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IMF STAFF DISCUSSION NOTE

Gone with the Headwinds: Global Productivity

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EXECUTIVE SUMMARY

Productivity growth—the key long-term driver of living standards—fell sharply following the global financial crisis, adding to structural headwinds already blowing before the crisis, and has remained sluggish ever since. This note explores the role of crisis legacies and these headwinds in slowing that growth, building on new research using country, industry, and firm-level data. The main findings include the following:

- The drop in total factor productivity (TFP) growth following the global financial crisis has been widespread and persistent across advanced, emerging, and low-income countries. And that decline—alongside weak investment in the case of advanced economies—has been the main contributor to output losses relative to precrisis trends. It cannot be ruled out that growing measurement issues might have played some role, but the bulk of the productivity slowdown appears to be genuine. For advanced and low-income countries, the sharp deceleration in TFP occurred on the back of a precrisis slowdown, while in emerging market economies, it meant a break in a precrisis acceleration.

- As in previous deep recessions, the aftermath of the global financial crisis in advanced economies has displayed "TFP hysteresis"—persistent TFP loss from a large and seemingly temporary shock. Three interrelated factors appear to be behind this pattern: *First*, in contrast to past recessions, weak corporate balance sheets, combined with tight credit conditions, have undermined TFP growth, partly by constraining investment in intangible assets in distressed firms. In a number of advanced economies, the boom-bust financial cycle and its corollary of weak corporates and banks has also increased misallocation of capital within and across sectors. *Second*, an adverse feedback loop of weak aggregate demand, investment, and capital-embodied technological change seems to have afflicted the advanced economies. *Third*, elevated economic and policy uncertainty may have further weakened TFP growth, partly by tilting investment away from higher-risk, higher-return projects. These crisis legacies are gradually waning, but they remain a significant drag on productivity growth, especially in continental Europe.

- Crisis-related factors added to important structural headwinds that have been dragging down global TFP growth since before the crisis, particularly including a waning information and communication technology (ICT) boom in the most advanced economies and its spillovers to other economies; an aging workforce, especially in advanced economies; slower human capital accumulation; and slowing global trade integration—including the maturing of China's integration into world trade. In emerging and developing economies, although driving forces have been less clear and the potential for TFP catch-up remains strong, the fading effects of earlier structural reforms and structural transformation seem to have played some role.

- Addressing crisis legacies may be the most promising avenue for boosting productivity growth in the near term, particularly in continental Europe, where the scars from the global financial crisis remain greater than in most other advanced economies. Stimulating demand, including by addressing remaining weak corporate and bank balance sheets, reducing policy uncertainty, and boosting investment on high-return infrastructure projects, would induce greater private investment and risk-taking and improve capital allocation. This could turn around the feedback

loop between investment and TFP, helping lift most advanced economies out of their current low-growth trap.

- Over the medium term, productivity prospects are highly uncertain. A revival driven by artificial intelligence and other breakthroughs is conceivable, although its magnitude and timing are difficult to predict. Until then, and even if crisis legacies are addressed, productivity growth is unlikely to return to the higher rates of the late 1990s (for advanced economies) or the mid-2000s (for emerging and developing economies) given the structural headwinds. Policymakers should proactively address the effect of headwinds, including by advancing structural reforms and nurturing open trade and migration policies, which have delivered sizeable TFP gains in past decades. In doing so, they should ensure gains are widely shared across and within countries. Attention should also be given to strengthening innovation, education, and training policies.

INTRODUCTION

1. **Context**. Productivity plays a key role in driving living standards. This is particularly true over the long term, and especially so of total factor productivity, a measure of an economy's overall efficiency in the use of its capital and labor. Greater efficiency helps create more of existing goods, but also frees up resources that can be devoted to producing other, new goods and services, thus replacing jobs and creating new ones. This was the case, for example, in past industrial revolutions. After decades of healthy gains in efficiency, however, productivity growth fell sharply in the aftermath of the global financial crisis and has remained subdued since then, most strikingly in advanced economies, but also in emerging and developing economies. This decline has been associated with subpar global economic growth and record-low real long-term interest rates. If sustained, low productivity growth would have profound adverse implications for progress in global living standards, the sustainability of private and public debts, social protection systems, and the ability of macroeconomic policies to respond to future shocks. It is therefore paramount to understand the root causes of the productivity slowdown and address market failures and policy distortions that may have played a role.

