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The wealth of working nations[☆]

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ABSTRACT

Due to aging populations, the gap between GDP growth per capita and GDP growth per working-age adult (or per hour worked) has widened in many advanced economies. Countries like Japan, which have shown lackluster GDP growth per capita, have performed surprisingly well in terms of GDP growth per working-age adult (or per hour worked). Many advanced economies are also following similar balanced growth paths per working-age adult despite significant differences in the levels of GDP per working-age adult. We calibrate a standard neoclassical growth model to reflect changes in the working-age population for each economy. This model aligns more closely with the data for all the economies in our sample when we match GDP growth per working-age adult rather than when we match GDP growth per capita, the "canonical" calibration target.

1. Introduction

As the populations of advanced economies age, output growth per capita is becoming a misleading indicator for some purposes. Changing demographics mean that output growth per capita can obscure important trends in output per working-age adult or output per hour worked, which are more natural summary statistics for growth theory to focus on.

Take the case of output per working-age adult.[1] This measure provides a metric of how much an economy is exploiting its production possibilities, given social norms about work-life duration. Also, output per working-age adult is straightforward to compute since data on output and working-age adults are readily available for many countries over long periods.

Japan exemplifies how useful it is to look at this metric. Between 1991 and 2019, GDP in Japan grew at an annual rate of 0.83%, much lower than the 2.53% of the U.S. This seemingly disappointing performance motivated a myriad of books and academic papers analyzing the origins of Japan's lackluster growth and presenting a multitude of policy remedies. Just as one example among many, Pesek (2014), who popularized the term "Japanization", writes:

> ...few lessons are more timely or critical than those offered by Japan, a once-vibrant model for developing economies that joined the world's richest nations, lost its way, and has been struggling to relocate it ever since.

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[1] We follow the OECD's standard definition of working-age adults as the population between 15 and 64 years old. See Section 2.4 for a detailed explanation of the definition and possible alternatives. Section 2.5 discusses the use of output growth per worker and TFP growth.

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> In this book I explore what the world can learn from a Japanese economic funk that began more than 20 years ago and has never really ended. That means exploring where Japan went wrong, how it sank under the weight of hubris and political atrophy, and missed opportunity after opportunity to scrap an insular model based on overinvestment, export-led growth, and excessive debt.

However, the outlook changes significantly when demographics are considered. From 1991 to 2019, Japan's GDP per working-age adult grew annually by 1.39%. In comparison, the U.S. grew at 1.65% in the same measure, a difference of only 0.26%. Suddenly, there is nothing enigmatic about Japan's GDP growth. It is the consequence of an annual decline in working-age adults by about 0.54%. Remarkably, from 1998 to 2019, Japan grew slightly faster than the U.S. in terms of GDP per working-age adult, with an accumulated growth of 31.9% compared to the U.S.'s 29.5%. Even more strikingly, Japan's growth in terms of GDP per working-age adult outperformed that of all the other G7 countries plus Spain from 2008 to 2019.

Since output per working-age adult does not fully account for variations in work-life lengths or average hours worked, we also consider output per hour worked. However, this metric has two limitations. First, reliable time series data for hours worked are unavailable for many countries and periods and are subject to considerable measurement challenges (Eldridge et al., 2022). Second, interpreting output growth per hour worked is ambiguous because hours worked are an endogenous variable influenced by numerous factors. For example, output per hour worked in the U.S. nonfarm business sector grew by 4.1% in 2009 and 5.2% in 2020 — coincidentally, the only two years of real GDP contraction in the U.S. during the 21st century so far.

Notably, our argument does not hinge on the choice of either metric. For example, from 1991 to 2019, Japan's GDP grew annually by 1.39% per working-age adult and 1.26% per hour worked. Over the same period, U.S. GDP grew by 1.65% per working-age adult and 1.53% per hour worked. The difference between the U.S. and Japan is nearly identical across the two metrics: 0.26% using growth per working-age adult and 0.27% using growth per hour worked. Thus, to streamline the discussion, we will focus on GDP growth per working-age adult. Nonetheless, we will report data for both metrics, enabling readers who prefer GDP growth per hour worked to interpret our analysis through that lens.

We begin by examining population and GDP growth for the G-7 countries plus Spain. Between 1991 and 2019, the working-age adult populations of Canada and the United States grew by 29%–31%, while those of Italy and Germany saw slight declines of about 2%. Japan experienced the most pronounced change, with its working-age adult population shrinking by roughly 14%.

Despite these substantial demographic variations, output growth per working-age adult has followed a remarkably similar trajectory across most economies, with the exception of Italy. From 1991 to 2019, annual output growth per working-age adult averaged between 1.33% (France) and 1.65% (U.S.). In contrast, Italy lagged significantly. Indeed, most of the economies we study appear to be on parallel trends, resembling the balanced growth paths of textbook growth models, although at different levels and without evidence of convergence. Furthermore, these trajectories are independent of diverging trajectories of the working-age adult population.

We then develop and calibrate a standard one-sector growth model with exogenous technological growth. The size of the working-age population varies according to the data for each economy. In this context, we ask the extent to which the observed growth patterns of developed economies are consistent with the predictions of basic theory.

The logic of the model is straightforward. The economy travels along a growth path determined by the exogenous growth of technology, the discount factor, and total population growth. However, since the production function depends on labor, not total population, variations in the ratio of labor over total population shift the slope of the growth path up or down and induce transitional dynamics. In terms of the Euler equation characterizing the equilibrium behavior of the economy, having a lower labor/population ratio is equivalent to having a negative technological shock in a standard real business cycle model (and with the same persistent and propagation effects).

This intuition illustrates that our key insight is that aging changes the ratio of working-age adults over the total population. In the very long run, as the consequences of lower fertility rates and longer life expectancy are worked out through the population pyramid, we might return to a situation where the labor/population ratio stabilizes. At that moment, output growth per capita and output per working-age adult will again become roughly the same.

Our model performs very well in tracking observed output per working-age adult, as evidenced by the mean squared errors (MSE) between the model and the data. More importantly, when calibrated to match output growth per working-age adult, our model tracks *both* output per working-age adult and output per capita far better than the same model calibrated to match output growth per capita — the "canonical" approach in the literature prescribed by Barro and Sala-i-Martin (2003) and Cooley and Prescott (1995). This calibration reduces the MSE relative to the "canonical" approach by substantial margins for all eight countries in our sample, with reductions of up to 66% for France and 76% for Japan. While we do not claim our model is the best possible, we argue that growth theory must focus sharply on the appropriate output metric to match, even with simple models and an interest in output per capita. We also perform some extensions of the model and discuss their implications.

We finish by considering two large growing economies in the midst of a structural transformation: China and India. In the case of China, the combination of very fast economic growth and a moderate growth rate of population and working-age adults between 1991 and 2019 means that looking at total GDP growth, GDP growth per capita, or GDP growth per working-age adult gives us roughly the same conclusions. Thus, China is a modern incarnation of the type of behavior common in more advanced economies in the 1960s or 1970s, when modern growth theory was developed. Nonetheless, as China's population ages over the next two decades, a gap between GDP growth per capita and GDP growth per working-age adult will appear. In contrast, India is the mirror image of Japan: fast growth of the working-age adult population means that the high rates of total GDP growth look less impressive in terms of working-age adults.

Policy implications. Our investigation underscores that evaluating economic policy requires considering them within the context of an economy's demographic evolution. For instance, criticizing Japanese monetary policy after 1998 for failing to deliver faster output growth per capita overlooks the fact that monetary policy has little influence over demographic trends.[2] Given that Japan's output growth per working-age adult surpassed that of the U.S. after 1998, it is hard to pinpoint what more the Bank of Japan could have achieved.

Since Japan's current demographic situation previews what many advanced and emerging economies will face (Delventhal et al., 2021), economists must learn to assess growth using appropriate metrics. We emphasize the importance of output per working-age adult (potentially redefining working age to reflect changing retirement patterns) as an easily computable summary statistic for growth performance.

However, we approach the policy implications of our findings with caution. The working-age adult population of a country can be influenced by migration and fertility policies — directly (e.g., child tax credits) or indirectly (e.g., low fertility due to high youth unemployment). Immigration, in particular, plays a key role in driving population growth in countries like Canada and the U.S. While our analysis does not examine the broader impact of immigration, at first glance, there is little correlation between immigration and output growth per working-age adult. For example, Japan, a low-immigration country, outperforms Canada, a high-immigration country, in this metric. This does not rule out positive effects of immigration but highlights that such effects may be harder to document than often assumed. In contrast, we are less concerned with endogenous fertility. Changes in the native-born working-age adults were determined by past fertility choices. For example, Japan's fertility rate fell below the replacement rate (2.1 children per woman) in 1974, when the economy was still booming.

