THREE

Stagnation vs. Singularity

The Global Implications of Alternative Productivity Growth Scenarios

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In 1978, the first Superman film was released. Starring as Superman, Christopher Reeve fought foes and vanquished villains in an action-packed battle between good and evil. Four decades later, Superman continues to feature in films. But he is often not alone. Superman now stars alongside Batman, Wonder Woman, the Flash, Aquaman, Cyborg, and many other superheroes. For the fans of DC Comics, it is a delightful coming together of childhood favorites. But for economists, it symbolizes a worrying decline in productivity. Where once a single superhero was able to save the world, now two or more are required to complete the same task (although the increase in superheroes needs to be adjusted by any change in crime rates).

As Oscar Wilde once said, life often imitates art. When the first Superman film was released, average annual total factor productivity (TFP) growth among advanced economies was almost ten times what it was in 2016 (figure 3-1; note that all figures are presented in the appendix at the end of this chapter). The emerging markets have fared a little better but have similarly struggled to replicate the productivity growth enjoyed in the recent past. Other measures show the same pattern. Cyclically adjusted TFP and labor-based measures show that productivity growth is not what it used to be.[1]

The world has a productivity problem. The problem is that there is not enough of it. Productivity growth is the fundamental driver of long-run living standards.[2] Weak productivity growth has been linked to poorer fiscal outcomes, weaker export competitiveness, lower wages, and higher income inequality, to name a few issues.[3]

But what is most striking about these data is the time period they cover. The period from 1990 to 2016 saw extraordinary advances in technology. An additional 3.5 billion people gained access to the internet. The processing power of computers increased exponentially. Their cost and size plummeted. Smartphones were invented. Online businesses flourished. Email, GPS, and advanced software became widespread. The sharing economy unlocked the full potential of our idle cars, unused bicycles, and empty rooms and houses. Information and communications technology (ICT) and artificial intelligence (AI) reshaped our industries. The accumulated history of human knowledge is now at our fingertips.

But where is the increase in productivity? Robert Solow famously remarked in the 1980s that "you can see the computer age everywhere but in the productivity statistics."[4] This anomaly, which has become known as the Solow paradox, continues to plague economists to this day.

Economists put forward a variety of explanations for this paradox. Some, like 2018 Nobel laureate William Nordhaus, point to historical data showing long lag times between technological advances and increases in productivity.[5] For these economists, a large surge in productivity is just around the corner (ten years away, wrote Iraj Saniee and his coauthors in 2017).

Other economists, such as Harvard's Martin Feldstein, argue that the paradox is driven by measurement failures. They argue that productivity has increased but our flawed statistical methods fail to detect it. They show how productivity statistics can struggle to measure changes in the quality of goods and services and the value created by new goods and services, particularly those in the digital space.[6] For these economists, the productivity slowdown is either partly or entirely an illusion.

Others argue that although technological advances have increased productivity, these benefits have been crowded out by other factors, including the aftershocks of the global financial crisis and "TFP hysteresis,"[7] weak demand and investment,[8] slowing trade and stalling growth in global value chains,[9] aging populations and demographic factors,[10] reduced investment in education,[11] the effects of automation on demand and inequality,[12] and weakening competition and business dynamism.[13]

Harvard's Marc Melitz suggests that the explanation for the paradox lies at the firm level. Some firms have been highly productive and contributed to strong, positive statistics, but their effects have been dragged down by laggard firms.[14] The Organisation for Economic Co-operation and Development (OECD) found that "frontier firms" have consistently achieved high rates of productivity since 2000, more than six times that of laggard firms, which have dragged down the average.[15] Some economists attribute this to the increased prevalence of "zombie firms"—unproductive firms kept alive by cheap money, low interest rates, and risk-averse investors.[16] There is similar evidence at the industry level. John Fernald of the Federal Reserve Bank of San Francisco shows that ICT productivity gains have been concentrated in specific industries, while other industries have failed to adopt these technologies.[17]

Some economists, notably Northwestern University's Robert Gordon, see no paradox at all. Gordon argues that the technological advances in recent decades are simply no match for the inventions of the previous century. Given the life-altering scale of the innovations between 1870 and 1970—such as electricity and the automobile—we should not be surprised that the relatively meager inventions since then have failed to register in the statistics.[18]

Others go further. Some point to evidence that recent technological advances are not just benign but may be reducing our productivity by distracting employees and reducing our attention span.[19] Others are less pessimistic about the impact of new technologies but still warn that the extent to which firms adopt ICT might be subject to diminishing returns over time.[20]

In short, there are many explanations for why recent advances in technology have not translated into increases in productivity. The upshot is that the future path of productivity is highly uncertain.

This uncertainty poses several challenges. The future path of productivity will have profound implications, not just for individual economies but for the global economy. It is possible, even likely, that individual economies and individual sectors could follow different productivity paths, with significant implications for trade flows, capital flows, the adjustments of real exchange rates, and global imbalances. For policymakers, this uncertainty raises challenging questions about the appropriate course of monetary, fiscal, and structural policies and whether there is a case for cooperation between countries.

These are the issues explored in this chapter. The chapter applies a global economic model to explore the implications of four alternative future productivity scenarios for the global economy, trade flows, capital flows, the adjustments of macroeconomic variables, the effects on individual economies, and what these alternative scenarios mean for policymakers. Each scenario is detailed in the next section, followed by a summary of the general equilibrium framework: the G-Cubed (G20) model of the global economy. The final two sections model the outcomes of each scenario and consider the policy implications that flow from this analysis, as well as possible extensions to the analysis.

Four Possible Paths of Productivity

The literature reviewed in the preceding suggests at least four possible paths for future productivity growth.

The first path is one where the weak productivity growth experienced by the advanced economies in recent years persists into the future. Under this scenario, there is a gradual catch-up in productivity growth by the emerging economies, but they are catching up to a more slowly growing frontier. This is the path predicted by Robert Gordon—who argues that today's technological advances are no match for those of the past[21]—and by those economists who argue that any recent improvements in productivity have been (and will continue to be) crowded out by other long-term structural factors, such as aging populations.

The second path is one where there is a global takeoff toward singularity, with all countries adopting the new technologies simultaneously. This is the path predicted by William Nordhaus and others, who believe the paradox is explained by a time lag between technological advances and increases in productivity.[22]

The third and fourth scenarios consider productivity paths that exhibit more asymmetry.

The third scenario explores the implications of a takeoff in productivity toward singularity that occurs only in economies that have invested in research and development of artificial intelligence. As in the first scenario, the other advanced and emerging economies are playing catch-up, but to the original productivity frontier. This scenario is consistent with analysis that shows sharp differences in the levels of investment between countries in research and development, particularly in artificial intelligence,[23] and studies that show that the rate of technological diffusion can vary widely between countries.[24]

The fourth scenario explores a takeoff in productivity across all countries but only in specific sectors. Under this scenario, the sectors that have invested the most heavily in research and development experience the largest increase, with other sectors playing catch-up. This is consistent with the predictions of John Fernald, who observes sharp differences in the productivity paths between industries, and Marc Melitz and the OECD, who observe significantly different productivity paths between firms.[25]

While there has been much research exploring why recent advances in technology have not translated into increases in productivity, there has been less research on the focus of this chapter: what these alternative paths might mean for the global economy. There are, however, some exceptions.

PwC used a spatial computable general equilibrium model to estimate the impact of AI on the global economy up until 2030. They found that 55 percent of the GDP benefits would be due to productivity increases and that North America and China stand to see the biggest economic gains, primarily due to their larger investment in AI technologies.[26] They found that the services industry benefited more than others.

Avi Goldfarb and Dan Trefler explored some of the factors that shape how AI influences the composition of global trade flows.[27] These include economies of scale and scope in the development of the technologies (for example, knowledge clusters), the extent of competition between firms, the extent and geography of knowledge diffusion and externalities, the role of behind-the-border domestic regulations (for example, regulations around privacy, cross-border data flows, competition, and consumer protection), and the impact of international agreements constraining AI, such as the North American Free Trade Agreement (NAFTA) and the Transpacific Partnership-11 (TPP-11).

Similarly, Laura Márquez-Ramos and Immaculada Martínez-Zarzoso use a gravity model to estimate the relationship between technological innovation and international trade.[28] They find a U-shaped relationship between exports and the creation of technology and between exports and diffusion of old innovations, whereas an inverted U-shaped relationship is found between exports and diffusion of recent innovations and between exports and human skills.

It should also be noted that many studies look in the opposite direction—exploring the role of trade and capital flows in boosting productivity, rather than the role of productivity in shifting flows of trade and capital.[29] The potential for a sharp increase in productivity from singularity makes this a pertinent time to explore this question.

The G-Cubed Model

The G-Cubed (G20) model is a multicountry, multisector, intertemporal general equilibrium model. It is designed to bridge the gaps between three areas of research—econometric general equilibrium modeling, international trade theory, and modern macroeconomics—by incorporating the best features of each.

Several versions of the model have been developed, which have been incrementally improved and built on over many years. The version presented in this chapter is the newest, and largest, version of the G-Cubed model, designed specifically to study the G20 nations (nineteen countries plus the EU) and the implications of its policy agenda. Previous versions of G-Cubed have been used to study a range of policy areas, including macroeconomic cooperation, international trade, monetary policy, fiscal policy, tax reform, and environmental regulation. Studies have shown the effectiveness of G-Cubed in explaining the adjustment process in many historical episodes, including Reaganomics, German reunification, European fiscal consolidation in the 1990s, the formation of NAFTA, and the Asian financial crisis. G-Cubed has also proven successful in helping to explain the "six major puzzles in international macroeconomics" highlighted by Maurice

Table 3-1. *Overview of the G-Cubed (G20) Model*

Countries (20)	**Regions (4)**
Argentina	Rest of the OECD
Australia	Rest of Asia
Brazil	Other oil-producing countries
Canada	Rest of the world
China	
Rest of eurozone	**Sectors (6)**
France	Energy
Germany	Mining
Indonesia	Agriculture (including fishing and hunting)
India	Durable manufacturing
Italy	Nondurable manufacturing
Japan	Services
Korea	
Mexico	**Economic Agents in Each Country (3)**
Russia	A representative household
Saudi Arabia	A representative firm (in each of the six production sectors)
South Africa	Government
Turkey	
United Kingdom	
United States	

Obstfeld and Kenneth Rogoff in a 2000 paper. It has also proven useful in understanding the 2009 global financial crisis.[30]

The G-Cubed (G20) model represents the world as twenty-four autonomous blocks: one for each G20 economy (including the rest of the eurozone) and four regions that represent the world's non-G20 economies. These regions are: the other economies of the OECD, the other economies of Asia, the other oil-producing economies, and a catch-all "rest of the world" (table 3-1). Each region in G-Cubed is represented by its own multisector econometric general equilibrium model with highly disaggregated, multisectoral flows of goods and assets between them.

Each region has six industries, which correspond to the production of six goods: energy, mining, agriculture (including fishing and hunting), durable manufacturing, nondurable manufacturing, and services. Each good in a region is an imperfect substitute for goods from other regions. Thus there are effectively 144 goods.

Each country consists of six representative firms, a representative household, and a government. The model also includes markets for goods and services, factors of production, money, and financial assets (bonds, equities, and foreign exchange). Finally, each country is linked through the flows of goods and assets. Some of the key features of the G-Cubed (G20) model are:

- specification of the demand and supply sides of economies
- integration of real and financial markets of these economies with explicit arbitrage linking real and financial rates of return
- intertemporal accounting of stocks and flows of real resources and financial assets
- imposition of intertemporal budget constraints so that agents and countries cannot borrow or lend forever without undertaking the required resource transfers necessary to service outstanding liabilities
- short-run behavior as a weighted average of neoclassical optimizing behavior based on expected future income streams and Keynesian current income
- a disaggregated real side of the model to allow for production of multiple goods and services within economies
- international trade in goods, services, and financial assets
- full short-run and long-run macroeconomic closure with macrodynamics at an annual frequency around a long-run Solow-Swan-Ramsey neoclassical growth model
- full rational-expectations equilibrium (consisting of a mix of rational and rule-of-thumb agents) annually from 2015 to 2100.

The rules for monetary and fiscal policies in the model are important for the results. Central banks in each economy follow a Henderson-McKibbin-Taylor rule with weights on output growth relative to trend, inflation relative to target, and in some cases weights on nominal exchange rates relative to target. Some countries such as Saudi Arabia peg exactly to the U.S. dollar so the weights on inflation and output growth are zero and the weight on the exchange rate is very large. Other countries such as China follow a crawling peg with some weight on inflation and the output gap but additional weight on change in the yuan/$US exchange rate. Within the eurozone, a single central bank sets monetary policy with weights on eurozone-wide output growth relative to target and eurozone-wide inflation. The nominal policy interest rate is equal across Germany, France, Italy, and the rest of the eurozone. Further details can be found in the model documentation in the accompanying working paper.[31] The fiscal rules followed by each country are standardized across countries. Government spending is set at a constant share of baseline GDP with tax rates on households and firms and tariff rates of trade constant at the rates in 2015. There is a lump-sum tax on households that changes in response to changes in the interest payments on government debt.[32] Budget deficits are endogenous given these assumptions, but fiscal sustainability is assured by the fiscal rule that sets lump-sum taxes as equal to the change in servicing costs on government debt. After a shock, in the long run the stock of debt to GDP will stabilize at the long-run primary fiscal deficit divided by the real growth rate of the economy. This implies that a fall in productivity will lead to a permanently higher stock of government debt to GDP, and a rise in productivity will lead to a permanently lower stock of debt to GDP. Alternative fiscal closures can significantly change the results described in this chapter. Future research will explore the interaction of the fiscal closure assumption and changes in productivity growth.

The following simulations elaborate further on some of these key features of the model.[33]

The Global Implications of Four Alternative Productivity Growth Scenarios

We first solve the model from 2016 to 2100 to create a baseline scenario. Our approach to generating a baseline projection is outlined in detail by Warwick McKibbin, David Pearce, and Alison Stegman.[34] This is a complicated procedure in a model such as G-Cubed where some economic agents have rational expectations. Stegman and McKibbin provide a comparison of the long-term projections with other global economic models in an earlier exercise.[35]

The key inputs into the baseline are the initial dynamics leading into 2016 (that is, the evolution of the economy from 2015 to 2016) and subsequent projections from 2016 onward for labor force growth and productivity growth (defined as labor augmenting technical change) by sector and by country. We take labor force growth from the United Nations population projections.[36] The productivity projections are generated following the approach of Robert Barro.[37] Over long periods of time, Barro estimates that the average catch-up rate of individual countries to the worldwide productivity frontier is 2 percent per year. We assume each sector in the United States has labor productivity growth of 1.4 percent per year. We use the Groningen Growth and Development ten-sector database, as outlined by Marcel Timmer and his coauthors to estimate the initial level of productivity in each sector of each region in the model in 2010.[38] Given this initial productivity, we then take the ratio of this productivity to the equivalent sector in the United States, which we assume is the frontier. Given this initial gap in sectoral productivity, we then use the Barro catch-up model to generate long-term projections of the productivity growth rate of each sector within each country. In the case where we expect that economic reforms will allow regions to catch up more quickly to the frontier (for example, in China) or that institutional rigidities will slow them down (for example, in Russia), we vary the catch-up rate over time.