2. **Technological innovation and diffusion**. Much attention in academic and policy debates has naturally focused on whether innovation and technological diffusion have slowed. After boosting aggregate productivity growth in the United States and some other advanced economies in the late 1990s and early 2000s, the gains from the production and use of information and communication technologies (ICT) appear to have waned (Fernald 2015). The debate is heated as to whether this slowdown in innovation is permanent (Gordon 2016) or temporary, as major advances in artificial intelligence and other breakthrough technologies offer the prospect of a productivity revival (Brynjolfsson and McAfee 2014). Such advances, however, may take time to spread throughout the economy, as did major inventions of the past, such as the electric dynamo during the second industrial revolution of the late 19th and early 20th centuries (David 1990). Other recent research highlights instead the role of slowing technological diffusion, pointing out the growing productivity gap between leading and lagging firms across many advanced economies and industries, and declining business dynamism, since the early 2000s (Andrews, Criscuolo, and Gal 2015; Decker and others 2016; Haltiwanger 2011; Haltiwanger, Hathaway and Miranda, 2014; OECD 2015).

3. **Structural headwinds**. Various policy and non-policy barriers to innovation and diffusion in advanced economies have been put forward as possible culprits. These include, among other things, changes in product market structure (such as the growing importance of specific knowledge-based capital and winner-takes-all dynamics) or mismatches and deficiencies in skills (Adalet McGowan and Andrews 2015a,b; Bloom, Sadun, and Van Reenen 2016). They also include insufficient labor and product market reforms (Cette, Fernald, and Mojon 2016) in the context of disruptive ICT-related technological change, and reduced fluidity in labor markets (Davis and Haltiwanger 2014; Molloy and others 2016). Other structural headwinds may have dragged on productivity growth by slowing innovation or technological adoption. These include adverse spillovers from a slowdown at the technological frontier across several industries (Dabla-Norris and others 2015), demographic factors such as aging populations (Feyrer 2007 and 2008; Maestas, Mullen, and Powell 2016), and slowing global trade integration (IMF 2016a). Slower economic transformation and structural reforms may be adding to these trends in emerging and developing economies.

4. **The legacies of the global financial crisis**. However, the abruptness, magnitude, and persistence of the slowing of productivity after the crisis cautions against blaming low productivity growth solely on slow-moving noncyclical forces. Despite extraordinary policy stimulus, aggregate demand has been weak since the global financial crisis and a key driving force behind sluggish investment (IMF 2015a). Likewise, to varying degrees across advanced countries, elevated economic and policy uncertainty, pockets of weak corporate balance sheets, as well as tight access to credit amid legacy assets and capital shortfalls in the banking sector, have characterized the environment since the crisis. Economic theory and evidence suggest that such conditions can bias business investment toward more liquid, low-risk/low-return projects (Aghion and others 2012; Baker, Bloom, and Davis 2016; Bloom and others 2014). In turn, these forces might have slowed technological progress—which is often embodied in new capital goods or results from risky investments (Greenwood, Hercowitz, and Krusell 1997; Solow 1959; Wolff 1991)—and led to an adverse feedback loop between weak and low-risk investment, TFP, and potential growth.

5. **Key questions and roadmap**. This note builds on new cross-country aggregate, sector- and firm-level research to shed light on the extent and nature of the productivity slowdown and assess the respective roles not only of secular headwinds, but also, importantly, crisis legacies. As such it complements previous IMF work (Dabla-Norris and others 2013a and 2015) that identified and underlined the need for policy reforms to lift productivity growth in advanced economies and emerging and developing economies. Specifically, this note addresses four groups of questions:

- **Timing, extent and nature of the productivity slowdown.** Has it taken place mostly before or after the global financial crisis? How widespread has it been? And is it primarily structural or cyclical?

- **Legacies of the global financial crisis.** Has the global financial crisis left permanent productivity scars? If so, what are these legacy issues? In particular, what are the roles of weak aggregate demand, weak corporate and bank balance sheets, and elevated policy uncertainty?