The second caveat is that our argument does not imply that total output growth or output growth per capita, are not relevant. For example, total output growth matters for public debt and social security sustainability (Faruqee and Mühleisen, 2003; Kitao, 2015). Broadly, output growth per capita gives us a sense of how fast the average resources available to each inhabitant of an economy are changing. Similarly, Klenow et al. (2017) argue for the importance of considering total population to evaluate social welfare growth. We are deliberately silent about welfare.

Related literature. In terms of the related literature, we highlight that we are not the first to report data or calibrate models in terms of per working-age adult. While this practice is less common than using per capita terms, many papers have followed it (see Klein and Ventura, 2021, or several of the chapters in Kehoe and Nicolini, 2022).[3]

More in general, a very large literature explores the links between economic growth and population aging, going back to the pioneering work of Auerbach and Kotlikoff (1990), Cutler et al. (1990), and Weil (1997). Instead of reviewing each aspect of this literature, we highlight a few recent contributions that are closely related to us. Kotschy and Bloom (2023) have already pointed out the link between population aging and economic growth. The main difference between that paper and ours is our emphasis on determining the right metric to assess GDP growth from the perspective of growth theory and our use of a standard neoclassical growth model to analyze the data instead of empirical regressions. Jones (2022) has used endogenous growth models in which people discover new ideas to study the possible stagnation of living standards as the population shrinks. In comparison, we take technological progress as given.[4] Our point is different: researchers need to be careful about the object of measurement in the context of growth theory when the number of working-age adults is falling or stagnating, regardless of our views on the production function for ideas.

Chen et al. (2007) account for Japan's observed saving rate in terms of population aging, productivity, and fiscal policy. Jaimovich and Siu (2009) demonstrate that demographic change explains approximately one-fifth to one-third of the decline in output volatility in the U.S. Similarly, Ferraro and Fiori (2020) argue that the aging of the baby boomers significantly diminishes the effects of tax cuts on aggregate unemployment. Cravino et al. (2022) quantify the extent to which population aging increases the share of services in total consumption. Acemoglu and Restrepo (2021) explore the relationship between automation and population aging, while Maestas et al. (2023) provide evidence that population aging reduced U.S. GDP growth per capita by 0.3% annually from 1980 to 2010. Hopenhayn et al. (2022) attribute the recent evolution of firm concentration, entrepreneurship, and the labor share to population aging. Likewise, Karahan et al. (2019) argue that demographic trends account for two-thirds of the decline in the start-up rate in the U.S. since the late 1970s. Finally, Aksoy et al. (2019) estimate a panel VAR to examine how demographic structures influence macroeconomic trends across OECD countries.

The paper is organized as follows. In Section 2, we document the facts of interest. In Section 3, we present the standard neoclassical model we use in our quantitative analysis. In Section 4, we present the calibration and solution of the model. Our quantitative results are in Section 5, while Section 6 discusses them and extends the analysis to China, India, and South Korea. We conclude in Section 7.

[2] For examples of negative assessments of Japan's fiscal and monetary policy due to low GDP growth, see Ito and Rose (2007) and Hamada et al. (2010).

[3] See, also, in the context of the public debate, https://archive.nytimes.com/krugman.blogs.nytimes.com/2012/01/09/japan-reconsidered-2/.

[4] See also Sasaki and Hoshida (2017). Sasaki (2019) explores ideas similar to those of Sasaki and Hoshida (2017) and Jones (2022) in the context of a neoclassical growth model with a falling population.

Table 1
G7 plus Spain: Output and population growth rates.

1991–2019	Canada	France	Germany	Italy	Japan	Spain	UK	U.S.
GDP	2.47	1.61	1.38	0.70	0.83	2.05	2.08	2.58
GDP per capita	1.40	1.10	1.25	0.52	0.76	1.35	1.53	1.63
GDP per working-age adult	1.48	1.33	1.47	0.79	1.39	1.41	1.62	1.65
GDP per hour worked	1.23	1.28	1.31	0.71	1.26	0.67	1.37	1.53
GDP per worker	1.05	0.98	0.90	0.45	0.65	0.53	1.25	1.49
Population	1.05	0.50	0.14	0.18	0.08	0.68	0.54	0.94
Working-age adults	0.98	0.27	−0.09	−0.08	−0.54	0.63	0.46	0.91
Total hours worked	1.23	0.33	0.08	0.00	−0.43	1.40	0.71	1.04

Table 2
Output growth decomposition.

1991–2019		Canada	France	Germany	Italy	Japan	Spain	UK	U.S.
GDP	Y_t	2.47	1.61	1.38	0.70	0.83	2.05	2.08	2.58
Population	N_t	1.05	0.50	0.14	0.18	0.08	0.68	0.54	0.94
Working-age per person	l_t	−0.08	−0.23	−0.22	−0.27	−0.62	−0.05	−0.08	−0.03
Emp. rate per working-age	e_t	0.42	0.35	0.57	0.34	0.74	0.90	0.36	0.17
Hours worked per worker	h_t	−0.17	−0.30	−0.40	−0.26	−0.61	−0.14	−0.11	−0.04
GDP per hour worked	y_t	1.23	1.28	1.31	0.71	1.26	0.67	1.37	1.53
GDP per worker	Y_t/E_t	1.05	0.98	0.90	0.45	0.65	0.53	1.25	1.49
GDP per working-age adult	Y_t/L_t	1.48	1.33	1.47	0.79	1.39	1.41	1.62	1.65
Total hours worked	H_t	1.23	0.33	0.08	0.00	−0.43	1.40	0.71	1.04
Working-age adults	L_t	0.98	0.27	−0.09	−0.08	−0.54	0.63	0.46	0.91

2. Data and facts

This section summarizes the data and facts used in our study. Our primary data source is the World Bank's World Development Indicators (WDI) database, which provides comparable statistics for a wide range of countries. Real GDP is measured in national constant prices, while the working-age population is defined as individuals aged 15 to 64. Since the WDI does not include data on hours worked, we use the measure from the Conference Board reported in PWT 10.0: "average annual hours worked by persons engaged". Our analysis focuses on the G7 countries. To this group, we add Spain, the largest Western European economy outside the G7, which has experienced a rapid demographic transition.

We compute growth statistics for these countries over the period 1991 to 2019. This timeframe is chosen for two key reasons. First, comparable data for all countries are not available before 1991. Second, and more importantly, the central focus of this paper – examining the relationship between population aging and GDP growth – only became relevant in the 1990s.[5]

Table 1 reports output and population growth rates (see Table 2 for more statistics). All the variables are annual growth rates and are expressed in percentage points. As in all the tables in the paper, we highlight a few numbers in red because they are salient to our presentation.

2.1. *GDP growth per working-age adult*

In the first row of Table 1, we see large differences in yearly GDP growth. While Italy (the worst performer in terms of GDP growth) has only grown 0.70% a year for four decades, the U.S. (the best performer) has grown 2.58%. This is a huge difference. In accumulated terms, the Italian economy has grown 121% since 1991, while the U.S. economy has grown 203%.

The second row of Table 1 shows that the differences in GDP growth become much smaller in per capita terms. Italy, still the worst performer, has grown at a rate of 0.52%, while the U.S. has grown at a rate of 1.63%. The fifth row, population growth, explains these differences: while Italy's population has grown at 0.18% a year, the U.S. population has been growing at 0.94%.

The third row of Table 1, where we report GDP growth per working-age adult, documents our main argument. The relative performance of Italy vs. the U.S. does not change much, but this is not the case for other countries. We compare first Japan and the U.S. (our numbers in red). Japan's GDP growth is much lower than the U.S., 0.83% vs. 2.58%, a difference of about 1.75 percentage points. However, in terms of per working-age adult, Japan becomes much closer to the U.S. (1.39% vs. 1.65%). The reason appears in the sixth row of Table 1: while the population of working-age adults has fallen in Japan (−0.54%) due to aging, it has grown in the U.S. at 0.91%.

If one drops the early 1990s from the sample (the years of the asset price collapse), Japan's performance is even better. From 1998 to 2019, Japan has grown *slightly faster* than the U.S. in terms of working-age adults: an accumulated 31.9% vs. 29.5%. Suddenly,

[5] We also computed statistics for the pre-1991 period for the subset of countries with comparable data. However, as demographics played no significant role before 1991, there are no notable differences between the various measures of GDP growth. These results are available upon request.