The exogenous sectoral labor productivity growth rate, together with the economy-wide growth in labor supply, is the exogenous driver of sector growth for each country. The growth in the capital stock in each sector in each region is determined endogenously within the model.

Given assumptions about monetary policy rules, fiscal rules, and other institutional rigidities in the model (including labor markets), we solve for a path for the world economy from 2016 to 2100. We then explore each of the scenarios on productivity by rolling the model forward to 2019 and beginning the shocks as surprise events all commencing in 2019.

In the results that follow, all variables are plotted relative to the baseline projection. Some variables, such as GDP, investment, consumption, and real effective exchange rates, are presented as a percentage change relative to the baseline. The trade balance is a percentage of baseline GDP change. Inflation and interest rates are percentage differences from the baseline. Any variable that is zero in the scenario means that the variable is unchanged relative to baseline values. A negative outcome is a variable below the baseline.

Persistently Weak Productivity Growth in the Advanced Economies, with Gradual Catch-up by the Emerging Markets

The first scenario is one in which the weak productivity growth experienced by the advanced economies in recent years persists into the future. While there is a gradual catch-up of productivity growth by the emerging economies (and advanced economies that are not at the frontier), the emerging economies are catching up to a more slowly growing frontier. This is the path predicted by Gordon and by those economists who argue that any recent improvements in productivity have (and will continue to be) crowded out by other long-term structural factors, such as aging populations.[39]

The underlying productivity growth in the frontier economy of the United States is assumed to be 1.4 percent per year in the baseline. Other countries will experience faster productivity growth in each sector depending on how far from the frontier each sector is located relative to the U.S. sector. The shock is illustrated in figure 3-2. This plots the level of labor productivity relative to the baseline in each year. The slope of the curve is the change in the growth rate.

In this section we assume that, commencing in 2019, it is discovered that there is weaker labor augmenting technical change in each sector in each advanced economy than was expected and that this downward revision will continue for the remainder of the century. The assumption that is implemented is a uniform reduction in productivity growth in each sector of 0.5 percent per year from 2019 to 2043. The decline in the growth rate eventually returns to zero, commencing in 2044 with the rate calculated as −0.5 plus 0.98 multiplied by the productivity decline in the previous year. This can be considered a permanent decline in productivity over the period we are considering, even though, for technical reasons, the steady state rate of productivity growth eventually returns to 1.4 percent in all economies.

The results for the surprise fall in productivity are contained in figure 3-3 through figure 3-13 for a selection of advanced economies (the United States, Japan, Germany, and Australia) and a selection of emerging economies (South Korea, China, and India). In figure 3-12 and figure 3-13 we show sectoral results for the United States and for South Korea to give some insight into the changes in sectoral outcomes that lie behind the macroeconomic adjustments. Recall again that all results are expressed as relative to baseline values.

Figure 3-3 shows the results for the economy-wide GDP growth rate for a range of countries. As expected, the uniform fall in sectoral labor productivity growth of 0.5 percent per year eventually leads to a sustained fall in GDP growth of 0.5 percent for each of the advanced economies. The short-term results also reflect the fact that the accumulation of capital in the model is endogenous. The surprise realization that productivity growth will be lower for longer causes forward-looking firms to reassess their investment decisions. Owing to the adjustment costs in capital accumulation, firms do not immediately reduce their capital stocks. They run them down smoothly over time, but the adjustment is front-loaded. Investment falls sharply in the advanced economies (figure 3-4), which causes GDP growth to fall more than the decline in trend growth for four years.

The sectoral disaggregation of the model shows some important macroeconomic differences across countries. The investment good that firms buy to build the capital stock largely comes from the durable goods sector, mining, and energy. When investment falls, the demand for durable goods falls by more than the demand for goods from other sectors. Economies that produce a large share of global investment goods (Germany, Japan, Korea) or rely on durable goods exports for income generation will be most affected by the fall in demand for investment in advanced economies. This will be offset to some extent by increased demand from emerging economies, but it depends on the country investing and the trade shares with the country exporting durable goods. The differential response to investment shown in figure 3-4 shows this clearly for Germany and Japan, who experience a much larger investment decline than either the United States or Australia.

Note that GDP growth rises in the emerging countries. There are two offsetting effects of the productivity slowdown in advanced economies: international trade and financial capital flows.

A decline in growth in the advanced economies means reduced demand for the exports from the emerging economies. However, the weaker growth prospects in the advanced economies also implies a higher relative return to investment in emerging economies. As a result, financial capital flows out of the advanced economies into emerging economies. This drives down the real interest rate globally and increases investment in the emerging countries. The role of advanced economy financial conditions in driving capital into the emerging markets has been well documented in the literature on the push and pull factors associated with capital flows.[40] Thus, while the trade effects are a negative demand shock for the emerging economies, the capital flow effect is a positive stimulus to their GDP.

In some countries the weakening on the U.S. dollar as capital flows out of the United States causes economies pegging to the U.S. dollar or leaning against currency appreciation to loosen monetary policies to soften their own currency appreciation. This is clear in figure 3-3 as China has a large monetary stimulus that temporarily raises GDP growth as it loosens monetary policy in response to an appreciating renminbi.

The results for consumption are shown in figure 3-5. Consumption rises in all emerging economies as capital flows in, real interest rates fall, and incomes rise. In advanced economies, the consumption profile is more complex. In the longer term, consumption falls along with the decline in real GDP. But for the first decade, consumption is above baseline. This shift reflects several interesting dynamics.

The first is that the lower rate of labor productivity growth acts to reduce the marginal product of capital. Real interest rates fall in parallel to the decline in the marginal product of capital (see figure 3-6). Lower real interest rates increase the human capital of households as they discount the lower future streams of income at a lower interest rate. This implies, initially at least, that human capital rises.

The second and more important channel is the realization by firms that they no longer need to invest as much as previously expected. Over time, firms return the funds that would have been used for real investment to shareholders as net transfers (that is, higher dividends and share buybacks). Thus, initially consumers' cash flow rises and backward-looking households (70 percent of all households) consume this windfall and sustain consumption for a decade, even though wealth is ultimately declining.

Figure 3-7 shows the trade adjustment that occurs globally. This reflects the reallocation of global capital as well as changes in the relative prices of traded goods. As capital flows out of the advanced economies, the real effective exchange rate depreciates. The emerging economies receiving the capital inflow experience an appreciation of their real effective exchange rates (figure 3-8). Thus, the trade balances of the United States, Germany, Japan, and Australia improve while the trade balances of the emerging economies deteriorate. The extent to which the trade balance changes also depends on the composition of exports and imports for each country. Countries such as Japan and Germany, although exporters of capital goods whose demand has fallen by more than other types of goods, experience larger investment declines and therefore a larger capital outflow than other countries. Thus their trade balances improve by more and their real exchange rate depreciates by more than those of other advanced economies.

Figure 3-8 shows that exchange rates in the long term move in the opposite direction in the short term. This reflects the consumption side of the model. Consumers in all countries consume goods from all countries. But these goods are imperfect substitutes. Thus, if goods from the United States are less available over time, their relative price will eventually rise. It also reflects the imposition of the intertemporal budget constraint on all countries that the present value of all future trade surpluses must equal the initial value of foreign debt. To the extent that relative incomes do not achieve this outcome, the real exchange rate will adjust to ensure solvency.

Figure 3-9 shows the results for inflation. It is clear from the figure that the shift in productivity growth has led to an inflation bias in the advanced economies. This is because it is assumed that the central banks do not adjust their estimates of productivity growth when the shock occurs. Thus they are continually trying to return the economy to the long-term growth path that existed before the decline in productivity. Since monetary policy cannot achieve this, inflation is permanently higher. These circumstances are assumed intentionally in this scenario to illustrate the importance of the monetary rule (discussed later in the chapter). In the remainder of the scenarios in this chapter we assume that the central banks know about the productivity shocks and revise their estimates of potential growth.

The outcomes for employment and real wages are shown in figure 3-10 and figure 3-11. The assumption in the model is that wages are sticky in all economies. This is because wages are based on wage contracts driven by past inflation, expected inflation, and the aggregate labor market condition. Firms in each sector hire workers to the point where the marginal product of the worker in that sector equals the nominal wage less the output price of that sector. Over time, the aggregate unemployment (or overemployment) will drive the economy-wide nominal wage to return to full employment.

In advanced economies, the persistent decline in productivity implies that the real wage stays above market clearing levels for many decades, leading to persistent unemployment. Eventually full employment will occur, but it is well past the period being considered. There is a persistent decline in real wages in advanced economies as a result of the decline in labor productivity.

The adjustment in emerging economies is very different. Financial capital flowing into these economies leads to higher investment and a larger physical capital stock. This increases the marginal product of workers and leads to higher real wages and more employment. Employment eventually returns to the baseline by assumption, but the rise in real wages persists.

Finally, it is useful to dig down into the sectoral adjustment that underlies the macroeconomic adjustment. It differs across economies; owing to space limitations, we consider only two economies in detail. The sectoral output results for the United States are shown in figure 3-12. While the decline in productivity is uniform across sectors, the endogenous adjustment of output differs across sectors. There are several reasons for this. The clearest, as noted earlier, is the large decline in the demand for durable goods that would normally go into investment. This is followed by the demand for energy and mining goods.

Figure 3-13 shows the sectoral results for Korea. Korea does not experience a decline in productivity, although the spillovers to Korea differ by sector. In particular, notice the decline in output of durable goods immediately and the gradual decline in the demand for energy goods due to the shocks in the advanced economies.

Overall, this simulation shows that a lower-productivity growth future for the advanced economies means weaker growth, investment, wages, and employment, particularly for those economies that export investment goods. But the financial side of the model is critical in showing how a reduction in the productivity differential between the emerging economies and the advanced economies is a boom for the emerging markets through capital flows and lower global interest rates. While the advanced economies suffer, the emerging economies benefit. This is a timely reminder of the incentives to undertake productivity-enhancing reforms and to boost investment in infrastructure. An economy that undertakes productivity-enhancing reforms will reap the domestic economic dividends from those reforms and, if their trading and investment partners are not undertaking reforms, they will also reap a global benefit, too, through shifts in capital. This highlights the prisoner's-dilemma incentive for countries to out-reform one another.

There are also some important lessons in these simulation results on trade. Productivity differentials between the advanced and the emerging economies play an important role in global trade and current account imbalances. A fall in productivity in advanced economies helps correct these imbalances. Conversely, a rise in productivity in the emerging economies would also help to correct these imbalances. It follows that, if advanced economies are primarily concerned about global trade imbalances, these results suggest that they would be wise to share their technologies with the emerging markets to help them raise productivity.

Productivity Takeoff in All Countries

In this section we consider the opposite scenario to that above: one in which productivity growth takes off rapidly. This is the path predicted by Nordhaus and others, who believe the productivity paradox is explained by a time lag between technological advances and increases in productivity.[41]

Although we refer to the simulation as "the takeoff toward singularity," we cannot technically model true singularity in the model because this implies productivity rising to infinity. Instead, we implement a form of the experience in which the widespread penetration of a range of digital networks (energy, health and sanitation, transportation, communication and production) leads to a surge in economy-wide productivity growth.[42] We assume that the widespread penetration of the digital technologies that have been emerging since 2000 leads to a sharp increase in productivity growth, beginning in 2019. Figure 3-14 shows the shock that we implement in the model, based on the findings of Saniee and coauthors.

As with historical productivity growth experience, the growth rate surge is ultimately temporary. But it leaves the economy at a much higher level of productivity. True singularity, such as that modeled by Nordhaus,[43] would have ever-rising productivity growth. However, for the purpose of the modeling exercise in this chapter, the surge in productivity from 2019 to mid-century would be similar to singularity over the initial decades on which we focus.

The results for this scenario are shown in figures 3-15 to 3-25.

There are three main differences between the productivity surge in this section and the decline in productivity in the previous section. The first is the sign of the change: positive versus negative. The second is the coverage of the shock. In this section the shock is assumed to be global, whereas in the previous section the decline in productivity only occurred in a group of advanced economies. The third is the nature of the future expected adjustment. In this section a large part of the productivity boom is expected to be in the future—the period between 2040 and 2060.

Figure 3-15 shows the change in the real GDP growth rate of a selection of economies. We have included Italy in place of Indonesia in the figures in this section and the following sections because it illustrates the importance of the eurozone common currency. The longer-run growth in figure 3-15 clearly reflects the surge in productivity. But when the shock is global rather than asymmetric, endogenous capital accumulation needs to ramp up as labor productivity rises. Since all countries are having the same adjustment, any resources that will be used to build the capital stock will have to come from increased output due to the shock, from current consumption or from changes in government savings, because the global economy is a closed system. In the previous scenario, where the coverage of the shock was not global, it was possible for savings to flow from countries outside the group of countries experiencing the shock to the booming economies.

In the first year, growth declines in most economies as consumers experience a fall in human wealth since interest rates rise before future income rises. The resulting reduction in consumption enables the investment buildup to begin immediately. The anticipation of higher future growth causes investment to rise in the short term. Countries that supply investment goods such as durable manufacturing, energy, and mining experience a much more rapid investment boom. The expected boom leads to a global reallocation of capital. Countries attracting capital such as Australia, the United States, and Germany experience some deterioration in the trade balance.

Real interest rates rise (see figure 3-19) over time, reflecting the increase in the marginal product of capital driven by higher labor productivity. By 2040, global real interest rates are between 4 percent and 7 percent higher. Higher interest rates dampen the investment response and increase savings in order to maintain the saving–investment balance. Interest rates eventually return close to baseline, driven back to the rate of time preference. This occurs well outside the period of focus, once the capital stock reaches a higher level through reduced consumption, which allows the substantial expansion. The higher productivity growth rate lasts until the end of the century.

Employment and real wages are driven higher (figures 3-22 and 3-23). The rise in labor productivity increases the marginal product of labor, which drives wages higher. Substantial sectoral changes cause job turnover. But the aggregate employment effects of labor augmenting technical change are significant. Over time, employment will return to baseline as real wages eventually eliminate the excess demand for labor in the booming global economy.

The sectoral output results for the United States are shown in figure 3-24 and for Korea in figure 3-25. The broad pattern is similar across countries. The expected future productivity surge leads to an investment response in all countries. The demand for goods that feed into creating capital goods rises sharply. The sectors that benefit most are durable goods, energy, and mining. No sectoral outputs fall since the inputs that are needed to expand global economic output are labor productivity, longer working hours for workers, and a rising capital stock.

In sum, this section shows that a global surge in labor productivity comes with substantial benefits in the form of growth, employment, and investment. But there are factors that can prevent economies from reaping the full benefits of the productivity boom. The first is that interest rates increase significantly because all countries call on the same pool of global savings. As a result, consumption is reduced as savings increase to finance the investment. If consumption is used as a measure of welfare, then the welfare benefits of this boom are reduced. For policy, this highlights the critical importance of having flexible financial markets, being open to global capital flows, and having a deep financial system, all of which improve an economy's access to much needed savings during the boom period.