- **Structural factors.** What longer-term forces have been driving the global productivity slowdown? In particular, what have been the roles of the pace of innovation at the technological frontier—notably in ICT—and various factors that may have slowed innovation and adoption of new technologies, such as population aging, slowing growth of global trade, or a diminishing rate of human capital accumulation?

Are trends in emerging and developing economies related to other secular forces, like economic transformation and the pace of structural reforms?

- **Policies to revive TFP growth.** What are the possible remedies to the productivity slowdown? In particular, what immediate policy actions are needed to address global financial crisis legacies, and what policies should be implemented to tackle the structural headwinds?

6. In the remainder of the note, section II presents stylized facts documenting the extent and magnitude of the slowdown in productivity and section III analyzes its causes, assessing the role of both crisis legacies and secular forces. Section IV discusses possible remedies to the identified impediments to productivity growth. Section V concludes.

THE LONG AND SHORT OF SLOWING GLOBAL PRODUCTIVITY

7. Stagnant growth and the role of TFP. Growth has been largely stagnant in the advanced economies, emerging market economies, and lower-income countries since the global financial crisis, with significantly slower growth than precrisis trends (Figure 1).[2] A supply-side decomposition of the drivers of potential output indicates that a marked deceleration in TFP growth contributed on average about 40 percent of the output loss in advanced economies. This reflected not only the immediate impact of the crisis, but also persistent effects—TFP growth in recent years remained below precrisis levels for three-quarters of advanced economies.[3] In emerging market economies and low-income countries, slower TFP growth represented an even greater share of output losses, although largely reflecting the rapid and possibly unsustainable speed of technological catch-up in the years immediately preceding the global financial crisis.[4] Idiosyncratic country circumstances played a role in some large emerging market economies (such as Brazil, China, and Russia), but the productivity slowdown is a broader phenomenon, encompassing most countries within this income group. The experience of low-income countries has been more heterogeneous, likely reflecting a greater importance of idiosyncratic factors at play. As such, the note focuses mostly on developments in advanced and emerging market economies.

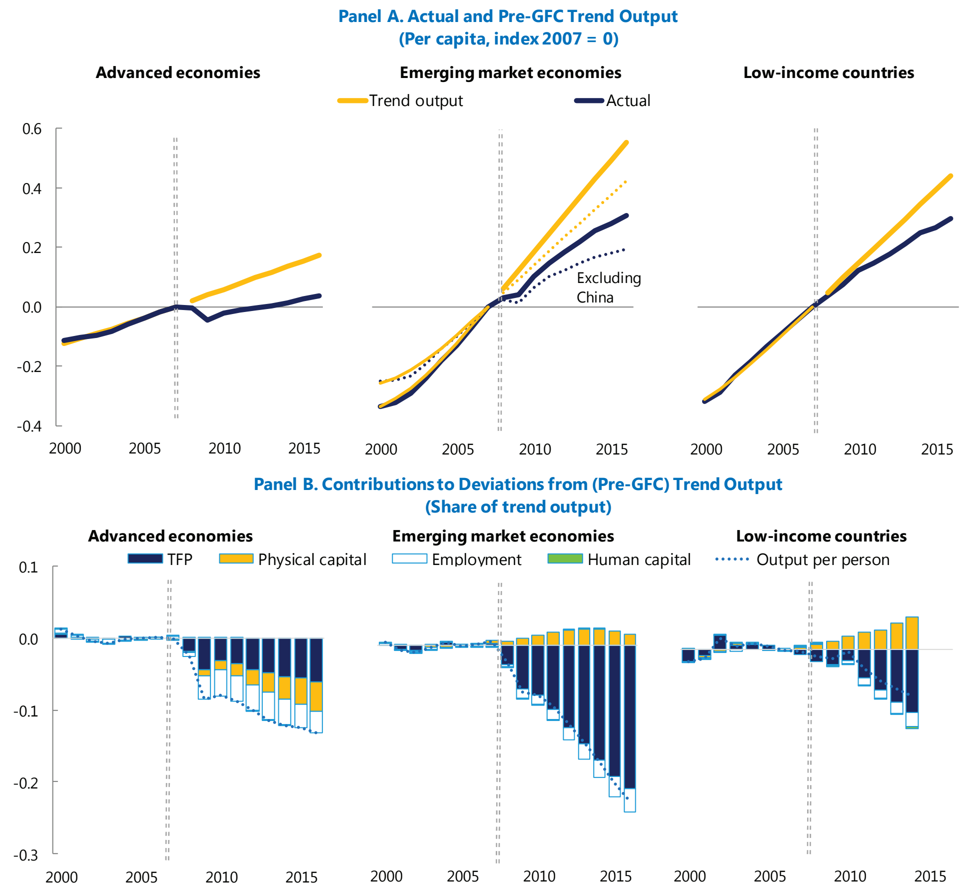
[2] See also Blanchard, Cerutti, and Summers (2015).