Japan's economic performance is transparent: there are fewer Japanese of working age, and a smaller labor input leads to lower total GDP growth. Or, to put it differently, for Japan to match the GDP growth of the U.S., its GDP growth per working-age adult would need to have grown at 3.12% a year, an outstanding feat once Japan had completed its neoclassical growth transition by the late 1980s.

A commonly cited fact about Japan is the high labor force participation rate of older adults. While this observation holds, the participation rate for those aged 65 and over in Japan has not changed much from 1991 to 2019. It stood at 25.3% in both 1991 and 2019, hitting a low of 19.8% in 2006. Comparatively, in the U.S., the participation rate for adults aged 65 and over rose from 11.5% in 1991 to 20.2% in 2019. This suggests that Japan's relative success cannot be attributed to an increasing employment rate among its older population. Nevertheless, Japan's aging has had a less detrimental impact than it would have in a country with a lower participation rate among older adults. We will return to this point when we discuss output growth per hour worked.

Fig. 2.1 plots the underlying time series for all countries. Look at the evolution of the population between ages 15 and 64 in each of the eight countries (bottom right panel). Compare the evolution of working-age adults in the U.S. (dashed blue line at the top) with the evolution in Japan (dashed green line at the bottom).

A key takeaway from the figure is that the wide dispersion in GDP per person across countries narrows significantly, with one exception — Italy, discussed further below. Excluding Italy, GDP growth per working-age adult ranges from 1.33 (France) to 1.65 (U.S.). This low dispersion in growth rates is notable given the differing *levels* of these economies' growth paths (output per working-age adult is normalized to 100 in 1991). For instance, Spain's output per capita in PPP terms is about one-third lower than the U.S., the highest-income country in the sample. Yet, there is no sign of convergence toward the U.S. and clear divergence for Italy.

The case of Italy is intriguing. Until the mid-2000s, Italy tracks the other countries in the sample (although closer to the bottom of the pack). However, after the financial crisis, Italy falls behind and cannot recover the level of output from before the crisis. Interestingly, Italy did not have a financial collapse (like Ireland), nor was it under a memorandum of understanding with the European Union (like Spain in July 2012). Italy's problems seem deeper than digesting the aftermath of a financial meltdown.

The data suggest that a common model can account for the experience of all these countries, delivering roughly equivalent growth experiences per working-age adult but different output growth path levels. This motivates us to postulate, in the next section, a simple neoclassical growth model with country-specific technological processes. But let us first look at hours worked.

2.2. GDP growth per hour worked

We focus now on the fourth row in Table 1, where we report GDP growth in terms of hours worked. Comparing it with row three reveals that GDP per hour worked evolved very similarly to GDP per working-age adult in all the other countries of our sample, with the exception of Spain. For instance, the difference in GDP growth per hour worked between Japan and the U.S. (1.53%–1.26% = 0.27%) is nearly the same as the difference in growth rates of GDP per working-age adult (1.65%–1.39% = 0.26%).

This is even clearer in Fig. 2.2, where we plot GDP per working-age adult in the left panel (this is the same plot as the bottom left panel of Fig. 2.1) and GDP per hour worked in the right panel. The paths of both variables are similar except for Spain. In Spain's case, output per working-age adult closely follows that of the majority of countries. In contrast, output per hour worked stagnated for several years until about 2005, then grew in parallel to other countries, and subsequently stagnated again at the level of Italy around 2015. A conjecture for this anomalous behavior relates to the disproportionate movements in immigration flows into Spain of less skilled workers. Alternatively, measurement error in hours may have played a role.

2.3. A growth decomposition

We now provide a more formal decomposition of output changes that we have described above, taking into account all different margins. Define the identity $Y_t \equiv N_t \cdot l_t \cdot e_t \cdot h_t \cdot y_t$ where:

1. N_t is total population at t.
2. l_t is working-age adults, L_t, per person L_t/N_t.
3. e_t is total employment (regardless of the age of the worker), E_t, as a fraction of working-age adults, E_t/L_t.
4. h_t is total hours worked (regardless of the age of the worker), H_t, divided by total employment H_t/E_t.
5. y_t is output per hour worked Y_t/H_t.

Table 2 reports the results of this decomposition plus the growth of GDP per worker, GDP per working-age adult, total hours, and working-age adults.

We focus, just for concision, on Japan. The key driver in Table 2 is the evolution of total hours worked, which fell 0.43% a year in Japan and increased by 1.04% in the U.S. The evolution of total hours in Japan, −0.43%, is very close to the evolution of the working-age adults, −0.54%. A similar result holds for the U.S.: a 1.04% growth of hours and a 0.91% growth of working-age adults.

While the population of working-age adults as a fraction of the total population has slightly fallen in the U.S. (0.03% per year), it has fallen strongly in Japan (0.62%). Increases in the employment rate in terms of working-age adults in Japan (0.74%) have been nearly exactly compensated by a fall in hours worked per worker (0.6%). The former increase is due to several factors, including higher female labor force participation. The latter decrease is mainly driven by the fact that hours per worker have fallen from an average of around 2000 h for full-time workers to around 1800 h, closer to the standard in the other G7 economies. In the U.S., in comparison, the employment rate per working-age adult and hours worked per worker have been flat. The main factor behind the differences in the U.S. total GDP growth and GDP per hour worked is the growth rate of its population, 0.94% per year.

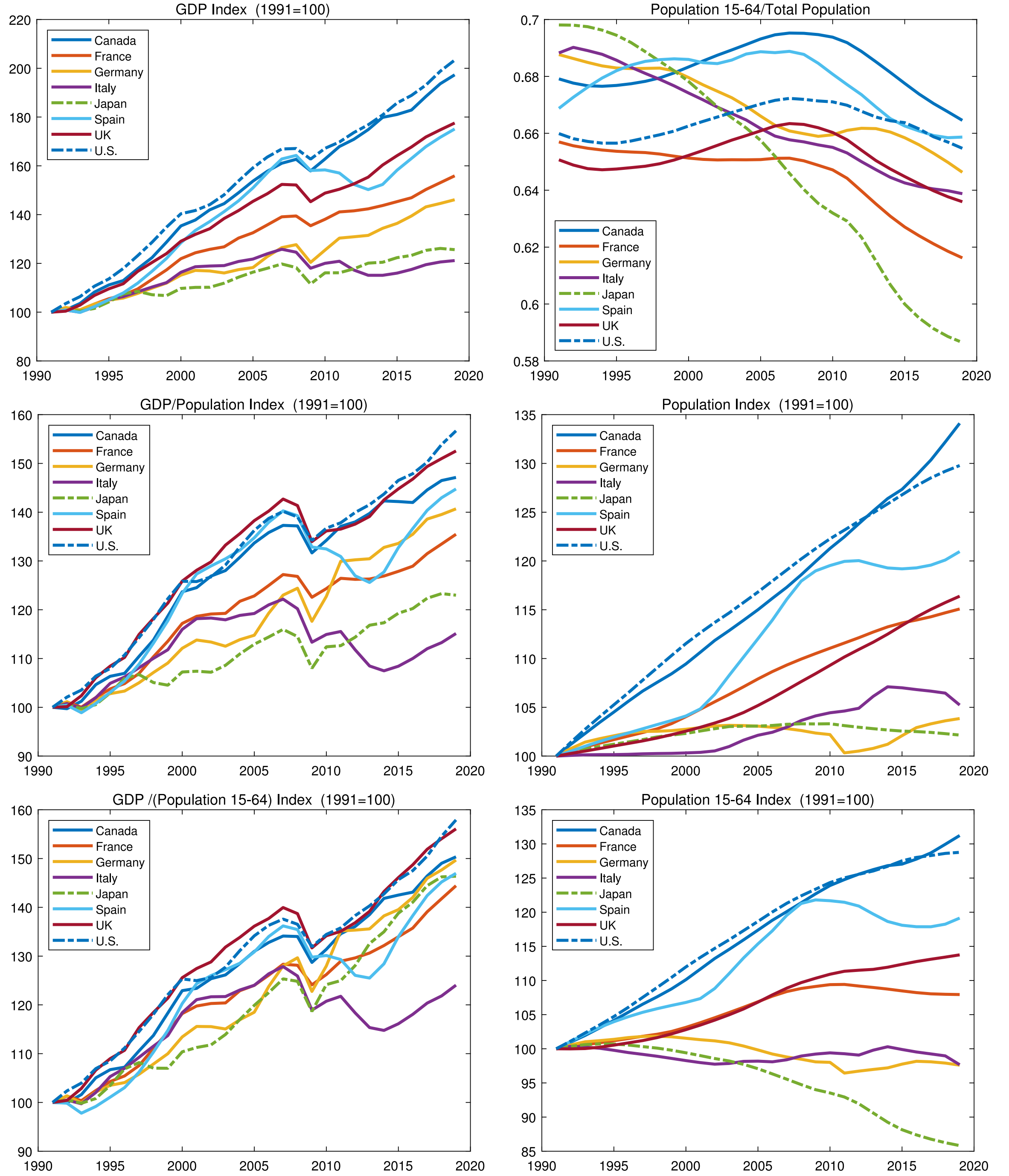

Fig. 2.1. G7 and Spain: 1991–2019. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

2.4. Redefining working age

So far, we have followed the standard definition used by statistical agencies worldwide of working-age adults as the population between 15 and 64 years old. Child labor is minimal in the economies we consider (the G7 plus Spain). On the other hand, participation rates for adults 65 and older are low but, in some cases, significant. In 2019 (the last year of our dataset), participation rates of adults 65 and older ranged from 2.5% in Spain to 25.3% in Japan (OECD, 2024).