The second factor that can prevent economies from reaping the full benefits of the productivity boom relates to labor markets. The results for this scenario show that the productivity boom increases both wages and employment. But the extent to which this occurs depends on the stickiness of wages (where the model assumes some nominal wage rigidity), the extent to which labor is mobile (the model assumes perfect labor mobility within, but not across, countries and regions), and the extent to which these technological advances are labor saving. If labor market rigidities are strengthened, the extent to which the benefits of the productivity boom are shared with labor is therefore reduced, highlighting the critical importance of flexible labor markets.

The third factor that can prevent economies from reaping the full benefits of the productivity boom relates to product markets. The productivity boom shifts relative prices between sectors and results in substantial reallocation of resources within and across economies. If there is inadequate competition between firms, or if there are government regulations that protect particular industries from competition, then this reallocation of resources will not occur as easily and the full potential of the boom may not be realized.

The critical policy insight in this simulation, therefore, is around the importance of economic flexibility. There is a lot of fear in the literature that technological advances will cause more pain than good. The two main dimensions that are important are (1) the issue of substitution of factors of production and (2) the greater wealth generated by greater labor productivity. This simulation shows that the negative outcomes that many people fear need not be realized, provided policymakers invest in flexible capital, labor, and product markets and remain open to capital and trade flows.

Takeoff toward Singularity in Some Technologically Advanced Economies While Other Economies Are Slow to Adapt

Given some of the challenges posed by a productivity surge that is global in nature, in this section we consider a more asymmetric scenario. We assume that the productivity surge implemented in the previous section is restricted to a small group of countries. This scenario is consistent with analysis that shows sharp differences in the levels of investment between countries in research and development, particularly in artificial intelligence,[44] and studies that show that the rate of technological diffusion can vary widely between countries.[45] Of key interest is not only what happens to the countries that have invested heavily but also what happens to the countries that have not.

The countries that experience the productivity surge are assumed to be the United States, Japan, Germany, France, the United Kingdom, China, and Korea. The results are shown from figures 3-26 to 3-36.

The real GDP growth rate of the booming economies (figure 3-26) follows a similar path as in the case of a global boom. Other economies experience declining GDP growth and capital moves from these economies to more innovative economies. A third group of countries, including Australia, produce goods such as mining and energy that are in rising demand in the booming economies, and they receive higher income as an indirect benefit of the boom.

Figure 3-27 shows the surge of investment in the booming economies. Japan and Germany in particular benefit from their expertise in producing capital goods that are in demand for investment purposes. Italy experiences a particularly large fall in investment. While Germany and France are booming, the strength of the euro causes a large contraction in Italy. Eurozone monetary policy targets Europe-wide growth as well as average inflation. Thus, Italy experiences a tightening of monetary policy and a strengthening of the euro. This is much like the experience under the

European Monetary System (EMS) that occurred during German reunification in the early 1990s. The internal contradictions of a fixed exchange rate within a monetary union with an asymmetric shock drove Italy out of the EMS at that time. The pressures in this scenario are also clear.

The asymmetric boom has an impact on the levels of global investment as well as the distribution of global investment. The extent of capital outflow from economies not directly experiencing the productivity boom is shown in the movement of trade balances in figure 3-29. Countries not experiencing the productivity boom, such as India and Australia, experience an outflow of capital. Global real interest rates rise by less than the global boom, but all countries, both booming and nonbooming economies, experience higher interest rates because strong global investment needs to be funded by higher global savings.

The employment outcomes differ across economies. While booming economies experience rising employment, the other economies experience only a small fall in employment, except Italy, which has a deep recession as the constraints of the euro fall on the Italian economy.

Real wages rise in the booming economies but fall in the other economies, reflecting the global reallocation of global capital, which reduces the return to labor in economies that lose capital. The nonbooming economies have different experiences based on their economic structure and the composition of exports. Real wages fall by less in Australia than in other economies because of the global demand for energy and mining goods. The results for sectoral output for Australia are shown in figure 3-36.

Overall, economies that have invested less in research and development are typically warned that they will be left behind by those that have invested more. The results in this section suggest a more complex story. Countries whose exports feed into the increase in investment and demand in the booming economies tend to benefit, even though their own productivity has not increased. The results depend on the characteristics of individual economies. Some, like Australia, benefit significantly while others are left with lower real wages as capital leaves their economies.

This section also highlights the importance of exchange rate and monetary policy frameworks. It provides a particular warning for the eurozone. A productivity surge in Germany creates significant strain on other countries in the eurozone that are not experiencing the shock. This underscores the importance of building more flexibility into the eurozone's macroeconomic frameworks and promoting increased labor mobility within the region.

Asymmetry in Sectors: Where the Service Sector Takes Off toward Singularity

The final scenario is a global productivity surge that is confined to the service sector—a sector that stands out globally as having invested significantly in technologies such as ICT and AI. This scenario illustrates the impact of differential sectoral productivity growth. It shows what productivity advances in one sector might mean for the lagging sectors of an economy. This scenario is consistent with the predictions of John Fernald, who observes sharp differences in the productivity paths between industries, and Marc Melitz and the OECD, who observe significantly different productivity paths between firms.[46]

This is a pertinent issue to explore. Warnings often appear in the popular media that industries that are failing to invest in emerging technologies will fall behind the soon-to-be frontier industries. The results in this section do not contradict these warnings. But they do show that such warnings are incomplete. Although sectors experiencing a productivity surge benefit more than their peers, other sectors that feed inputs into the surging sectors (and the countries in which those sectors are dominant) also experience important benefits.

The results are shown in figures 3-37 to 3-45.

Although the results for individual economies differ, the overall impact of higher productivity in the service sector is a reallocation of resources between sectors, both domestically and globally. Because of higher productivity growth, service sectors now have a higher return to capital than previously. This leads to an increase in investment and an increase in production in the service sector (figure 3-38).

The increased production in the service sector also benefits other sectors through increased demand and shifts in relative prices. The effect is strongest for those sectors that feed inputs directly into the production processes of the service sector. This is particularly the case for durable manufacturing, which sees an increase in investment and production (figure 3-45). Higher productivity growth also means that the service sector requires less labor, freeing up resources that move into other sectors. The sectors that are less integrated into the service sector also benefit from the higher productivity in services but to a smaller extent than is the case for durable manufacturing. The mining and resource sectors, for example, feed into the production of durable goods, which in turn feed into the surging service sector.

The aggregate effect on the service sector is substantial. Investment increases significantly. Given that the productivity surge is global, countries not only experience the benefits from their own increased domestic production but also enjoy the positive spillovers from increased production in other economies through greater demand for their exports. These benefits, however, are partly offset by shifts in interest rates. With the service sector in all countries experiencing the productivity surge at the same time, there is a substantial call on the global pool of savings, pushing up global interest rates; higher interest rates then constrain investment.

These country-by-country results are largely driven by the relative importance of services in these economies, rather than by any other consideration related to the type of firm heterogeneity you get within sectors and countries. The economies that tend to have the largest service sectors, such as Japan, experience the largest long-run increases in GDP, employment, and investment. Capital inflows to those economies, however, mean that they also experience the largest partially offsetting appreciation in their real effective exchange rates and the largest declines in their trade balance.

Overall, the findings of this scenario at the sectoral level are similar to the findings of the previous scenario at the country level. Even when advances in productivity are asymmetric, either by sector or by country, sectoral and cross-country linkages mean that such advances are not a zero-sum game. Spillovers across countries and sectors mean the benefits of productivity are shared more widely.

Policy Implications and Conclusions

Productivity growth has flatlined in most economies despite rapid advances in technology. Economists suggest competing explanations for this paradox. Some argue that the current stagnation will persist because recent technological advances are no match for those of the past or that deep structural challenges will offset any productivity increases. Others argue that the historical time lag between technological advances and increased productivity means that a productivity surge is just around the corner. This chapter explores the implications of alternative productivity growth scenarios for the global economy, particularly for growth, labor markets, and the flows of trade and capital, as well as the implications for policymakers.

If economists such as Robert Gordon are correct,[47] productivity growth in the advanced economies will remain lackluster for the foreseeable future. The consequences, should this scenario play out, are significant. A slowdown in productivity growth in advanced economies causes real interest rates to fall globally. For advanced economies, it results in a sharp drop in investment. Unemployment increases in the short term and is reduced only once real wages fall. While consumption initially increases in the short term, it is below the baseline in the longer term.

Even if Gordon is correct, there is still substantial productivity growth to be achieved in emerging economies that are behind the current technological frontier. It is common to interpret Gordon's argument as an explanation for why global productivity will be weak, but it is a U.S.- and European-centric view that only applies to the economies at the frontier of innovation. Investment rises in the economies not experiencing the decline in productivity. The global reallocation of capital away from slowing economies leads to trade deficits in economies that are receiving capital and to trade surpluses in economies that are losing capital. A reduction in the productivity differential between the emerging economies and the advanced economies is a boon for the emerging markets through capital flows and lower global interest rates. While the advanced economies suffer, the emerging economies benefit. This is a timely reminder of the incentives to undertake productivity-enhancing reforms. An economy that undertakes productivity-enhancing reforms will reap the domestic economic dividends from those reforms and, if their trading and investment partners are not undertaking reforms, they will also reap a global benefit through shifts in capital. This highlights the prisoner's-dilemma incentive for countries to outreform one another. The chapter also highlights important considerations for central banks. It shows that if central banks do not reevaluate their estimate of potential growth, their monetary rules can introduce an inflationary bias into the economy over time.

Not everyone predicts a bleak future for productivity. If researchers such as Nordhaus and Saniee and colleagues are correct, the future path of productivity could be much rosier.[48] In the case of the global productivity boom, the results are similar to those for the productivity decline, but with the opposite sign. A big difference in the simulation is the rapid acceleration in the productivity uplift, which front-loads the investment boom. In contrast to popular discussions of the impact of a new industrial revolution that suggest unemployment would rise, we find that the prosperity that is generated by higher labor productivity raises global production and incomes and is shared through intersectoral linkages in the economy as well as through international trade and investment channels.

But this chapter also shows that a large increase in productivity has its costs. The productivity boom leads to sectoral changes, which cause substantial transitions and disruptions in the short term. When all economies boom at the same time, the call on the global pool of savings and labor tends to highlight supply-side constraints. Interest rates rise sharply, acting to offset some of the benefits of the boom. And while employment is boosted, labor markets face significant disruption. The chapter therefore highlights some of the critical factors that can prevent economies from reaping the full benefits of the productivity boom. Having flexible financial markets, being open to global capital flows, and having a deep financial system all improve an economy's access to much needed savings during the boom period. If labor market rigidities are significant, the extent to which the benefits of the productivity boom are shared with labor is therefore reduced, highlighting the critical importance of flexible labor markets. If there is inadequate competition between firms, or if there are government regulations that protect particular industries from competition, then the necessary reallocation of resources within and across economies will not occur as easily and the full potential of the boom will not be realized. The critical policy insight, therefore, is around the importance of economic flexibility. There is a lot of fear in the literature that technological advances will cause more pain than good. This simulation shows that this need not be the case as long as policymakers invest in flexible capital, labor, and product markets and remain open to capital and trade flows.

A globally symmetric boom in productivity, however, is not guaranteed. Some analyses suggest that the levels of investment and the rate of technological diffusion differ greatly between countries.[49] Economies that have invested less in research and development are typically warned that they will be left behind by those that have invested more. The results presented here suggest a more complex story. Countries whose exports feed into the increase in investment and demand in the booming economies tend to benefit, even though their own productivity has not increased. The results depend on the characteristics of individual economies. Some, like Australia, benefit significantly while others bear the brunt of lower real wages as capital leaves their economies. The introduction of asymmetry between countries also finds that the assumption about monetary policy, and particularly on the nature of the exchange rate regime in different countries, matters greatly. For example, in the case where Germany and France experience a productivity boom but Italy does not, the constraints of the euro impose a deep recession on Italy. This underscores the importance of building more flexibility into the eurozone's macroeconomic frameworks and promoting greater labor mobility within the region. When China has a crawling peg against the U.S. dollar, a slowdown in U.S. productivity growth causes a depreciation of the U.S. dollar and induces a relaxation of monetary policy in China, which gives an additional short-term stimulus to the Chinese economy and adds to the flow of capital into the emerging economies seeking higher rates of return.

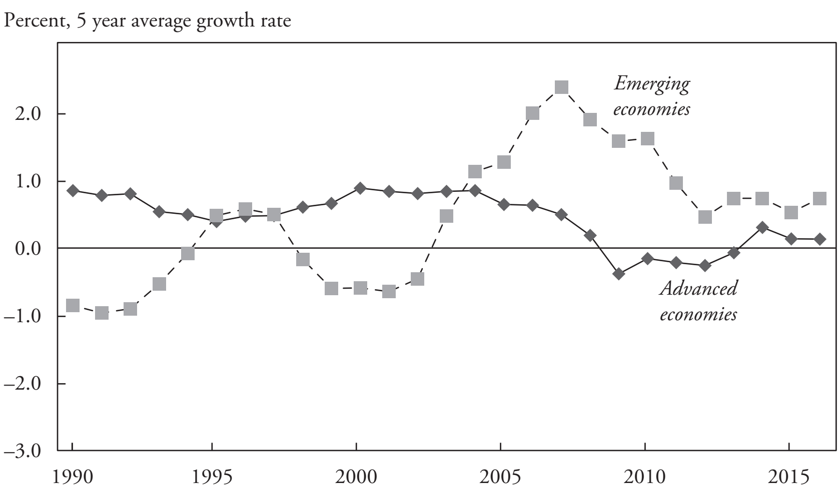
Whether a productivity takeoff occurs in a particular sector or is economy wide changes the magnitude and the relative economic outcomes; but all sectors eventually gain, whether the higher productivity is localized or broad-based. This outcome is the result of having endogenously determined capital investment. If there is a fixed amount of capital in an economy, the expansion of one sector must imply the contraction of another sector. If the stock of capital can rise either through domestic investment or through the inflow of foreign capital, then it is not necessary for one sector to shrink so another can grow. The intersectoral linkages have important macroeconomic implications. Although this is a positive for sectors within an economy, at the global level some countries can shrink when there is strong productivity growth in some countries and the nonproductive countries' trade is competing with the booming countries rather than being inputs into the production sectors in the booming economies.

The scenarios in this chapter are intended to illustrate some of the main issues that arise from a global general equilibrium perspective on the debate about productivity slowdowns and new industrial revolutions. They explore a small number of the many issues related to this debate. One issue is the importance of the fiscal rule in a world of changing productivity. An issue that has not been explored but could be a fruitful area of future research with the model used here is the role of public sector infrastructure investment either to support productivity surges or to dampen productivity slowdowns.[50] The chapter highlights the critical importance of structural reforms that build flexibility into economies, particularly reforms in labor, capital, and product markets. Such reforms will be key to avoiding the pitfalls of the Gordon scenario by boosting productivity. Similarly, in the Nordhaus scenario, increased flexibility will be key to reaping the greatest benefits from the productivity boom. As the Chinese proverb tells us, "The best time to plant a tree is twenty years ago. The second-best time is now." The same is true for structural reform.