[3] A noticeable exception is the United States, where TFP growth recovered more rapidly toward its precrisis pace, in part because of already low TFP growth in the years immediately preceding the global financial crisis. Nonetheless, cumulative TFP losses have been significant in the United States, with levels remaining below the precrisis trend.

[4] Unlike in the advanced economies, capital formation in the emerging market economies continued supporting output growth immediately following the global financial crisis, reflecting record-low global interest rates, a recovery of commodity prices, and a public investment boost—all of which gradually weakened. See IMF (2015a and 2015c).

Figure 1. Trend Output and Post-Global Financial Crisis Total Factor Productivity Losses

(Per capita)



Sources: Penn World Table 9.0; IMF, *World Economic Outlook*; and IMF staff calculations.

Note: GFC = global financial crisis, TFP = total factor productivity. Purchasing power parity GDP weighted average of largest 20 economies per income group is reported. Trend output refers to a projection based on the Hodrick–Prescott filter trend in the years preceding the GFC.

8. **Secular forces**. Consistent with previous findings for the United States—such as in Fernald (2014) and Furceri Celik, and Schnucker (2016)—measured TFP growth points to an incipient productivity slowdown in advanced economies before the global financial crisis (Figure 2). This fact has elicited discussion about possible mismeasurement issues, especially related to the increasing importance of ICT-related services and products, as they may not be properly accounted for in national accounts statistics. This remains a lively debate, but the evidence so far indicates that, while mismeasurement exists—including because TFP is measured as a residual after all—it is unclear whether it has worsened. It is therefore unlikely to account for the magnitude of the observed slowdown in TFP growth, especially its abrupt drop after the financial crisis (Box 1).[5] Similarly, while cyclical factors that cannot be fully adjusted for may affect measured TFP—such as capacity utilization and labor hoarding—different adjustment approaches all point to a slowdown (Figure 3).[6] Yet, the observed pattern of the slowdown in emerging market economies is quite different from advanced economies, with TFP growth in the former peaking in the years immediately preceding the global financial crisis, followed by sharp deceleration afterwards, albeit at pace still faster

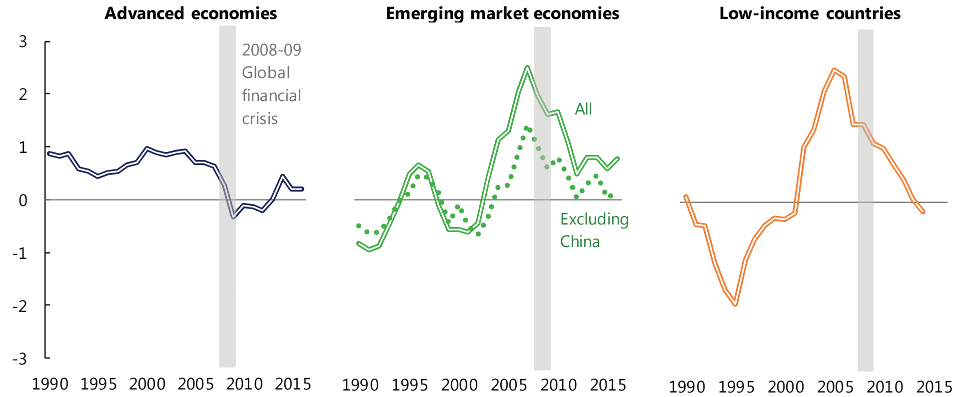
[5] See also Byrne, Fernald and Reinsdorf (2016) and Syverson (2016).