However, Oshio et al. (2018) document that many of those over 65 who are working in Japan are between 65 and 69. For example, around 50% of men and around 35% of women between 65 to 69 continue working, with participation rates falling

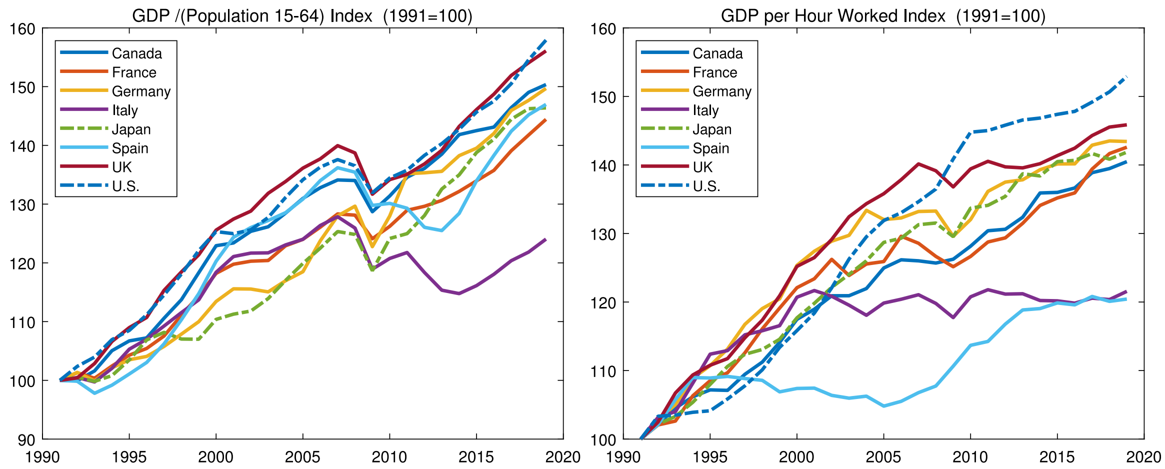

Fig. 2.2. G7 and Spain: GDP per working-age adult and GDP per hour worked.

Table 3
GDP Facts: Different working age definition.

1991–2019	Canada	France	Germany	Italy	Japan	Spain	UK	U.S.
GDP	2.47	1.61	1.38	0.70	0.83	2.05	2.08	2.58
GDP per w.-age adult (15–64)	1.48	1.33	1.47	0.79	1.39	1.41	1.62	1.65
GDP per w.-age adult (15–69)	1.39	1.25	1.40	0.74	1.21	1.38	1.60	1.58

drastically after 69. This observation motivates a redefinition of working age to include all adults between 15 and 69 years old and a recomputation of our statistics to check for their robustness to the 64-year-old cutoff line.

Table 3 presents the new results in the third row, alongside GDP growth per working-age adult (15–64) in the second row for comparison (identical to the third row of Table 1). The table shows that our argument holds for alternative definitions of the working-age population. GDP growth per working-age adult (15–69) is slightly lower than for ages 15–64 in all countries, as the 65–69 age group grows with aging. However, the relative rankings remain similar. For instance, growth drops by 0.07% in the U.S. and 0.18% in Japan, increasing the gap between them to 0.37%, still a relatively small difference.

2.5. Why not GDP growth per worker or TFP growth?

There are alternative measures of GDP growth per working-age adult and per hour worked. One such measure is GDP growth per worker. However, we prefer GDP per hour worked, as it captures both the intensive and extensive margins of labor supply. As we mentioned above, in Japan, hours worked by full-time employees have declined as the length of the workweek has converged with that of other G7 countries. Nonetheless, line 7 of Table 2 shows that using GDP growth per worker would not alter the key findings: while growth rates are generally lower (reflecting fewer hours worked per worker), the relative performance of countries remains consistent, whether we examine output per working-age adult or per hour worked.

Another alternative is TFP growth, but this is not our primary focus, as we aim to provide a summary statistic for economic growth. TFP measures the efficiency of input use, not the quantity of inputs employed. A country could exhibit weak GDP growth due to underutilized labor, even with robust TFP growth. The U.S. from 1929 to 1941 offers a clear example: during the Great Depression, U.S. TFP grew at 1.86% per year, faster than any period between 1899 and 2007 except 1948 to 1973 (Crafts and Woltjer, 2015), leading (Field, 2011) to call the 1930s the "most progressive decade". Yet, in 1939, real GDP per capita was still about 27% below trend (Cole and Ohanian, 2004).[6]

From a practical standpoint, calculating TFP involves numerous assumptions, such as functional forms and methods for estimating stocks of physical and human capital. Even minor variations in these assumptions can lead to significant differences in TFP growth values. For instance, in our sample, Italy, Japan, and Spain have significantly increased the percentage of working-age adults with tertiary education. This is problematic from the standpoint of the literature, which has shown the challenges associated with converting additional years of higher education into human capital and its quantitative implications for TFP estimates.[7]

[6] GDP per capita below trend and accelerated TFP growth are compatible with the neoclassical growth theory introduced in the next section. Accelerated TFP growth creates a positive wealth effect, but since productivity gains occur in the future, households smooth utility by reducing labor supply and investment, lowering current output. This contrasts with the response to temporary TFP shocks, which lead to an increase in output above trend.

[7] Cubas et al. (2016) and Schoellman (2011), among others, document significant disparities in education quality across countries. As a result, comparing the human capital of an adult with 14 years of education in Spain to that of an adult with the same level of education in Germany is challenging.

3. A standard neoclassical growth model

We formulate a standard neoclassical growth model with exogenous technological change and demographics. Each country is modeled as a different economy, without any interaction except a possible common technology trend. This simple model will help us determine how much the growth experience of the eight countries in our sample fits standard theory. To ease notation, we will work directly with the social planner's problem. Since both welfare theorems hold in our model, the solution to the social planner's problem is also the market allocation.

3.1. Preferences and technology

The economy is populated by an infinitely lived representative household of varying size N_t. Later, when we take the model to the data, we will equate N_t with the total population.

The preferences of the representative household over per capita consumption are represented by:

$$\max_{C_t/N_t} \sum_{t=0}^{\infty} \beta^t N_t \log\left(\frac{C_t}{N_t}\right),$$

where β is the discount factor and C_t is aggregate consumption.

We do not have an endogenous labor choice. We abstract from it because we want to focus on the growth properties of our economy, not its business cycle features (the frequency at which most labor fluctuations occur). The textbook formulation of the neoclassical growth model selects utility functions that ensure the working-age population's labor supply is constant along the balanced growth path. Hence, in the interest of simplicity, we drop the labor choice.[8]

Output is given by $Y_t = K_t^{\theta}(A_t L_t)^{1-\theta}$ where K_t is capital, and L_t is the working-age population. A_t is the level of labor-augmenting technology, which grows at a constant rate g, $A_t = A_0(1+g)^t$. Thus, in this economy, total factor productivity (TFP) equals $A_t^{1-\theta}$.

Output is used for consumption or investment I_t: $C_t + I_t = Y_t$. Given a depreciation rate δ, the law of motion for capital is $K_{t+1} = I_t + (1-\delta)K_t$. Finally, N_t grows at an exogenously given time-varying rate n_t, so that $N_t = \prod_{i=1}^{t}(1+n_i)$, given $N_0 = 1$.