Appendix: Figures

Introduction

FIGURE 3-1. **TFP Growth in Advanced and Emerging Economies**[a]

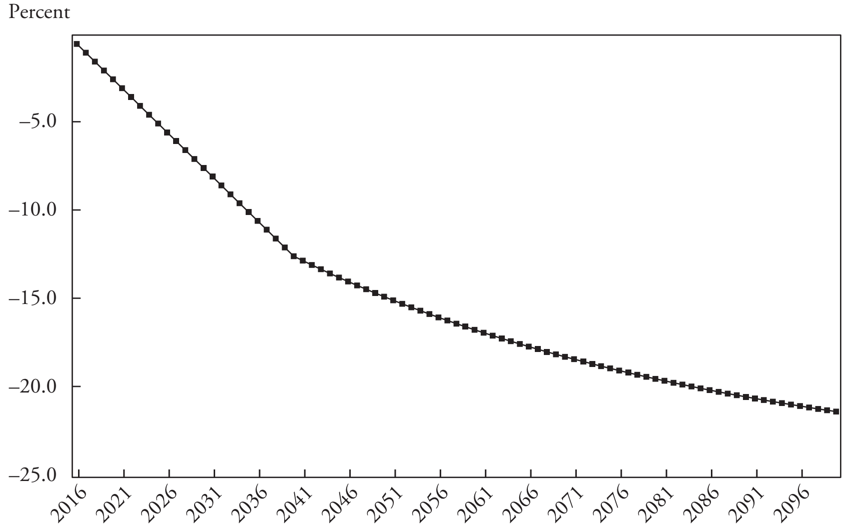


Source: Penn World Table 9.0.

a. Group averages are weighted using purchasing power parity GDP.

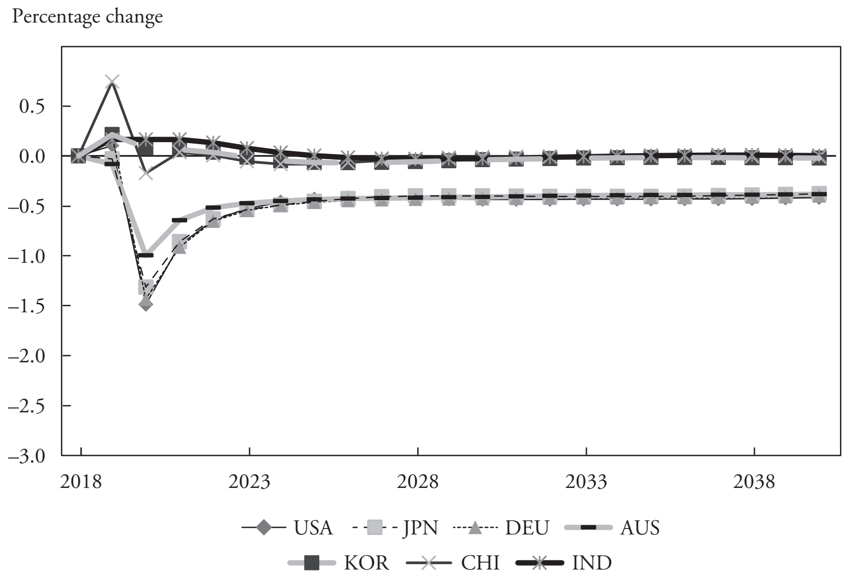
Simulation 1: Slowdown in Productivity Growth in Advanced Economies

FIGURE 3-2. **Productivity Growth Slowdown Shock in Advanced Economies**



Source: Authors' calculations.

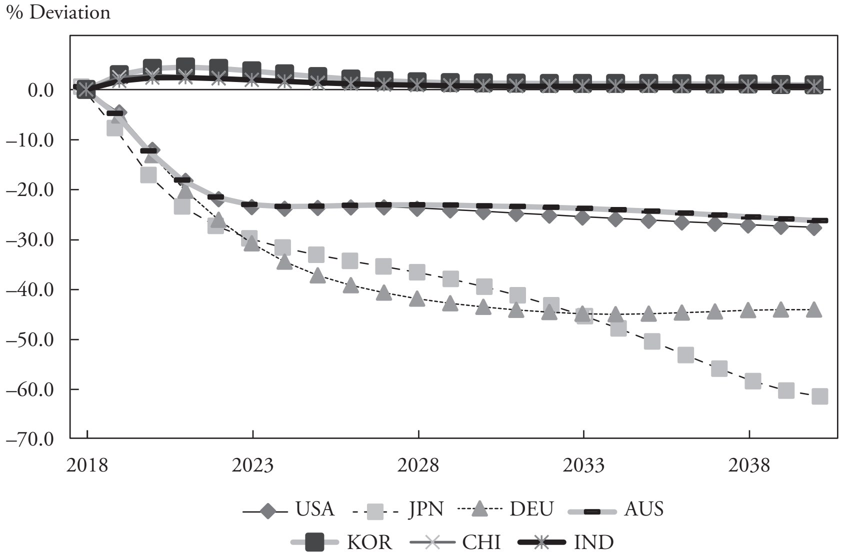
FIGURE 3-3. **Slowdown in Productivity Growth in Advanced Economies: Real GDP Growth**



Source: Authors' calculations.

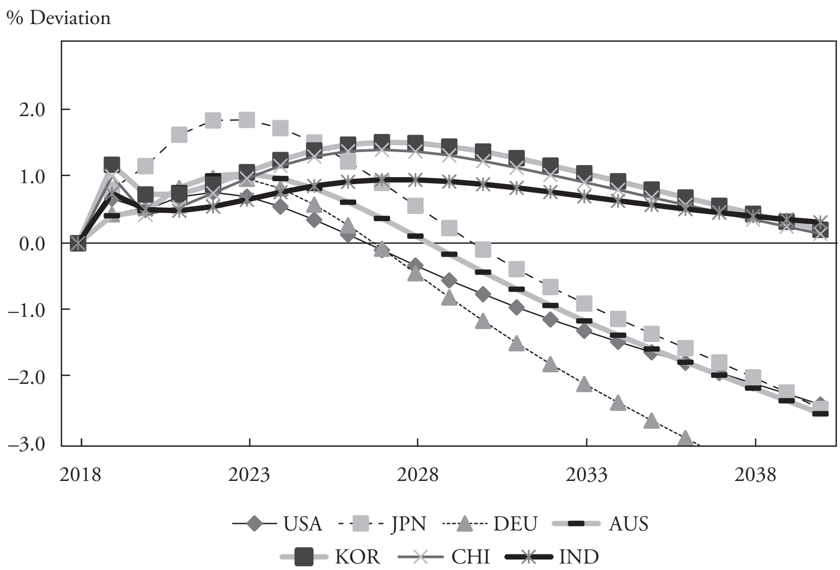
Note: "DEU" is Germany. "IND" is India. "IND" is Indonesia. See Table 3.1 for full list of countries.

FIGURE 3-4. Slowdown in Productivity Growth in Advanced Economies: Private Investment



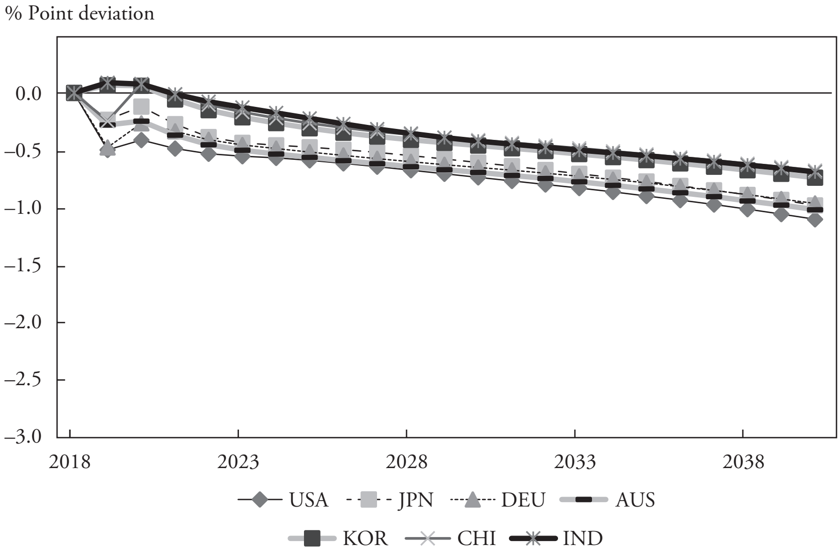
Source: Authors' calculations.

FIGURE 3-5. Slowdown in Productivity Growth in Advanced Economies: Consumption



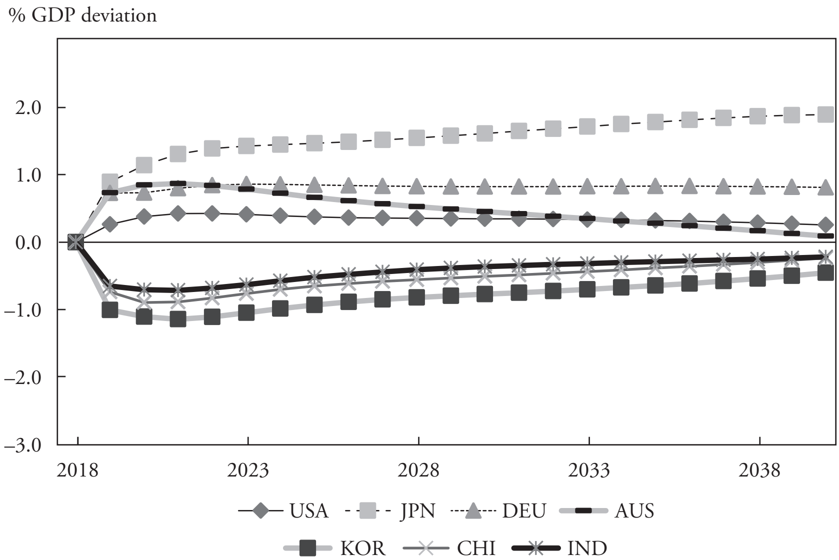
Source: Authors' calculations.

FIGURE 3-6. Slowdown in Productivity Growth in Advanced Economies: Real Interest Rates



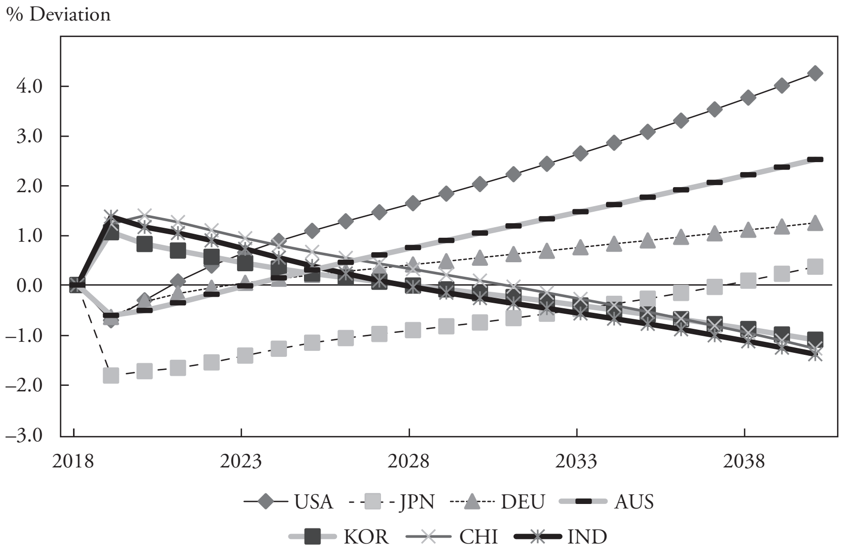
Source: Authors' calculations.

FIGURE 3-7. Slowdown in Productivity Growth in Advanced Economies: Trade Balance



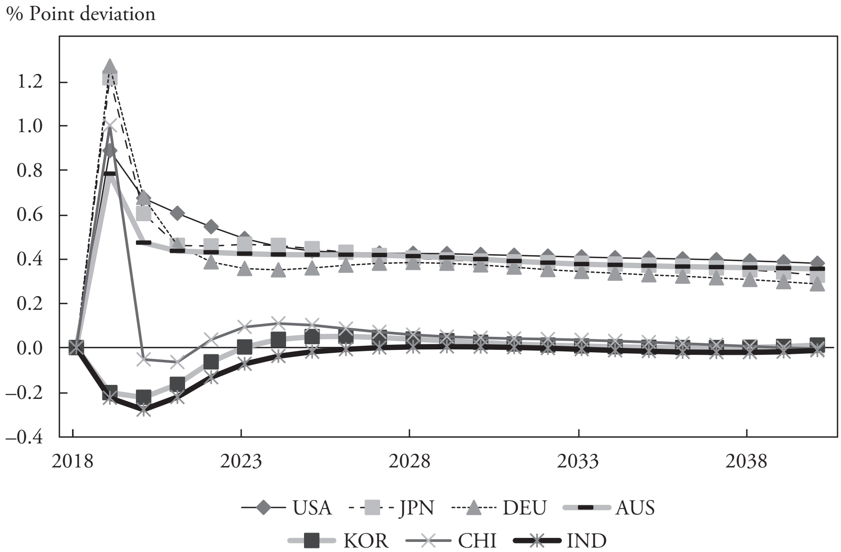
Source: Authors' calculations.

FIGURE 3-8. Slowdown in Productivity Growth in Advanced Economies: Real Effective Exchange Rates



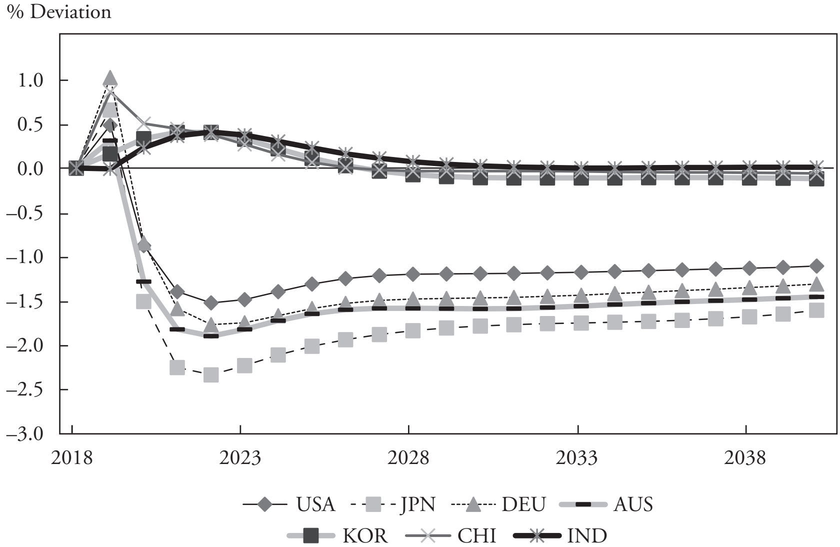
Source: Authors' calculations.