[6] See further discussion of TFP measurement issues in Feenstra Inklaar, and Timmer (2015) and O'Mahony and Timmer (2009).

than in previous decades. In the low-income countries, after picking up during the late 1990s and early 2000s, TFP growth has also fallen sharply since the global financial crisis. That said, these patterns in the emerging market economies and, especially, the low-income countries should be interpreted with caution given data limitations and greater difficulty in properly adjusting for cyclical factors.

Figure 2. Total Factor Productivity Growth, 1990–2016

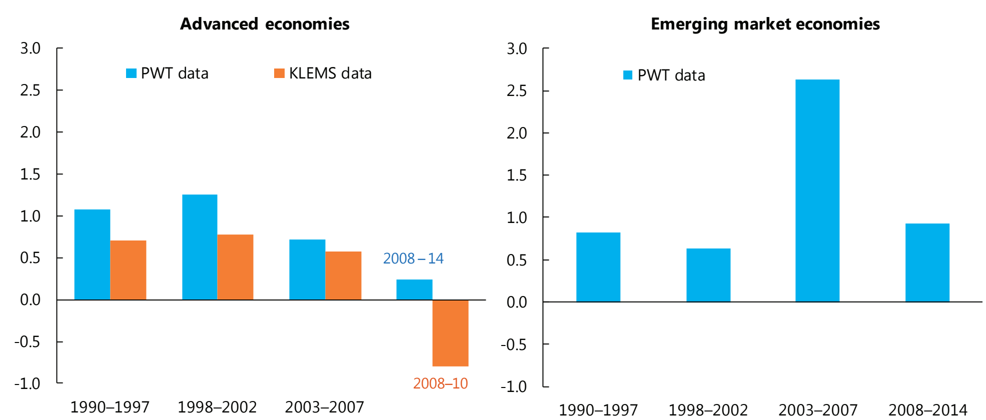
(5-year average growth rate, percent)



Sources: Penn World Table 9.0; IMF, *World Economic Outlook*; and IMF staff calculations.
Note: Group averages are weighted using purchasing power parity GDP.

Figure 3. Cyclically Adjusted Total Factor Productivity Growth, 1990–2014

(Annual average, percent)



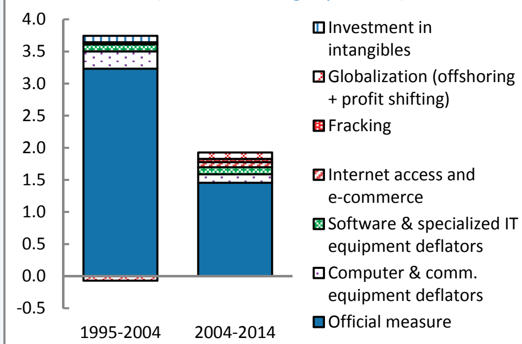
Sources: Penn World Table 9.0; EU KLEMS and WORLD KLEMS data; Furceri, Çelik, and Schnucker (2016); and IMF staff calculations.
Note: Purchasing power parity GDP weighted average by group, based on IMF, *World Economic Outlook* country classification. Cyclically adjusted measure based on Basu, Fernald, and Kimball (2006). Average hours worked used as a proxy for capacity utilization. Post-global financial crisis data on total factor productivity from KLEMS is available only for 2008–10.

Box 1. Can Mismeasurement of the Digital Economy Explain the U.S. Productivity Slowdown?[1]

Productivity growth has slowed sharply in most advanced economies. Because the pace of innovation in the hard-to-measure digital economy seems as rapid as ever, measurement error has been put forward as an explanation. The presence of effects causing underestimation of GDP growth is not in doubt, but a stable measurement error in the GDP growth rate would not cause productivity growth to slow. The question, therefore, is whether measurement error got larger around the time the estimated rate of productivity growth slowed.

Byrne, Fernald, and Reinsdorf (2016) find that the measurement error in the deflators for computers and communication equipment is, indeed, larger after the information and communications technology (ICT) boom period (2004–14) than in the boom years (1995–2004). However, the weight on those deflators in U.S. GDP growth calculations is smaller because production of ICT equipment moved offshore. Including the measurement error in the software deflator implied by Byrne and Corrado (2016), adjustment for measurement errors in ICT equipment and software prices adds 24 basis points to average annual labor productivity growth in the United States over 2004–14, compared to 38 basis points in the ICT boom years (Figure 1.1).