Given the growth of technology g, we must normalize the variables. We use the country's technology and population level to make the problem stationary. Specifically, let l_t be the exogenously given working-age population rate L_t/N_t. Then:

$$c_t = \frac{C_t}{A_t N_t},$$
$$k_t = \frac{K_t}{A_t N_t},$$
$$i_t = \frac{I_t}{A_t N_t},$$
$$y_t = \frac{Y_t}{A_t N_t} = \left(\frac{K_t}{A_t N_t}\right)^{\theta}\left(\frac{A_t L_t}{A_t N_t}\right)^{1-\theta} = k_t^{\theta} l_t^{1-\theta}.$$

With these transformations, we can rewrite the social planner's problem as follows:

$$\max_{c_t} \sum_{t=0}^{\infty} \beta^t N_t \log c_t$$
$$\text{s.t. } y_t = k_t^{\theta} l_t^{1-\theta},$$
$$c_t + i_t = y_t,$$
$$i_t = (1+g)(1+n_{t+1})k_{t+1} - (1-\delta)k_t.$$

A standard Euler equation characterizes the solution to this optimization problem:

$$c_t^{-1}(1+g) = \beta c_{t+1}^{-1}\left(\theta(k_{t+1})^{\theta-1}(l_{t+1})^{1-\theta} + 1 - \delta\right).$$

This Euler equation looks like the optimality condition of the textbook neoclassical growth model with population and trend technological growth except for the presence of a time-varying term l_{t+1}.[9] Consider the case that $l_{t+1} = \hat{l}$ is constant, i.e., the working-age population is a constant fraction of the total population. This is equivalent to a constant in front of the (normalized) production function and, hence, irrelevant to the dynamics of the model.

Conversely, consider when l_{t+1} changes. This shifts the level of the (normalized) production function, akin to a technological shock: a rise in l_{t+1} increases total production, boosting investment and output; a drop in l_{t+1} lowers production, reducing investment and output. Thus, changes in l_{t+1} mimic technological shocks in an RBC model without labor choice, with the same persistence and propagation.

[8] Similarly, we drop the international aspect of the model. In an international model where the different economies are on their balanced growth paths and have a common β (as we will use in our calibration), this international aspect would not change any conclusion of importance to us.

[9] As such, shocks to N_t and A_t have the usual effects on output and investment.

Table 4
Calibration.

Parameter		Value
Discount factor	β	0.944
Capital share	θ	0.39
Depreciation rate	δ	0.04
Labor augmenting technology growth rate, Canada	g	0.0148
Labor augmenting technology growth rate, France	g	0.0133
Labor augmenting technology growth rate, Germany	g	0.0147
Labor augmenting technology growth rate, Italy	g	0.0079
Labor augmenting technology growth rate, Japan	g	0.0139
Labor augmenting technology growth rate, Spain	g	0.0141
Labor augmenting technology growth rate, UK	g	0.0162
Labor augmenting technology growth rate, U.S.	g	0.0165

4. Calibration and solution

Our model is indexed by the parameters β, θ, and δ plus the exogenous values for g and N. The parameter A_0 is a scaling parameter that we will pick to match the initial value of GDP per working-age adult in 1991. Furthermore, we assume that each economy is at its balanced growth path in terms of per working-age adult at the start of the simulation.

We calibrate β, θ, and δ on an annual basis to match the data for 1991–2019, following commonly used targets. See Table 4 for a summary of the calibration.

We select a discount factor β of 0.944 to replicate a 7.7% annual rate of return to capital reported by the PWT 10.0 for the U.S. between 1991 and 2019 (given our model, we want to match the return on all capital goods, not on bonds or other financial assets). We pick the capital share $\theta = 0.39$ to match the average shares between 1991 and 2019 from PWT 10.0. The depreciation rate is the average depreciation rate from PWT 10.0: $\delta = 0.04$ for the U.S. These values imply a capital/output ratio of about 3.34. The low value of the depreciation rate and high value of the capital-output ratio are consistent with a broad notion of physical capital that includes residential capital, land, inventories, consumer durables, and government-owned capital.[10]

These three parameter values are common for all countries, even if our target values come from the U.S. Our presumption is that preferences, capital shares, and depreciation are roughly the same across all G7 countries plus Spain. More importantly, imposing common parameter values constrains our degrees of freedom and limits the model's flexibility to match each country's observations by varying the parameter values. Nonetheless, in extensive sensitivity analyses, we checked that the model is robust when we allow for country-specific parameter values.

Next, we show how to calibrate the model for the U.S. case. Analogous steps are used for all other countries, but we skip their explanation in the interest of space. First, we select A_0 to match the level of U.S. GDP per capita in 1991. This is just a normalization. The population growth rates match the observed data year by year in the U.S. Finally, we calibrate $g = 0.0165$ to match GDP growth per working-age population from 1991 to 2019 in the U.S.

To find the planner's solution, we take the initial steady state in 1991 and its final steady state in 2019 and compute the transition path between the two using the Euler equation and the investment and resource constraint equations using a nonlinear equation solver. More concretely, k_0, the U.S. capital in 1991, satisfies the steady-state Euler equation:

$$1 + g = \beta \left(\theta \left(k_0\right)^{\theta-1} \left(l_0\right)^{1-\theta} + 1 - \delta \right),$$

where l_0 is the U.S. working-age population ratio in 1991. To compute $i_0 = (1+g)(1+n_0)k_0 - (1-\delta)k_0$, we take population growth, n_0, to be the population growth observed in 1991.

The final steady-state capital of the U.S. k_T is given by:

$$(1 + g) = \beta \left(\theta \left(k_T\right)^{\theta-1} \left(l_T\right)^{1-\theta} + 1 - \delta \right),$$

where l_T is the U.S. working-age population ratio in 2019. To compute investment at T, n_T, we use the population growth observed in 2019.

5. Quantitative results

5.1. Benchmark results

Fig. 5.1 plots the evolution of GDP per worker (i.e., the model equivalent of a working-age adult in the data) in each of the eight countries in the sample 1991–2019.[11] In each panel, the dashed blue line represents the model, and the solid red line represents the

[10] In a well-known calibration exercise, Cooley and Prescott (1995) calculate a depreciation rate of 0.048 and a capital–output ratio of 3.32 under a broad notion of capital including government-owned capital.

[11] Values in Fig. 5.1 and subsequent model-based figures are normalized to log values in the year 1991. Thus, each value in the model and the data is given by $\frac{\log(y_t)}{\log(y_{1990})}$.

Table 5
Percentage reduction in MSE between "Canonical" and baseline calibration.

1991–2019	Canada	France	Germany	Italy	Japan	Spain	UK	U.S.
GDP per capita	27.54	65.82	31.52	50.21	72.93	3.96	19.84	5.85
GDP per working-age adult	27.61	66.00	33.59	50.43	76.19	3.41	19.86	5.80

log-level data for one country (normalized to be 1 in each case in 1991). While the dashed blue line might appear to be a straight line at first sight, it presents, in fact, small fluctuations due to varying growth rates of the working-age adult population. However, since those variations within one country from year to year are relatively small, they do not change the slope of the dashed blue line much.

The left panel in the top row shows the U.S., where the model closely tracks the economy's evolution during the sample. The MSE between the model and data for output per working-age adult is only 30 basis points. The most notable divergence is the 4% drop in income per worker after the 2007–2009 financial crisis, which permanently lowered the trend level.

A similar picture of a permanent drop in the output level of around 4.7% holds for Spain (the left panel in the bottom row) and 5.9% for the U.K. (the right panel in the bottom row). The U.S., Spain, and the U.K. were economies where many researchers identified a large real estate boom in the early 2000s, which has left long-lasting scars. To explore the idea that there has been a trend change in income growth per worker, in Section 6.2, we explore an alternative specification of the model for the U.S. with two different g's, one before and one after 2007.

The right panel in the top row is Canada. The model does surprisingly well here, as well as in France (the left panel in the second row) and Germany (the right panel in the second row), with remarkably minor deviations between the data and the model.

The left panel in the third row is Italy. This is the country for which our calibration of the model misses the dynamics of the data. The Italian economy stopped growing in the early 2000s (see Fernández-Villaverde et al., 2023a, for details on Italy's abysmal performance). The only way the model can capture this observation is by being calibrated to a low level of growth over the whole period 1991–2019, which leads to a large and persistent undershooting of the model from 1991 to 2000. As we mentioned above, for the case of the U.S., a simple solution for this problem of the model would be to introduce two different trends in g for Italy. We will evaluate this modification of the model in Section 6.2.