FIGURE 3-9. Slowdown in Productivity Growth in Advanced Economies: Inflation



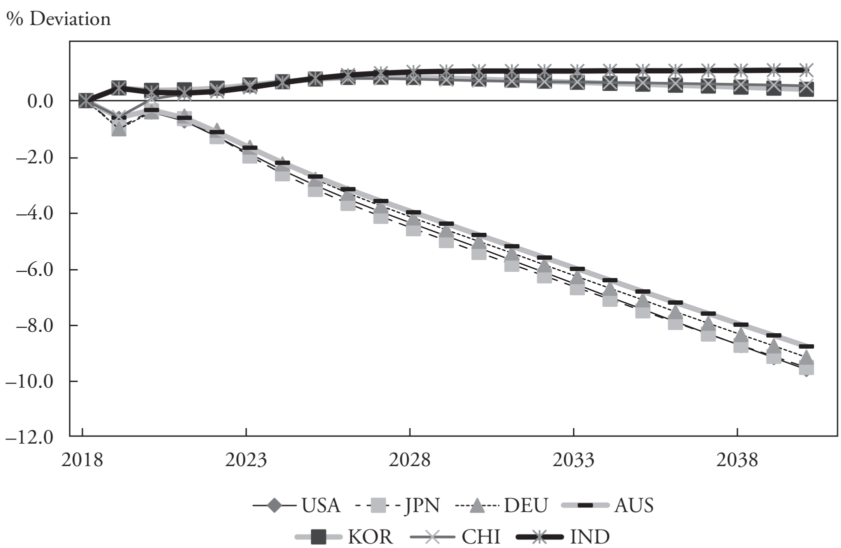
Source: Authors' calculations.

FIGURE 3-10. Slowdown in Productivity Growth in Advanced Economies: Employment



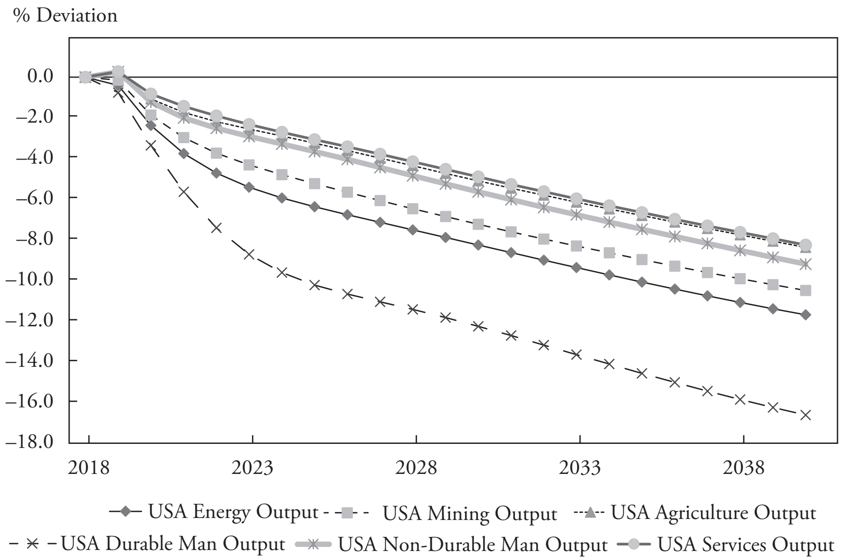
Source: Authors' calculations.

FIGURE 3-11. Slowdown in Productivity Growth in Advanced Economies: Real Wages



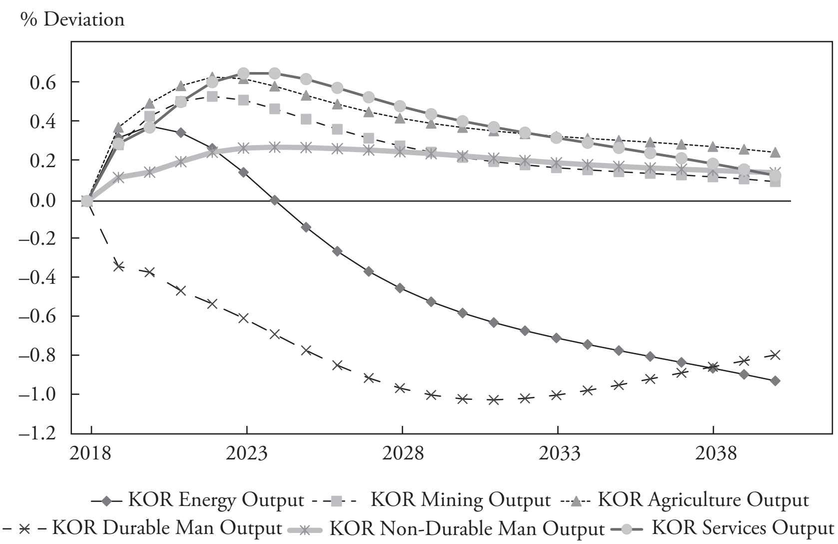
Source: Authors' calculations.

FIGURE 3-12. Slowdown in Productivity Growth in Advanced Economies: U.S. Sectoral Output



Source: Authors' calculations.

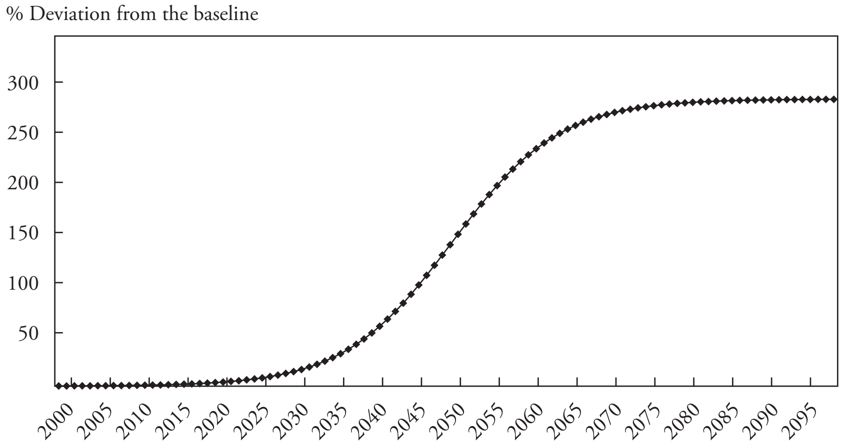
FIGURE 3-13. Slowdown in Productivity Growth in Advanced Economies: Korea Sectoral Output



Source: Authors' calculations.

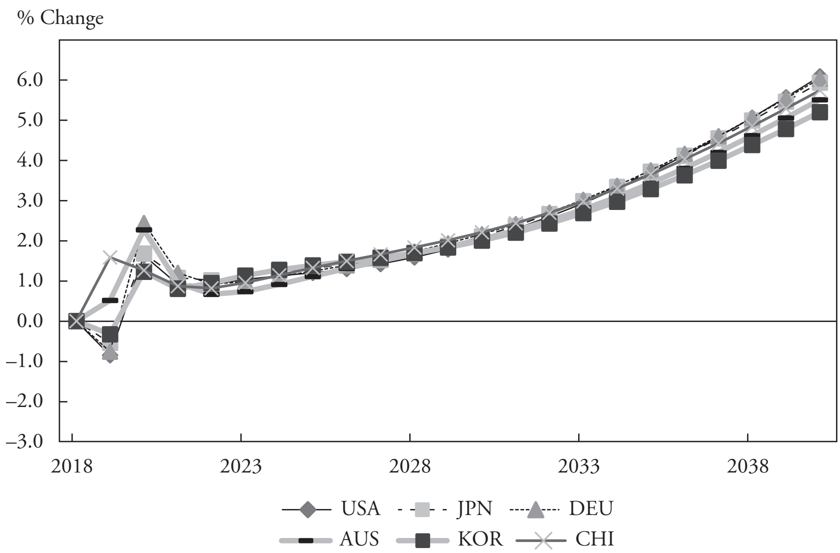
Simulation 2: Takeoff in Global Productivity Growth

FIGURE 3-14. The "S-Curve": Change in the Growth Rate of Labor Productivity Relative to the Baseline



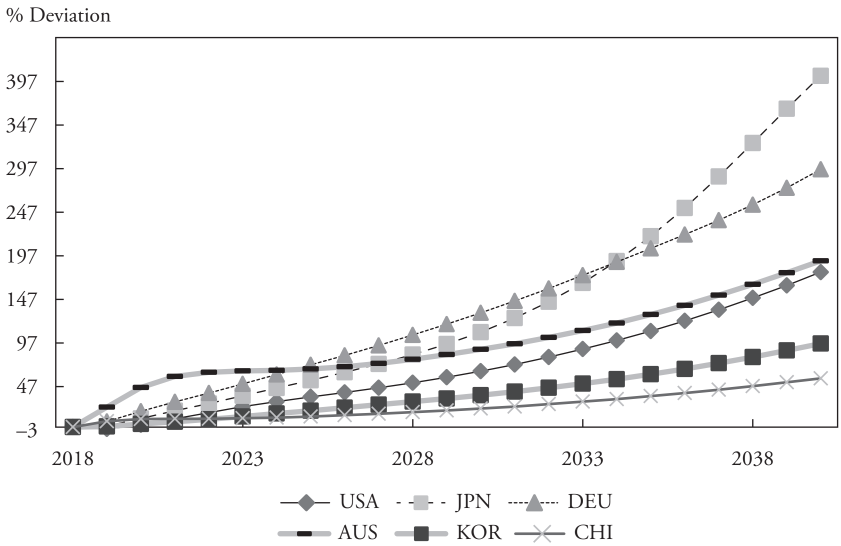
Source: Authors' calculations.

FIGURE 3-15. Takeoff in Global Productivity Growth: Real GDP Growth Rate



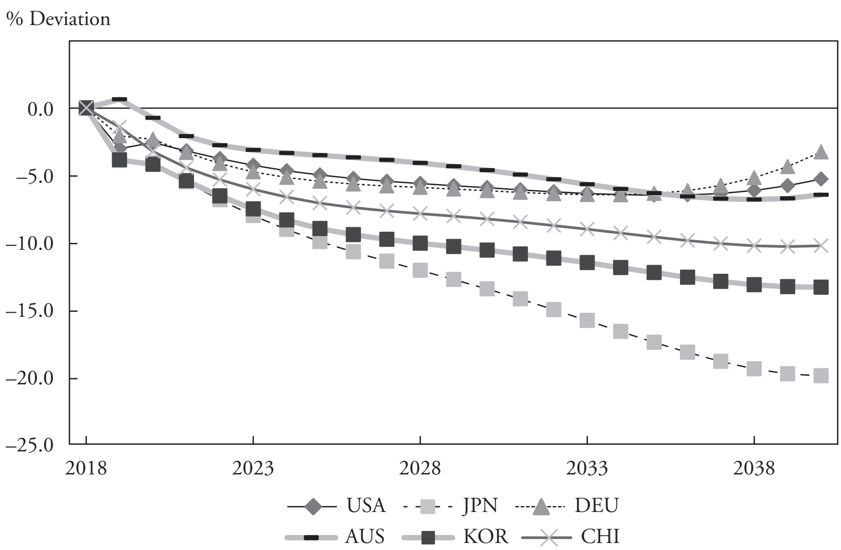
Source: Authors' calculations.

FIGURE 3-16. Takeoff in Global Productivity Growth: Private Investment



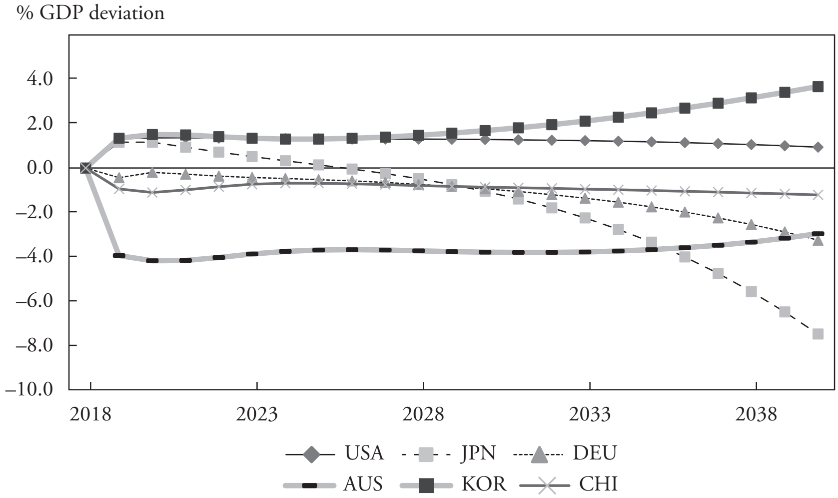
Source: Authors’ calculations.

FIGURE 3-17. Takeoff in Global Productivity Growth: Consumption



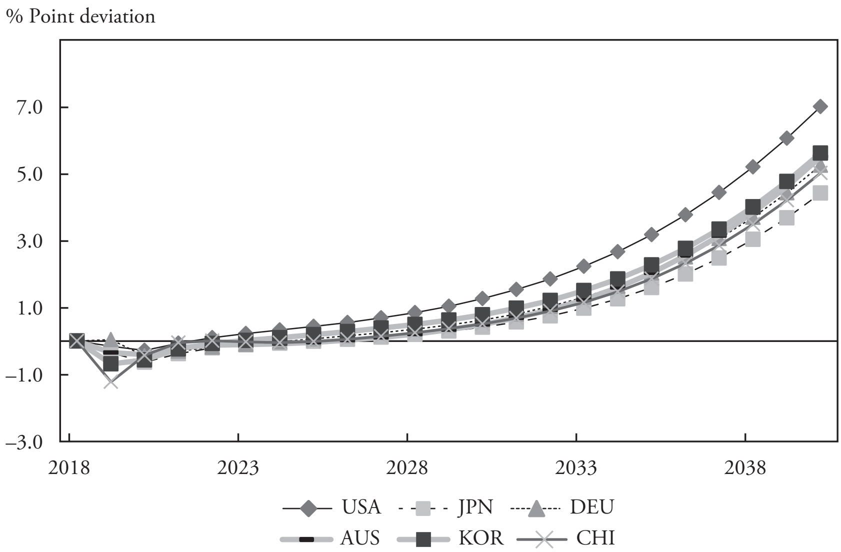
Source: Authors’ calculations.

FIGURE 3-18. **Takeoff in Global Productivity Growth: Trade Balance**



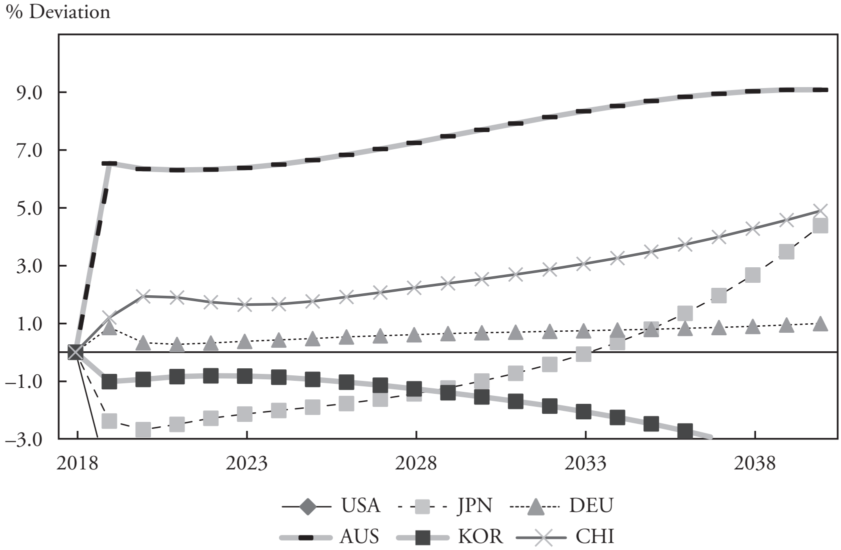
Source: Authors' calculations.

