10 (-0.23)	0.82 (0.87)
2011–2018	**0.79** **(0.49)**	-0.07 (0.02)	0.33 (0.22)	0.51 (0.25)
1981-2018	**1.68** **(1.50)**	**-0.02** **(-0.02)**	**0.49** **(0.26)**	**1.21** **(1.26)**

Table A.8. Benchmark model's sectoral contributions to weighted labor productivity growth and residual effects, data in parentheses (percentage points)

Period	Aggregate Y/H	Agriculture	Industry	Services
1981–1990	**2.86 (3.05)**	**-0.05 (-0.02)**	**1.03 (1.13)**	**1.91 (1.93)**
WLPG	2.95 (2.54)	0.10 (0.14)	1.37 (1.31)	1.48 (1.09)
RELPYL	0.01 (0.55)	-0.03 (-0.00)	-0.21 (0.02)	0.25 (0.52)
HRSR	-0.07(-0.05)	-0.11 (-0.16)	-0.14 (-0.20)	0.18 (0.30)
1991–2000	**2.17 (1.64)**	**0.05 (-0.05)**	**0.67 (-0.08)**	**1.44 (1.77)**
WLPG	2.18 (1.83)	0.04 (0.04)	0.68 (0.70)	1.46 (1.10)
RELPYL	-0.00 (-0.20)	0.02 (-0.02)	0.15 (-0.31)	-0.18 (0.13)
HRSR	-0.02 (-0.01)	-0.00 (-0.06)	-0.17 (-0.47)	0.15 (0.53)
2001–2010	**0.72 (0.60)**	**-0.01 (-0.04)**	**-0.10 (-0.24)**	**0.82 (0.87)**
WLPG	0.76 (0.41)	0.00 (-0.05)	0.40 (0.49)	0.35 (-0.03)
RELPYL	-0.00 (0.15)	0.02 (-0.00)	-0.11 (-0.29)	0.09 (0.45)
HRSR	-0.02 (0.03)	-0.03 (0.01)	-0.39 (-0.43)	0.38 (0.45)
2011–2018	**0.79 (0.49)**	**-0.07 (0.02)**	**0.33 (0.22)**	**0.51 (0.25)**
WLPG	0.78 (0.51)	0.04 (0.01)	0.54 (0.45)	0.19 (0.05)
RELPYL	0.02 (-0.02)	-0.05 (0.04)	-0.26 (-0.01)	0.33 (-0.05)
HRSR	-0.03 (-0.00)	-0.06 (-0.03)	0.04 (-0.22)	-0.01 (0.25)
1981–2018	**1.68 (1.49)**	**-0.02 (-0.02)**	**0.49 (0.26)**	**1.21 (1.26)**
WLPG	1.72 (1.37)	0.05 (0.04)	0.76 (0.75)	0.91 (0.58)
RELPYL	0.01 (0.13)	-0.01 (0.00)	-0.10 (-0.15)	0.11 (0.28)
HRSR	-0.04(-0.01)	-0.05 (-0.06)	-0.17 (-0.34)	0.19 (0.39)

price increases for services and the mediation of their impact for labor productivity growth through services' value-added share. The rest of the table shows that in every decade, while the model does a good job of matching weighted labor productivity growth contributions of agriculture and industry it significantly overpredicts that of services. It also significantly underpredicts the hours reallocation price contribution of services in every decade, and the relative price contribution in every decade except the 2010s. The model's predictions for agriculture's relative price and hours reallocation contributions in each decade are quantitatively close to those in the data but sometimes of the wrong sign; the predictions for industry's relative price and hours reallocation contributions are less accurate. The decomposition is, in this sense, much like that for TFP growth; the model does a decent job of matching weighted within-sector labor productivity growth contributions but is much less accurate in decomposing the residual contributions of sectors in sources.