A similar pattern is observed for Japan, shown in the right panel of the third row. The model outperforms Japan's actual output per working adult during the 1990s when the country faced a deep crisis following the asset price collapse in 1992. However, Japan recovered in the 2000s and ended the sample close to the model's prediction. These findings have significant implications for fiscal and monetary policy. For instance, how can one judge Japan's fiscal and monetary policy as a failure if the country has grown faster than other G7 nations since the early 2000s?

Finally, there is no evidence of convergence among the different countries toward the U.S., the highest-income country. All countries travel along their paths at their own levels.

5.2. *The importance of demographics*

The lesson we get from Fig. 5.1 is *not* that our neoclassical growth model accounts for all features of the data (or that the model is superior to other frameworks, such as an overlapping generations model) but how, once we look at the data in terms of per working-age adult, there is more agreement between theory and data than when using total or per capita terms.

To illustrate, we recalibrate the model to match GDP growth per capita rather than GDP per working-age adult, following the approach recommended by Barro and Sala-i-Martin (2003, p. 58) and Cooley and Prescott (1995, p. 20). We term this alternative the "canonical" calibration. Then, we compare the match of our baseline calibration and the "canonical" calibration to the data using the MSE between the data and the path generated by the model.

Table 5 reports the results in terms of the reduction of the MSE between the model and the data when we switch from the "canonical" calibration to our calibration. We do so in terms of GDP growth per capita (the moment matched by the "canonical" calibration) and GDP growth per working-age adult (the moment matched by the baseline calibration).

For all countries but the U.S., the MSE reductions are large, with around 50% for Italy, 66% for France, and 73%–76% for Japan. That is, even if one only cares about GDP growth per capita (the moment matched by the "canonical" calibration), one still wants to calibrate the model GDP growth per working-age adult. For the U.S., the improvement is smaller (5.85%–5.80%) because L_t/N_t does not change much in our sample. Yet, a 5.85%–5.80% difference is significant in the context of the relative empirical fit of DSGE models: it is about 40% of the improvement in the MSE one gets in a standard DSGE model by introducing price and wage stickiness.

Recall that our calibration is quite simple. For instance, we assume that g is constant (see, though, next section). However, this is not important for the results in Table 5. If we let g change (e.g., to capture the slowdown of TFP growth observed in many countries), we improve the MSE of both calibrations but leave their relative performance roughly unchanged. In summary, considering demographics is a first-order task, even for the basic neoclassical growth model.

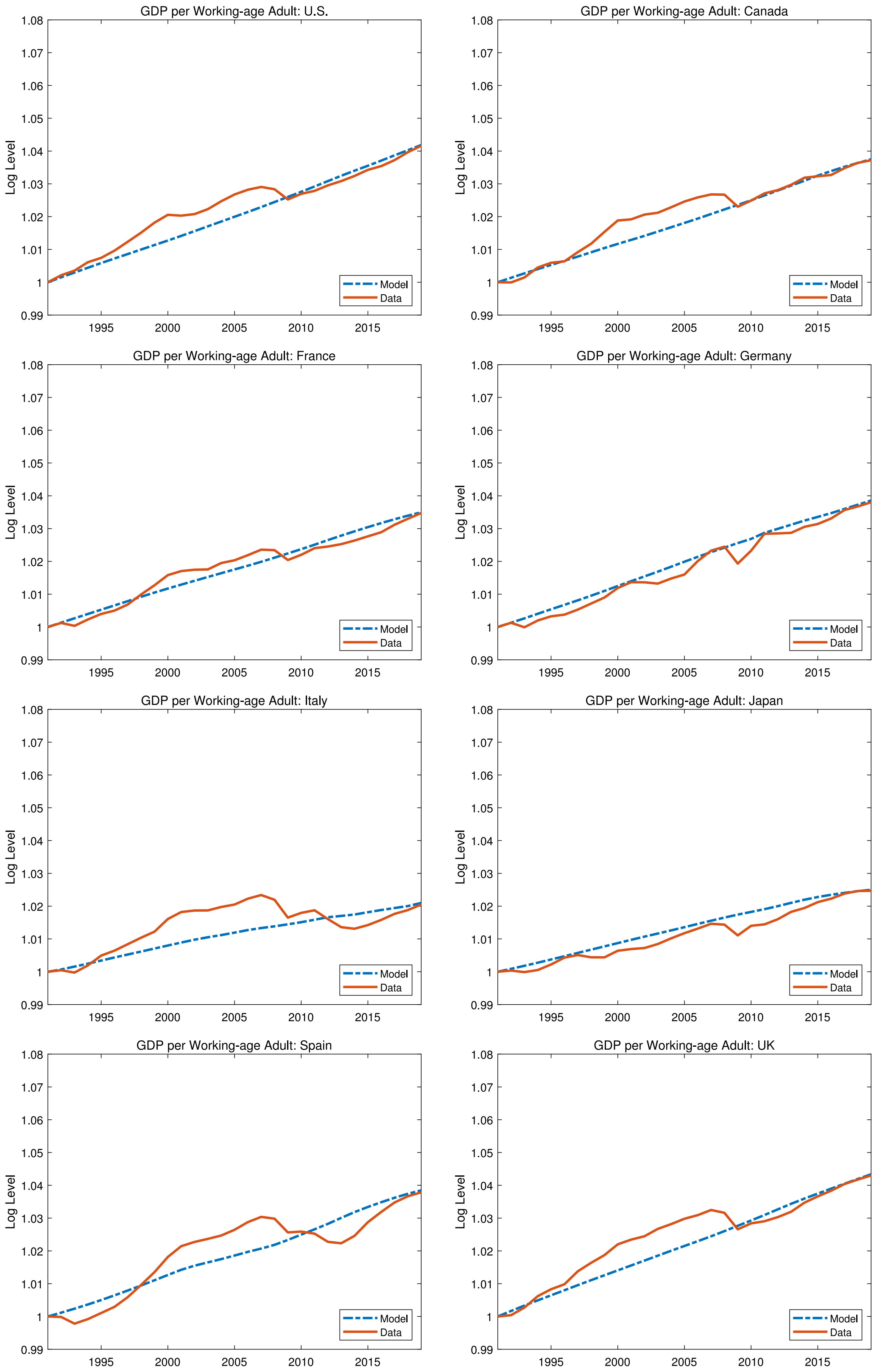

Fig. 5.1. Transitional dynamics: 1991–2019. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Table 6
G7 plus Spain: Basic growth and population facts, 1991–2007.

1991–2007	Canada	France	Germany	Italy	Japan	Spain	UK	U.S.
GDP	3.03	2.09	1.49	1.45	1.14	3.10	2.67	3.26
GDP per capita	2.01	1.52	1.31	1.27	0.94	2.15	2.25	2.14
GDP per working-age adult	1.86	1.58	1.56	1.55	1.43	1.96	2.13	2.02
Population	1.00	0.56	0.17	0.18	0.20	0.94	0.41	1.10
Working-age adults	1.15	0.50	−0.07	−0.10	−0.28	1.12	0.53	1.21

Table 7
G7 plus Spain: Basic growth and population facts, 2008–2019.

2008–2019	Canada	France	Germany	Italy	Japan	Spain	UK	U.S.
GDP	1.79	1.03	1.27	−0.23	0.58	0.61	1.43	1.81
GDP per capita	0.65	0.61	1.16	−0.36	0.68	0.38	0.71	1.11
GDP per working-age adult	1.07	1.11	1.35	−0.11	1.49	0.78	1.10	1.34
Population	1.13	0.42	0.11	0.14	−0.10	0.23	0.71	0.70
Working-age adults	0.71	−0.07	−0.08	−0.12	−0.90	−0.16	0.33	0.46

6. Discussion

In this section, we present several extensions of our study. More concretely, we analyze a case with a common trend growth across countries and a case with a time-varying trend and extend our sample to include China, India, and South Korea.[12]

6.1. Using a common g

In the baseline calibration, we calibrate a country-specific g. The motivation was that technological progress in each country might be mediated by local institutions and social norms that imply that not all scientific and engineering discoveries and business practice developments are implemented equally across the economies (on the latter point, see Bloom and Van Reenen, 2010).

In our first robustness exercise, we instead impose that each country's GDP growth rate per worker is the same as in the U.S., 0.0165. The time-varying population growth rate and working-age population ratio remain country-specific. This exercise assesses what our model predicts for each country if there are no differences in implementing the new technology.[13] In particular, this exercise controls for the possibility that different aging speeds in each country might lead to different g's (for example, by slower adoption of new technologies by an aged workforce).