FIGURE 3-19. **Takeoff in Global Productivity Growth: Real Interest Rates**



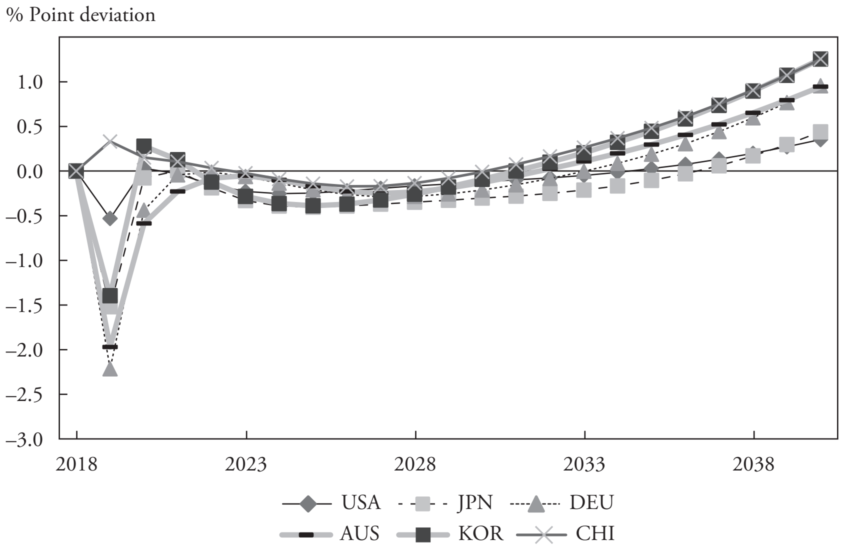
Source: Authors' calculations.

FIGURE 3-20. Takeoff in Global Productivity Growth: Real Effective Exchange Rates



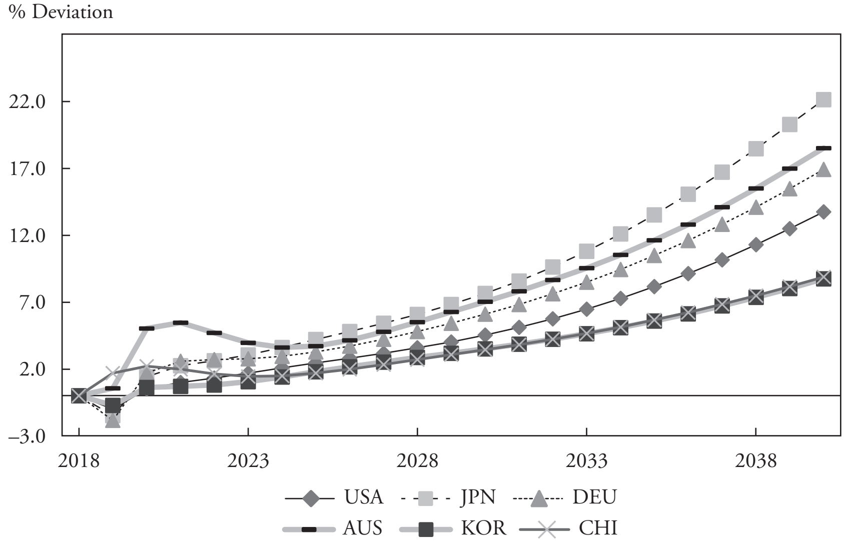
Source: Authors' calculations.

FIGURE 3-21. Takeoff in Global Productivity Growth: Inflation



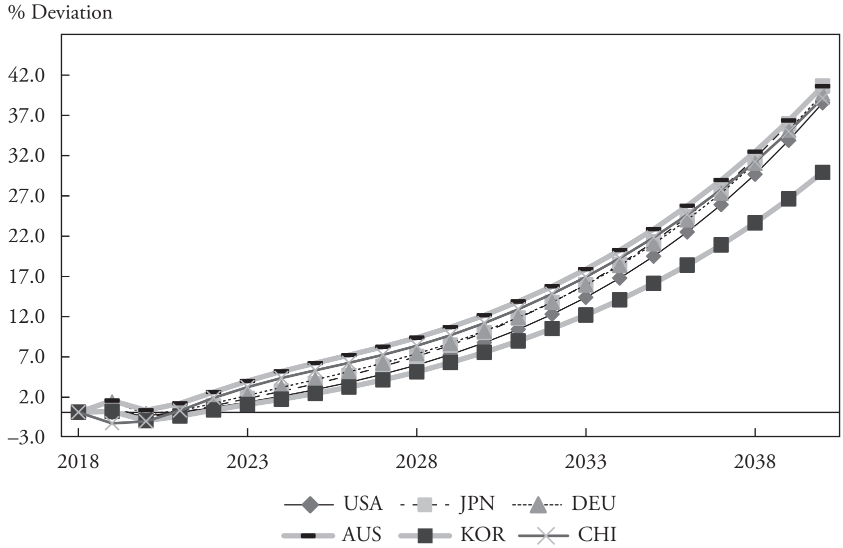
Source: Authors' calculations.

FIGURE 3-22. Takeoff in Global Productivity Growth: Employment



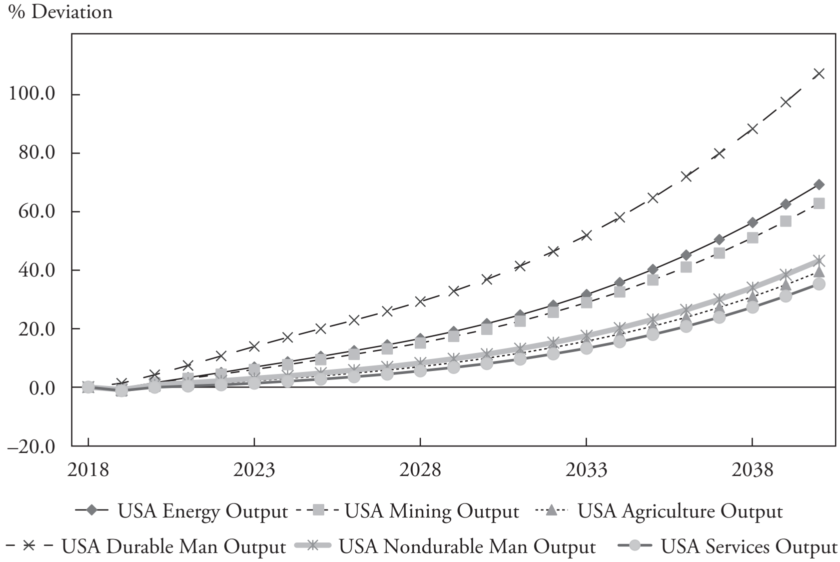
Source: Authors' calculations.

FIGURE 3-23. Takeoff in Global Productivity Growth: Real Wages



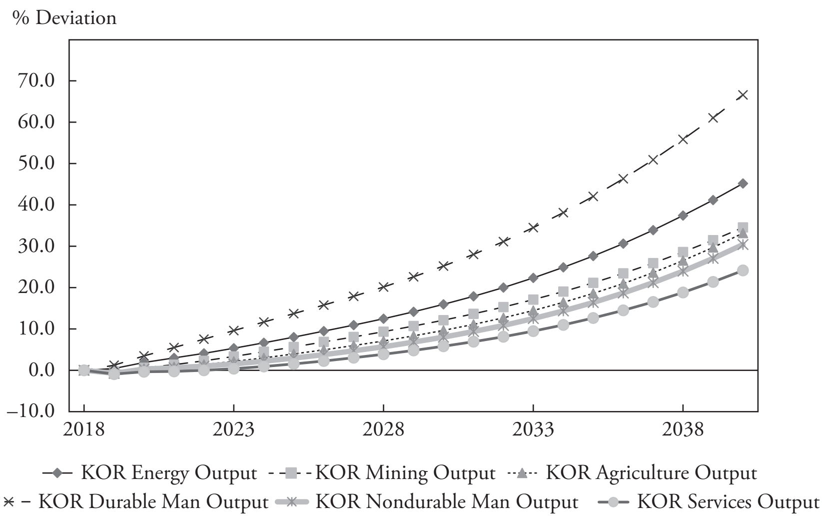
Source: Authors' calculations.

FIGURE 3-24. Takeoff in Global Productivity Growth: U.S. Sectoral Output



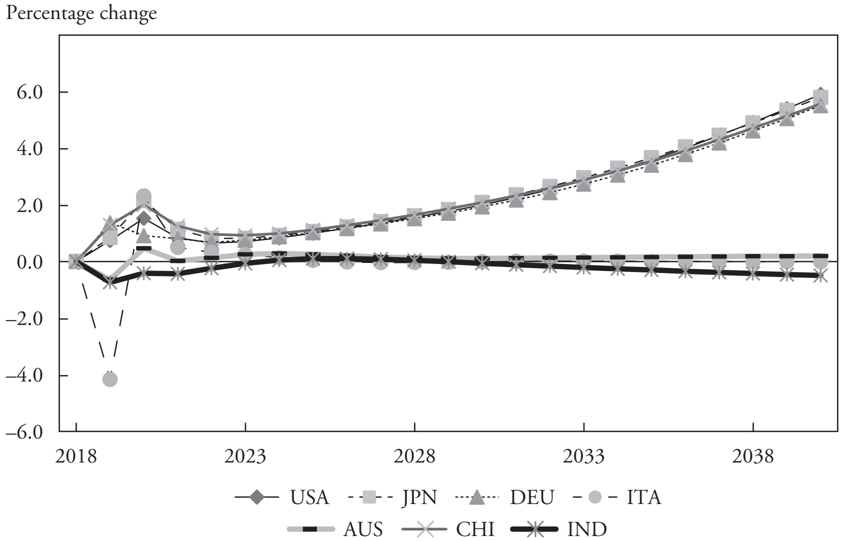
Source: Authors' calculations.

FIGURE 3-25. Takeoff in Global Productivity Growth: Korea Sectoral Output



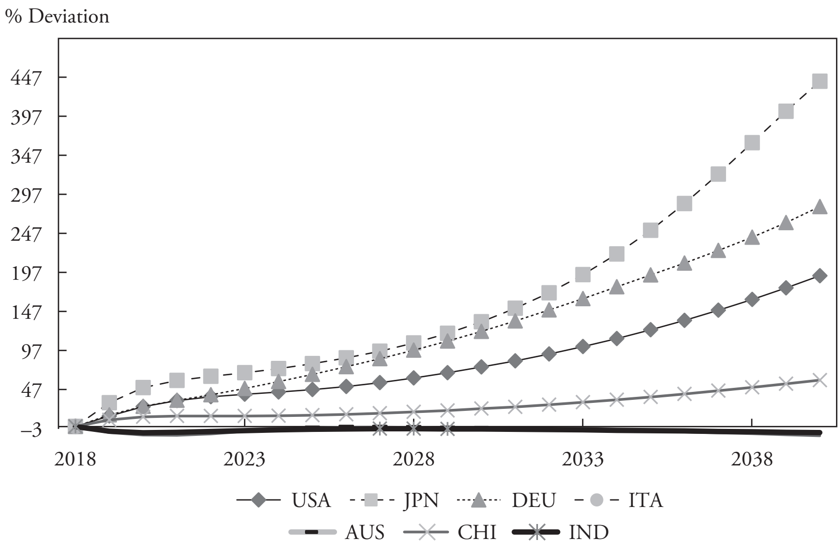
Source: Authors' calculations.

FIGURE 3-26. Takeoff in Productivity in Select Countries: Real GDP Growth Rate



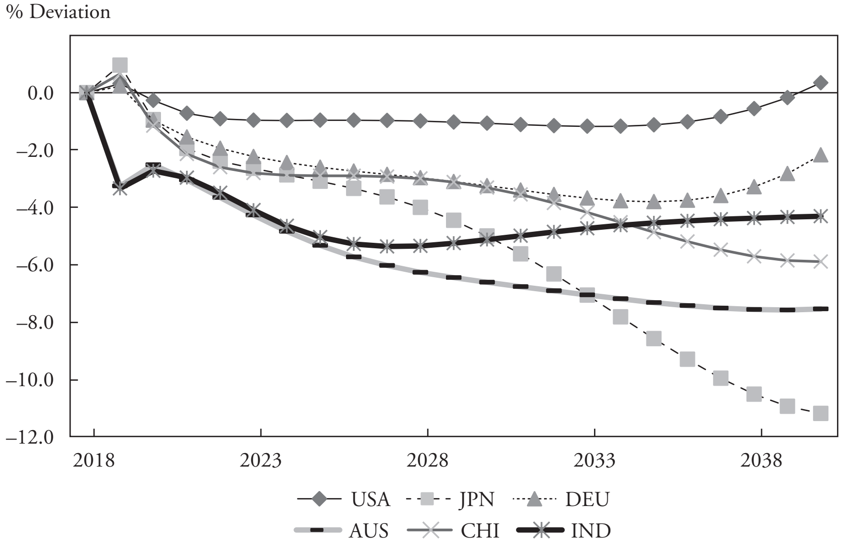
Source: Authors' calculations.

FIGURE 3-27. Takeoff in Productivity in Select Countries: Private Investment



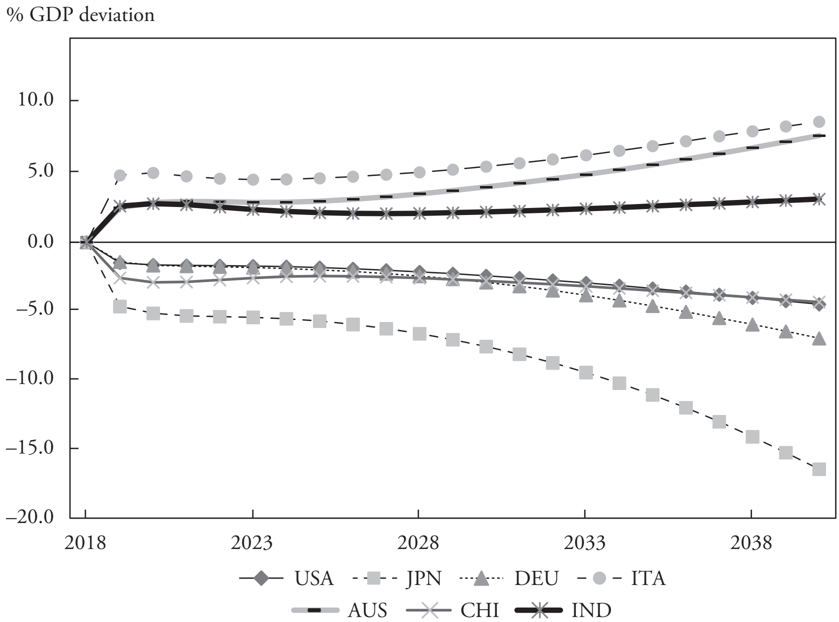
Source: Authors' calculations.