Figure 1.1. U.S. Productivity Growth: Official and Adjusted Measures
(Annual average, percent)



Sources: Byrne, Fernald, and Reinsdorf (2016); IMF staff calculations.

Other forms of mismeasurement affect the estimation of productivity growth. As Figure 1.1 shows, Byrne, Fernald, and Reinsdorf (2016) estimate upward adjustments to U.S. labor productivity growth that are larger in 2004–14 for improvements in internet access and outlet substitution bias from e-commerce, as well as for new fracking technology. Also, in 1995–2004, they estimate an upward adjustment for unmeasured investment in intangible assets and a downward adjustment for unmeasured declines in input prices from offshoring to China and other emerging market economies, as documented in Houseman, Kurz, Lengermann and Mandel (2011) and Reinsdorf and Yuskavage (2016). Together, these bring the total adjustment to labor productivity growth in the post-ICT boom to 37 basis points, compared with 41 basis points during the ICT boom years. In other words, measurement error stemming from these various factors does not appear to have increased.

Byrne, Fernald, and Reinsdorf 2016 also find no increase in the measurement error for total factor productivity when its growth rate slowed.

Another likely source of underestimation of U.S. output that appears to be larger in the post-ICT boom period is the reporting of income in low-tax jurisdictions that really comes from U.S. activity. Multinational enterprises use techniques such as re-domiciling intellectual property assets to shift the location where income is reported and lower their tax bill. Rassier (2014) finds that profit shifting could have caused underestimation of nominal U.S. GDP levels of 0.9 percent in 2005–09. If the annual growth of the underestimation is an order of magnitude smaller than its level, the productivity growth rate effect is around 10 basis points per year during 2004–14, with a smaller effect in earlier years. In addition, increasing the weights on the deflators for ICT equipment to include the production wrongly attributed to other economies might add a few basis points to the adjustment to U.S. productivity growth in 2004–14.

Internet platforms and smartphone apps have also been suggested as sources of measurement error. One concern is the exclusion from GDP of the value to consumers of the free information, social networking, and entertainment that is funded by revenue from advertising and selling information about the users. Putting consumption of free products in GDP would, however, be inconsistent with the conceptual framework that underlies the measurement of productivity, because, in that framework, prices provide the correct measure of value. Furthermore, Nakamura, Samuels and Soloveichik (2016) find that alternative approaches to consumption of advertising-funded products have virtually no effect on U.S. productivity growth.

The introduction of peer-to-peer services intermediated by internet platforms (such as Uber and Airbnb) raises a different set of issues. These services appear to be fully captured in GDP levels (which are in nominal terms), but not in GDP growth rates. Incorporating a new product in the relevant deflator in a way that reflects its relative price level is difficult because of the need to adjust for quality differences (Ahmad and Schreyer, 2016). Commonly used procedures for bringing a new product into a deflator implicitly assume that the quality-adjusted prices of the new product and the product that it competes with are the same. But if the new peer-to-peer services have lowered the quality-adjusted prices, as suggested by their popularity, their contribution to growth is underestimated by the standard methods.

Box 1. Can Mismeasurement of the Digital Economy Explain the U.S. Productivity Slowdown? (Concluded)

Nonetheless, new kinds of peer-to-peer services remain a very small part of U.S. output, so improving the deflators to better capture the price declines would not have much of an effect on productivity.