Fig. 6.1 shows our results. The left panel in the top row, the U.S., is by construction the same as in Fig. 5.1. The model accounts well for the behavior of the UK (right panel in the fourth row). This is not a surprise, since we know from Table 1 that the UK's output growth rates per working-age adult in 1991–2019 were only slightly below that of the U.S. Thus, substituting their own g with the g of the U.S. makes little difference. Conversely, we see large gaps appearing for the other countries, in particular, France and Italy, which is evidence of problems for these countries in keeping up with the world technology frontier.

6.2. Changing trends

Our findings in Section 5 suggested the importance of considering changes in the growth trend of technology. To explore this possibility, we split our sample between the periods 1991–2007 and 2008–2019, or before and after the financial crisis.

Fig. 6.2 illustrates the effects of a time-varying trend in our neoclassical growth model. In the interest of space, we only report the case of the U.S. and Italy (the results for the other countries are roughly similar). The growth of g from 1991 to 2007 is given by its value in Table 6, and the economy is transitioning along its balanced growth path. Then, in 2008 and in an unanticipated way, the growth of g drops to its value in Table 7 from that moment on, and we compute the transition to a new balanced growth path in 2100 (sufficiently far in the future to ensure we have a complete view of the transition). The model now better matches the observations for the U.S. and Italy, including the latter's stagnation. However, our model is silent about the sources of the change in g.

Table 6 reports growth and population facts from 1991 to 2007. Similarly, Table 7 reports the same statistics for the sample period 2008–2019. As expected, we see large drops in the rates of GDP growth per working-age adult. In the U.S., the rate falls from 2.02% to 1.34%. In the case of Italy, it even goes negative, from 1.55% to −0.11%. Interestingly, the country with the highest growth rate of output per working-age adult in this later period is Japan, with 1.49%.

[12] Many additional results, including further robustness analysis regarding the calibration and varying the sample, are available in the working paper version of this paper, Fernández-Villaverde et al. (2023c).

[13] The U.S. GDP growth rate per working-age adult in 1991–2019 is the highest in our sample. Thus, as a first-order approximation, we consider the U.S. g as a measure of the growth of the world's technological frontier.

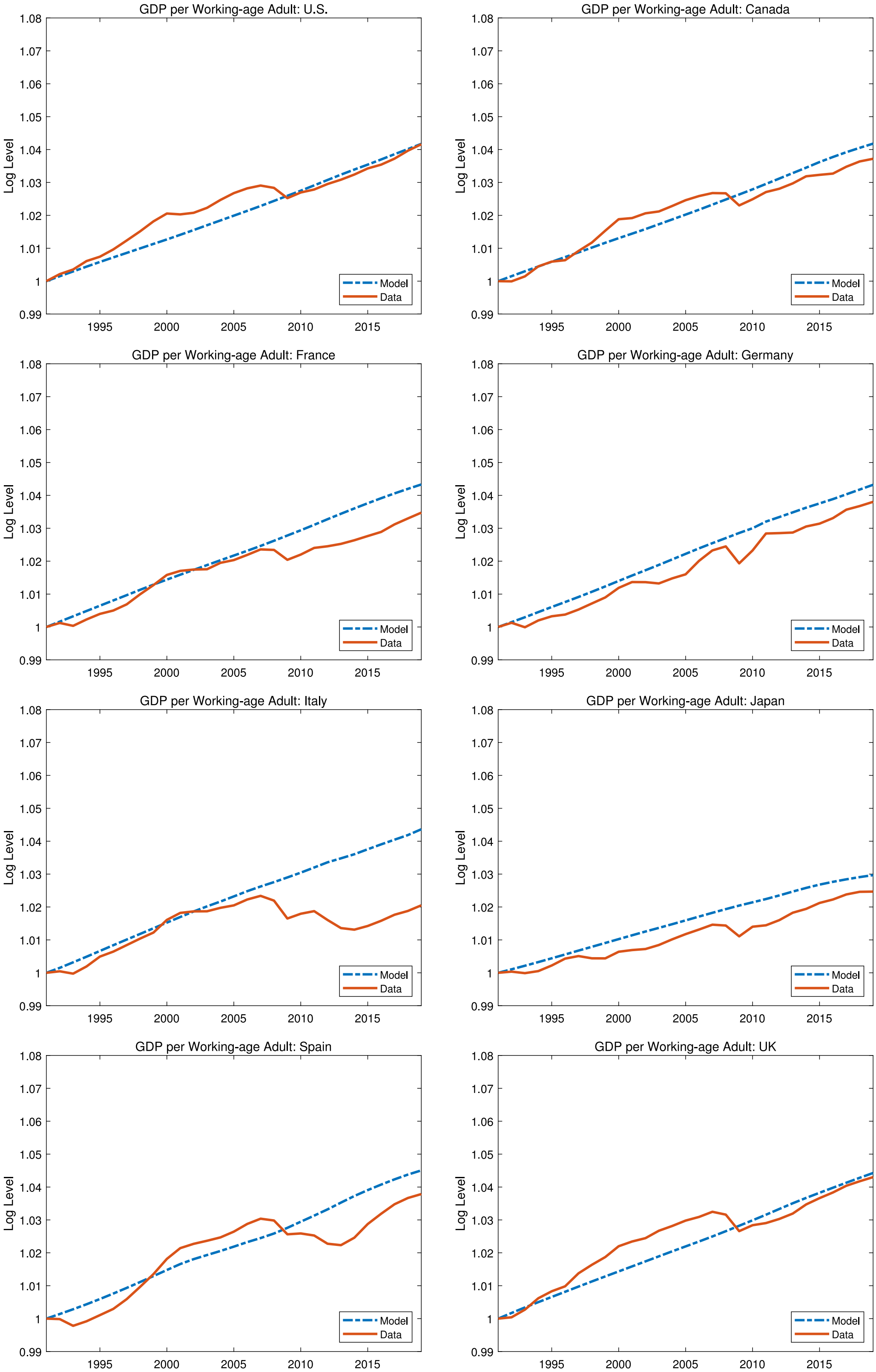

Fig. 6.1. Transitional dynamics: 1991–2019, common g.

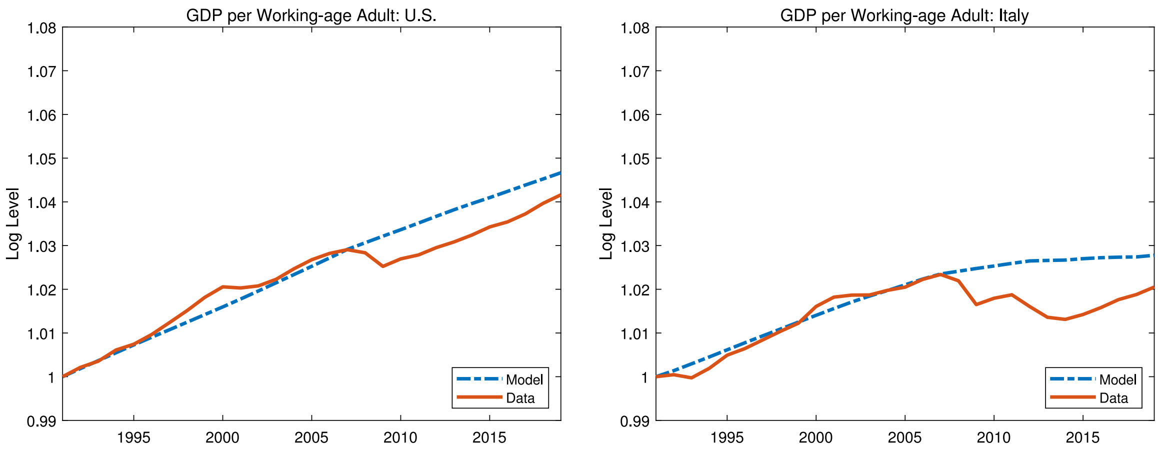

Fig. 6.2. U.S. and Italy: 1991–2019, change in trend.