FIGURE 3-28. **Takeoff in Productivity in Select Countries: Consumption**



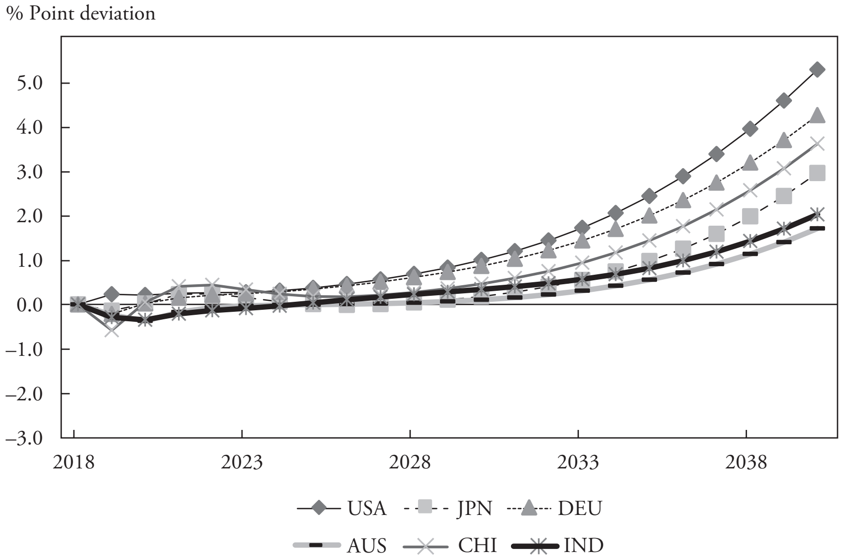
Source: Authors' calculations.

FIGURE 3-29. **Takeoff in Productivity in Select Countries: Trade Balance**



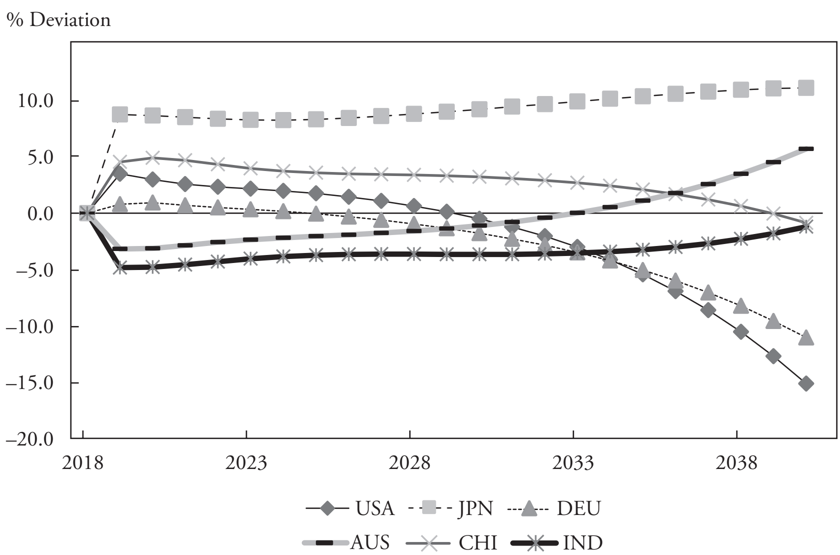
Source: Authors' calculations.

FIGURE 3-30. Takeoff in Productivity in Select Countries: Real Interest Rates



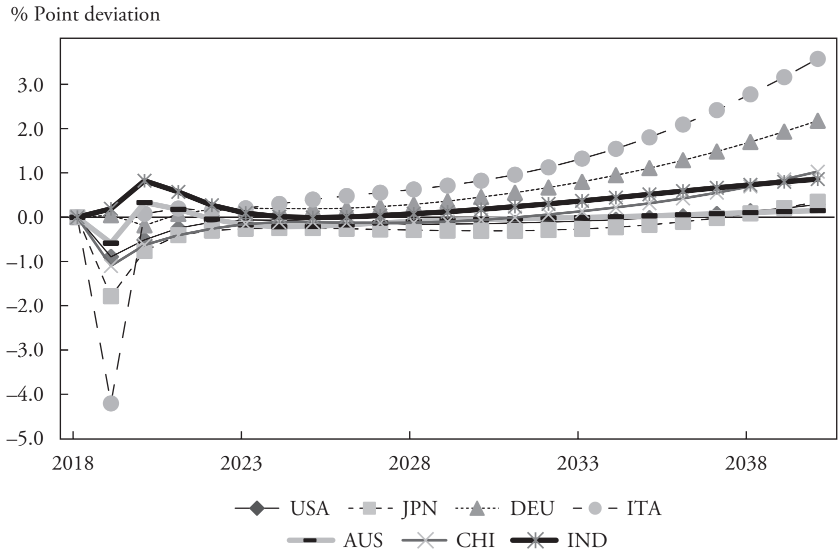
Source: Authors' calculations.

FIGURE 3-31. Takeoff in Productivity in Select Countries: Real Effective Exchange Rates



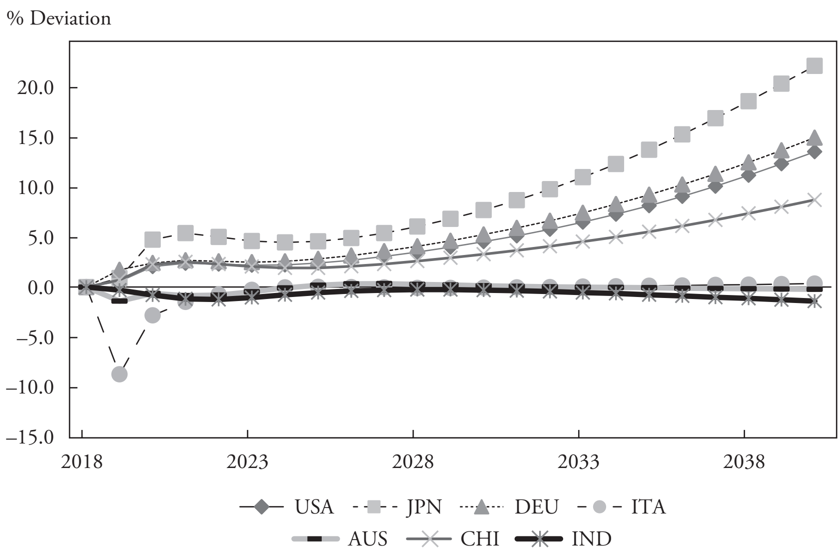
Source: Authors' calculations.

FIGURE 3-32. **Takeoff in Productivity in Select Countries: Inflation**



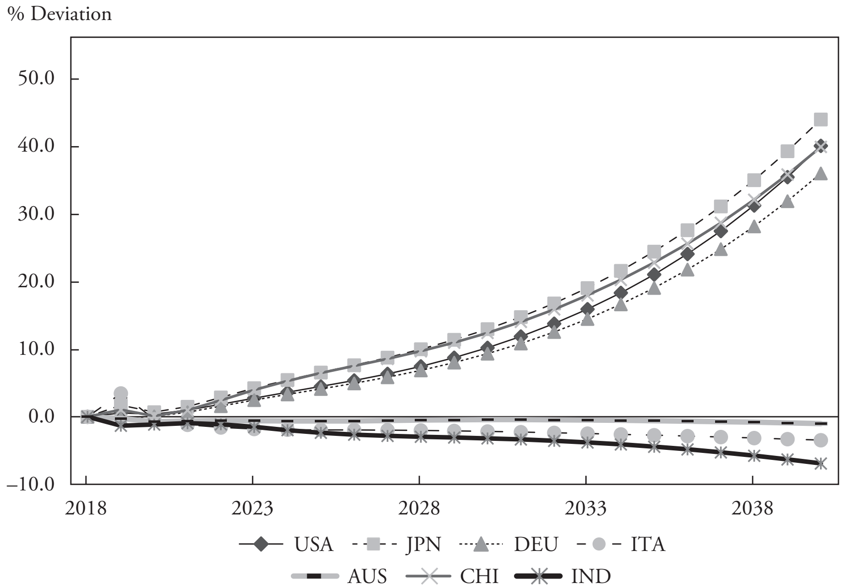
Source: Authors' calculations.

FIGURE 3-33. **Takeoff in Productivity in Select Countries: Employment**



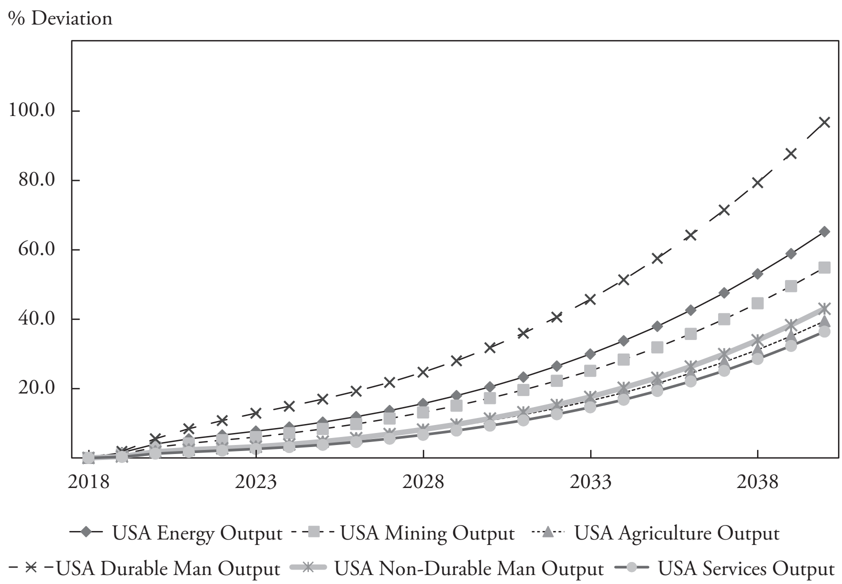
Source: Authors' calculations.

FIGURE 3-34. Takeoff in Productivity in Select Countries: Real Wages



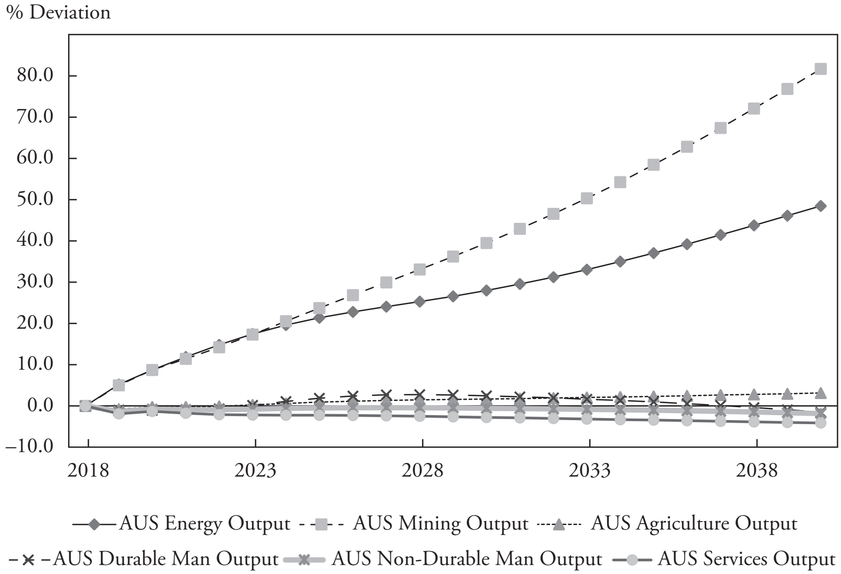
Source: Authors' calculations.

FIGURE 3-35. Takeoff in Productivity in Select Countries: U.S. Sectoral Output



Source: Authors' calculations.

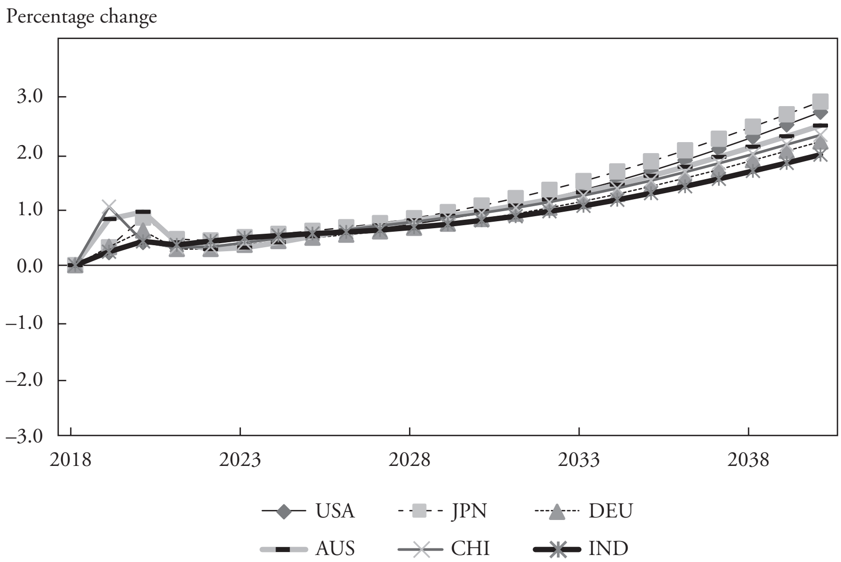
FIGURE 3-36. Takeoff in Productivity in Select Countries: Australia Sectoral Output



Source: Authors' calculations.

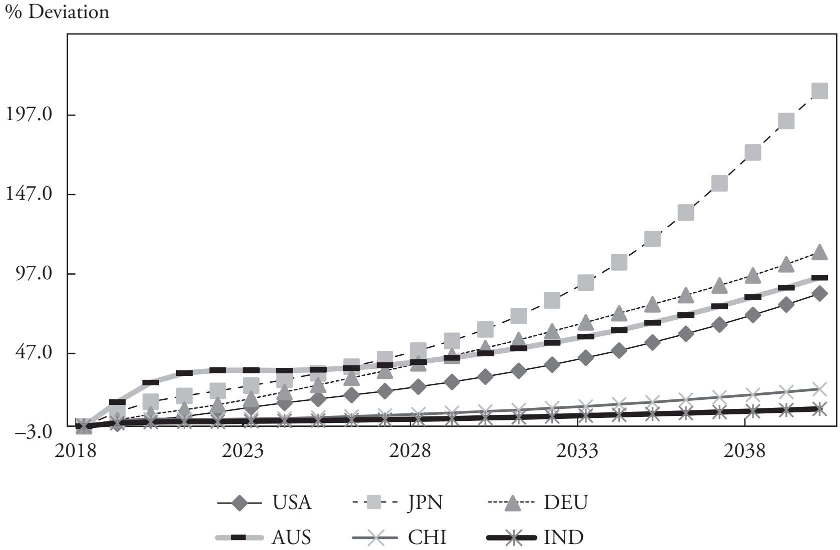
Simulation 4: Global Takeoff in Service Sector Productivity Growth

FIGURE 3-37. Global Takeoff in Service Sector Productivity Growth: Real GDP Growth Rate



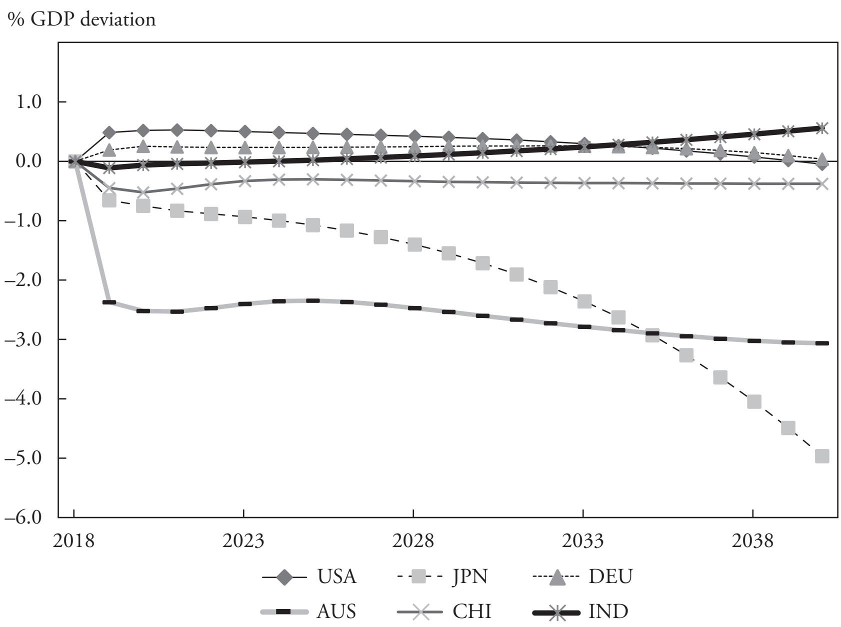
Source: Authors' calculations.