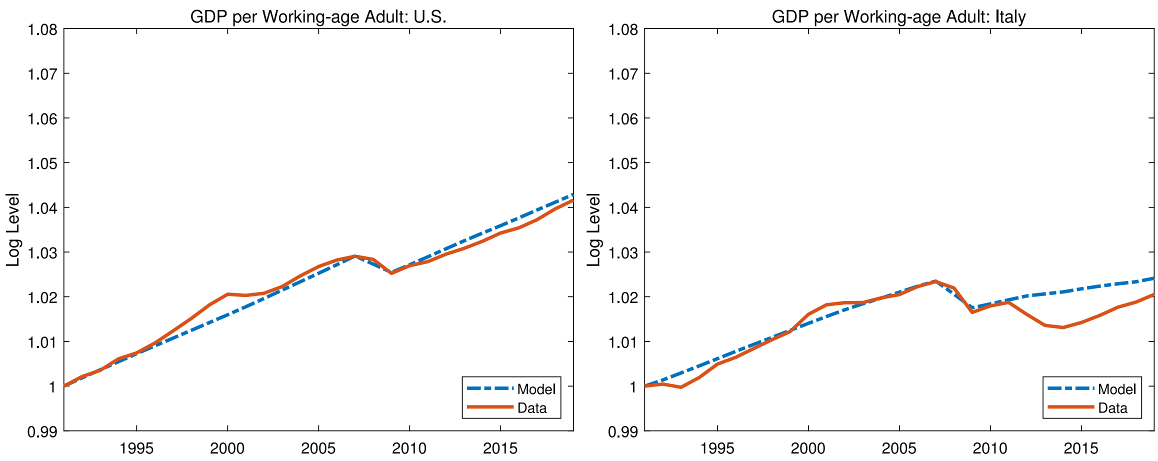

Fig. 6.3. U.S. and Italy: 1991–2019, drop in trend.

Table 8
China and India: Basic growth and population facts 1991–2019.

1991–2019	China	India
GDP	9.54	6.44
GDP per capita	8.75	4.77
GDP per working-age adult	8.52	4.25
Population	0.72	1.59
Working-age adults	0.93	2.10

A possible alternative to having two trends would be to have a shock to the level of the growth path. In terms of our model, this would correspond to a sudden drop in A. As shown in Fig. 6.3, with this change in trends, the model fits the data even better. The improvement is particularly salient when we let A fall in 2008 and 2009 and continue at its old growth rate. This suggests that the financial crisis permanently reduced the level of technology in our economies.

6.3. China and India

We now extend our analysis to China and India, the two most populated economies in the world. This exercise illustrates when it is relevant to distinguish among different output growth rates in economies with behavior different from that of the G7 and Spain.

Table 8 reports growth and population facts for China and India. Both countries have experienced very fast growth since 1991: 9.54% and 6.44%, respectively. The different growth rates for China do not change much whether we look at them in total, per capita, or working-age adult terms: 9.54%, 8.75%, and 8.52%. This similarity reflects the underlying strong growth of the economy after the start of the economic reforms in 1978 and the relatively moderate growth of the population and working-age adults.

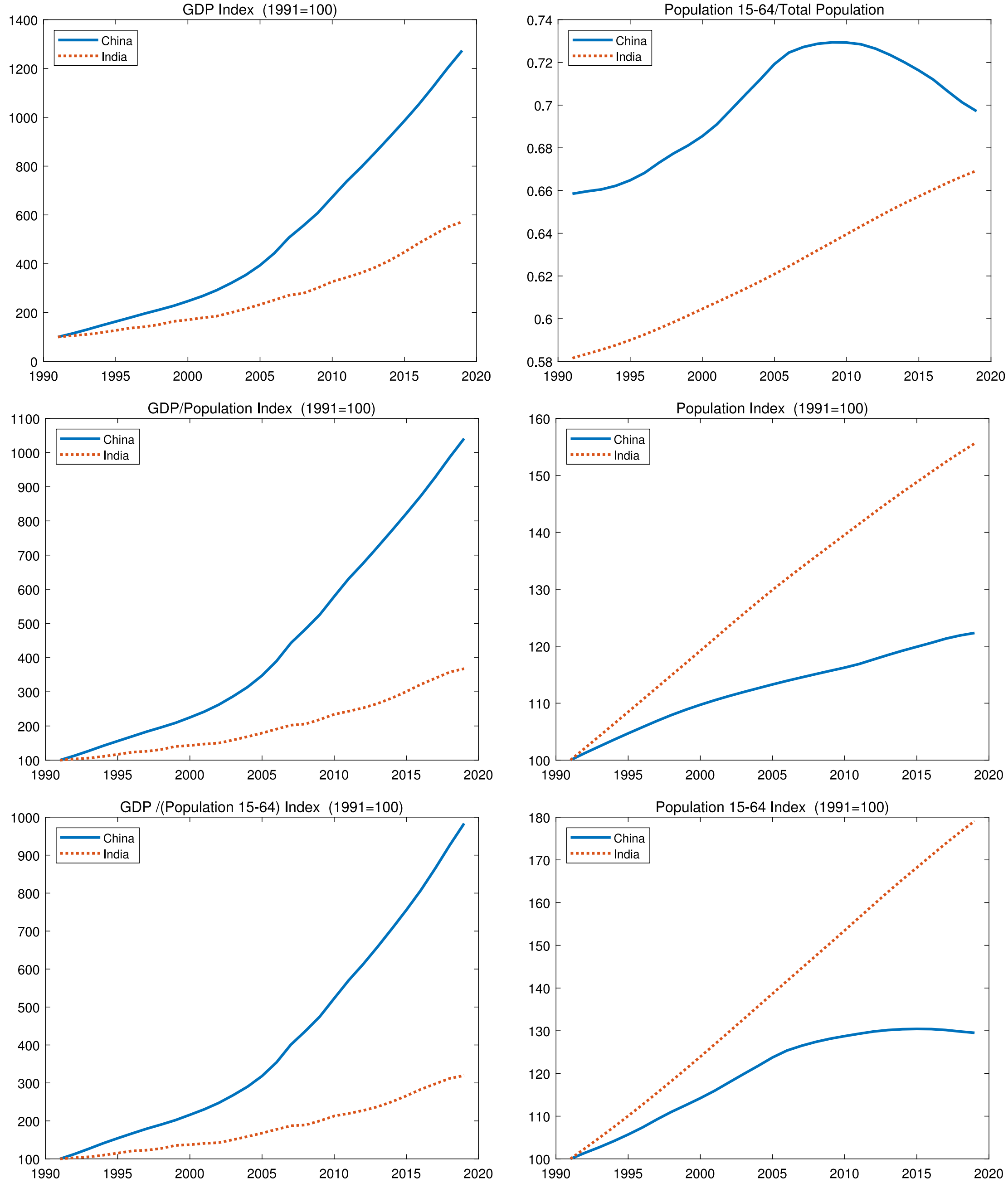

Fig. 6.4. China and India: 1991–2019.

In the case of India, however, we have a mirror image of Japan: the GDP growth rate per working-age adult of 4.25% looks much less impressive than the high rate of total GDP growth, 6.44%, due to the fast growth rate of working-age adults (2.10%). For completeness, Fig. 6.4 plots the time series for these two Asian countries. No matter in which terms we compute output growth rates, the difference between China and India is staggering.

We do not include a simulation of our neoclassical growth model for these two countries and compare it to the data. To understand China's and India's growth paths through the lenses of the neoclassical growth model, we need to consider the process of convergence to the advanced economies. This exercise would require the introduction of additional elements in the model. See, for example, Fernández-Villaverde et al. (2023b), where a neoclassical model similar to the one in this paper is calibrated to capture China's technological catch-up with the U.S.

6.4. South Korea

So far, we have not discussed South Korea, despite it being a paradigmatic case of demographic change with extremely low fertility rates. For our analysis period (1991–2019), demographic change in South Korea is not a first-order issue from the perspective of growth theory. The ratio of working-age adults to the population grew modestly at an annual rate of 0.14%, with most of the increase occurring early in the sample. From 2009 to 2019, the ratio remained essentially constant. This contrasts with China, where the working-age adult-to-population ratio grew significantly early in the sample but declined sharply at an annual rate of −0.45% between 2009 and 2019.

As a result, during 1991–2019, South Korea's GDP per capita growth (4.15% per year) closely matches GDP per working adult growth (4.0%). In the later years of the sample (2009–2019), growth rates declined, with per capita and per working-age adult values effectively equal at about 2.83–2.82%.

7. Concluding remarks

As Lucas (1988) famously remarked, "Once one starts to think about them [the questions involving economic growth], it is hard to think about anything else". To address these questions properly, however, we need the right measurements. Traditionally, economists have relied on total and per capita output growth rates to assess economic performance and test growth (and business cycle) theories. In this paper, we have argued that, with aging populations, these metrics have become increasingly misleading since the early 1990s.

Of course, output growth per working-age adult or per worker is not without its limitations. For instance, more older individuals are remaining in the labor force, a trend likely to accelerate in the coming decades. Yet, for our purposes, this trend has a limited impact. As we have demonstrated, any reasonable redefinition of working age yields similar results. While output growth per capita remains a meaningful measure of individual welfare, it is increasingly more confusing than clarifying in the context of economic performance. It is time to seek a better metric.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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