FIGURE 3-38. Global Takeoff in Service Sector Productivity Growth: Private Investment



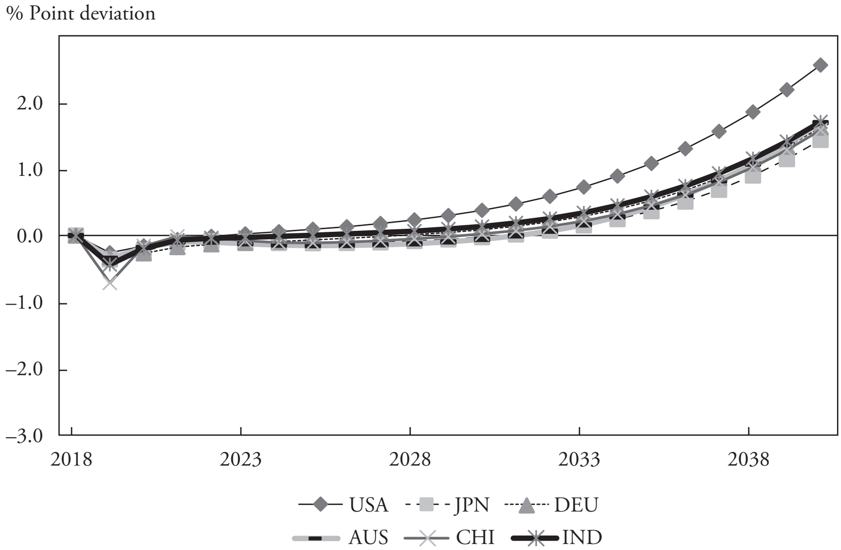
Source: Authors' calculations.

FIGURE 3-39. Global Takeoff in Service Sector Productivity Growth: Trade Balance



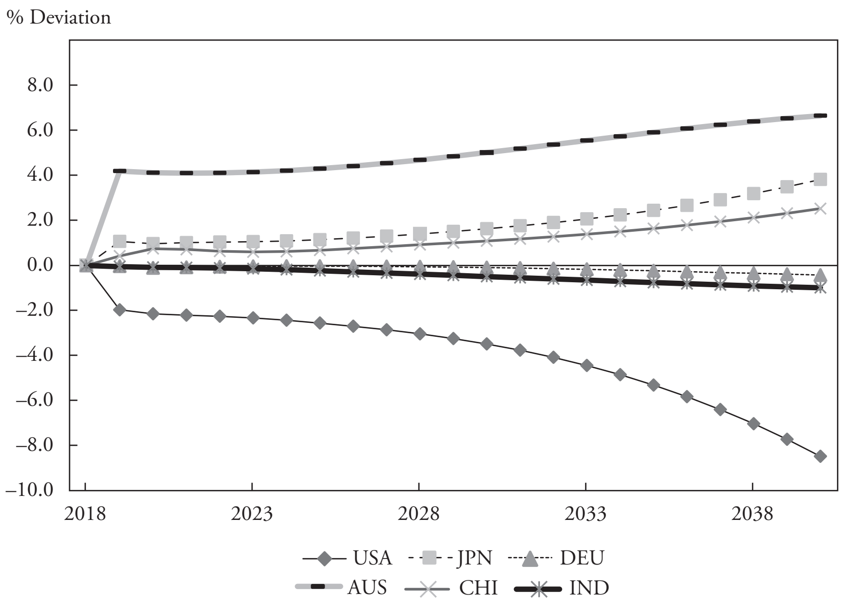
Source: Authors' calculations.

FIGURE 3-40. Global Takeoff in Service Sector Productivity Growth: Real Interest Rates



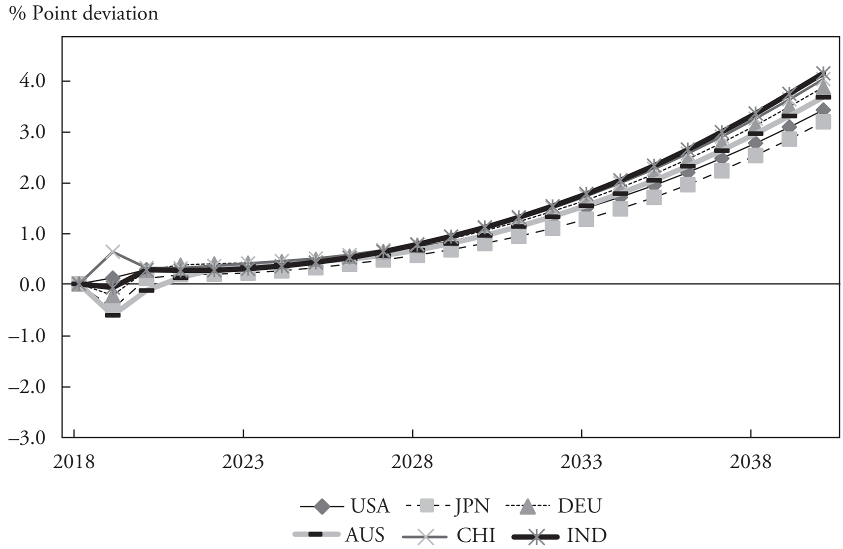
Source: Authors' calculations.

FIGURE 3-41. Global Takeoff in Service Sector Productivity Growth: Real Effective Exchange Rates



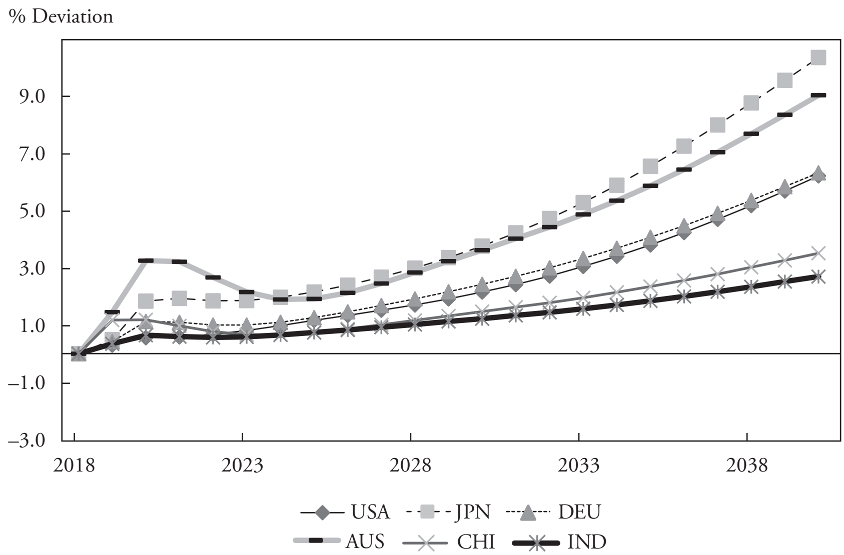
Source: Authors' calculations.

FIGURE 3-42. Global Takeoff in Service Sector Productivity Growth: Inflation



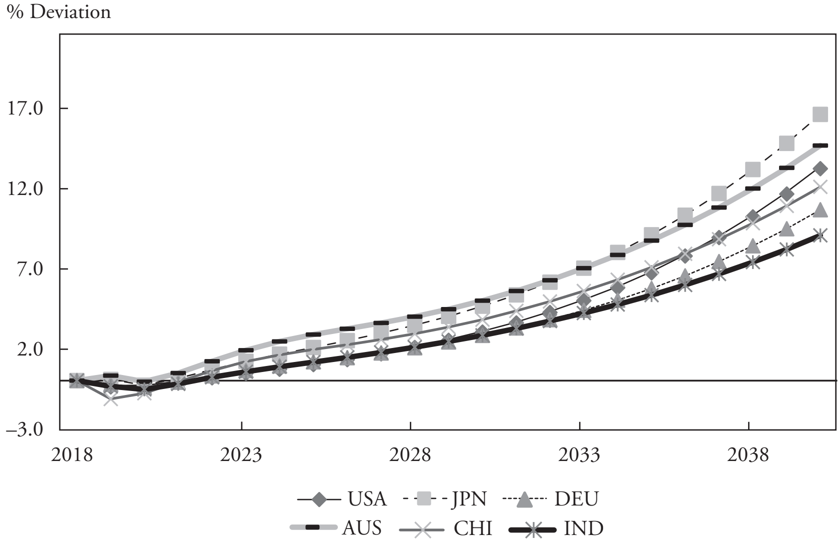
Source: Authors' calculations.

FIGURE 3-43. Global Takeoff in Service Sector Productivity Growth: Employment



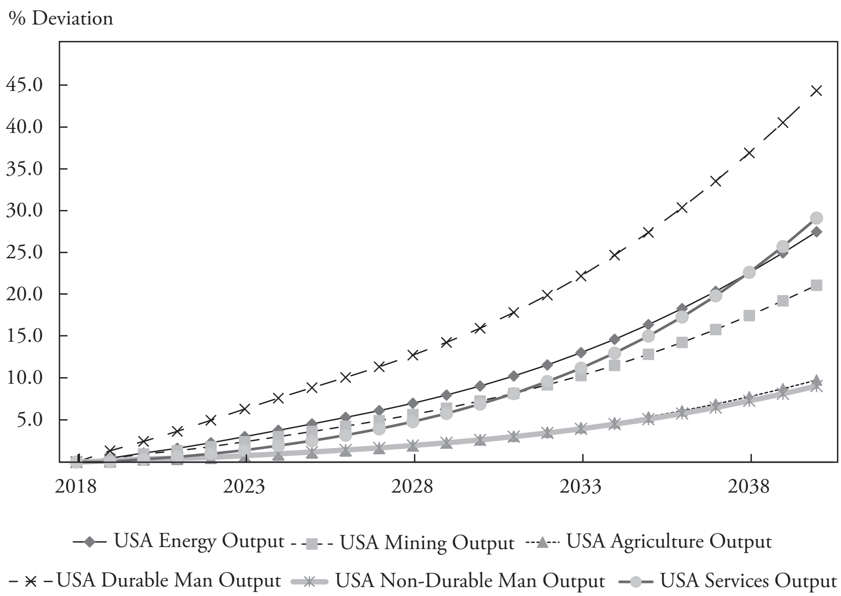
Source: Authors' calculations.

FIGURE 3-44. Global Takeoff in Service Sector Productivity Growth: Real Wages



Source: Authors' calculations.

FIGURE 3-45. Global Takeoff in Service Sector Productivity Growth: U.S. Sectoral Output



Source: Authors' calculations.

NOTES

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1. See Adler and others (2017).

2. Krugman (1997).

3. See, respectively, Mehrotra (2019); Duggar (2019); Mauro and others (2019); Stansbury and Summers (2019); Furman and Orszag (2019).

4. Solow (1987).

5. Nordhaus (2015); Saniee and others (2017); Basu, Fernald, and Kimball (2006).

6. Feldstein (2017).

7. Byrne, Oliner, and Sichel (2013); Adler and others (2017).

8. United Nations (2016).

9. Lileeva (2008); De Loecker (2007); United Nations (2016); Adler and others (2017).

10. Aiyar and Ebeke (2016).

11. Organisation for Economic Co-operation and Development (2015).

12. Kotlikoff and Sachs (2012); Akst (2013); Brynjolfsson and McAfee (2016); Goldin and Katz (2008).

13. Qureshi (2018); Decker and others (2014).

14. Melitz (2003).

15. Organisation for Economic Co-operation and Development (2015).

16. McGowan, Andrews, and Millot (2017).

17. Fernald (2014).

18. Gordon (2016).

19. See Frankel (2016); and Nixon (2007).

20. Aral, Brynjolfsson, and Van Alstyne (2007).

21. Gordon (2016).

22. Nordhaus (2015); Saniee and others (2017); Basu, Fernald, and Kimball (2006).

23. PricewaterhouseCoopers (2018).

24. See Goldfarb and Trefler (2018).

25. Fernald (2014); Melitz (2003); Organisation for Economic Co-operation and Development (2015).

26. PricewaterhouseCoopers (2018) use the EU and World KLEMS databases, which contain more aggregated data series of capital stock groupings that

contain AI technologies and therefore can capture the potential effect of AI on productivity (assuming the impact of AI is similar to that of other emerging technologies in the grouping).

27. Goldfarb and Trefler (2018).

28. Márquez-Ramos and Martínez-Zarzoso (2010).

29. European Central Bank (2017); Melitz (2003); Lileeva (2008); De Loecker (2007).

30. Obstfeld and Rogoff (2000).

31. McKibbin and Triggs (2018).

32. McKibbin and Sachs (1991) call this an incremental interest payments rule.

33. Further details are available in McKibbin and Triggs (2018).

34. McKibbin, Pearce, and Stegman (2007).

35. Stegman and McKibbin (2013).

36. United Nations (2017).

37. Barro (1991, 2015).

38. Timmer, de Vries, and de Vries (2015).

39. Gordon (2016); Adler and others (2017).

40. Calvo, Leiderman, and Reinhart (1993) and Hannan (2018) for a review of this literature.

41. Nordhaus (2015); Saniee and others (2017); Basu, Fernald, and Kimball (2006).

42. This experience is documented by Saniee and others (2017).

43. Nordhaus (2015).

44. PricewaterhouseCoopers (2018).

45. Goldfarb and Trefler (2018).

46. Fernald (2014); Melitz (2003); Organisation for Economic Co-operation and Development (2015).

47. Gordon (2016).

48. Nordhaus (2015); Saniee and others (2017).

49. PricewaterhouseCoopers (2018); Goldfarb and Trefler (2018).

50. The importance of infrastructure in the impacts of fiscal policy in the G-Cubed (G20) model is explored in McKibbin, Stoeckel, and Lu (2014).

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