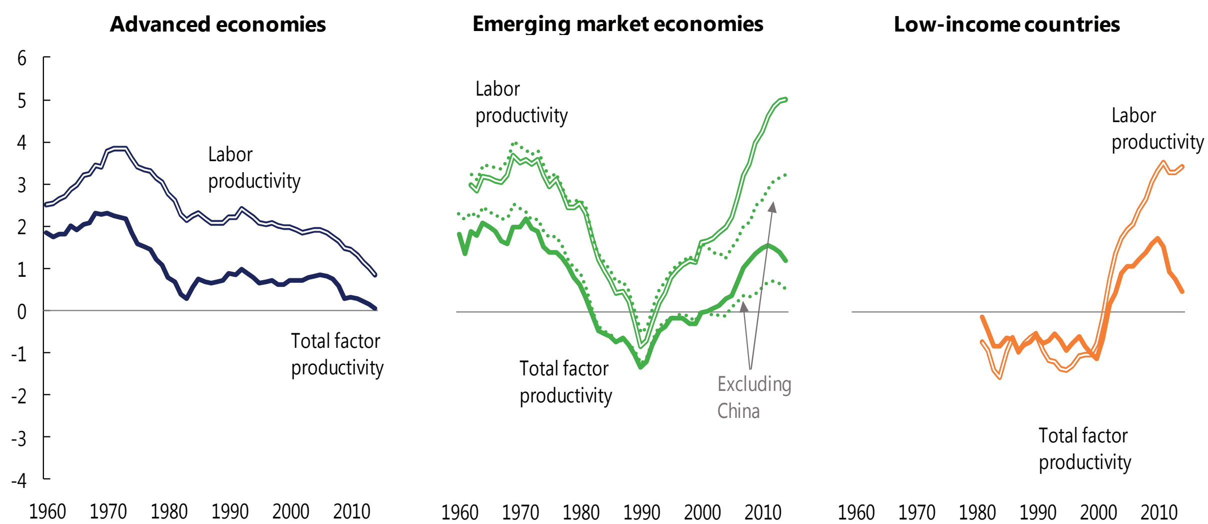
Overall, while there is no doubt that measurement error is an issue, to be the main factor behind the observed productivity slowdown, measurement error must have become much larger over time. Adding all the possible adjustments discussed above, the change in measurement error accounts for less than one- tenth of the slowdown in the United States productivity growth rate. Measurement issues go beyond the digital economy; for example, they affect the area of health care, where quality improvements are difficult to capture in full and the weight in GDP has grown. However, growing mismeasurement in these other areas is unlikely to account for a significant share of the productivity slowdown.

[1] Prepared by Marshall Reinsdorf.

9. A long-term perspective. The recent TFP slowdown in advanced economies does not just mark a return to low but steady growth rates after some ICT-related uptick during the late 1990s and early 2000s. Average TFP growth has been nearly zero over the last 10 years, below any similar period in the last 6 decades (Figure 4). Slower capital accumulation has added to slowing TFP growth, leading to a greater deceleration in labor productivity. While far less dramatic than in the 1970s, the productivity slowdown of the 2000s has been substantial. For emerging market economies and low-income countries, labor productivity grew rapidly—in historical terms—during the 2000s, but driven primarily by rapid capital accumulation including in the post-crisis period, likely reflecting an environment of historically low borrowing costs. TFP growth, while slowing, has remained above the average of the previous two decades—although, in emerging market economies, not above the rates of the 1960s and 1970s.

Figure 4. A Long-Term View of Total Factor Productivity Growth, 1950–2014

(10–year growth rate)

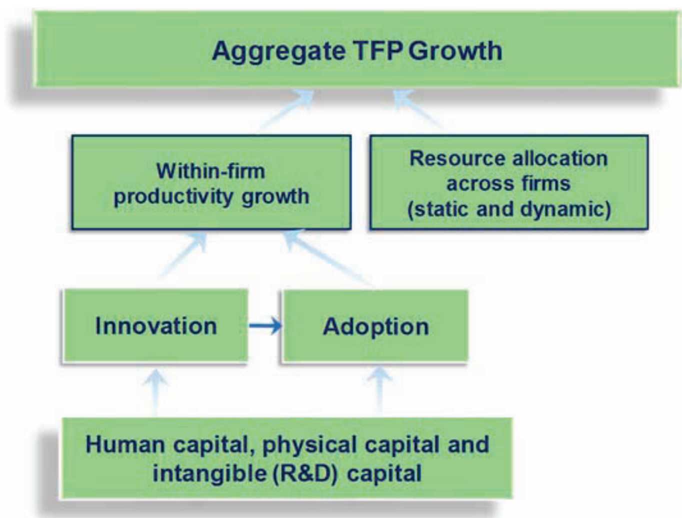


Sources: Penn World Table 9.0; IMF, *World Economic Outlook*; and IMF staff calculations.
Note: Purchasing power parity GDP weighted average of largest 20 economies per income group is reported.

DRIVING FORCES

10. **Aggregate TFP growth reflects improvements in both productive efficiency within firms and allocative efficiency between them**. Figure 5 presents a simple illustration of the mechanisms that drive TFP growth. Within-firm TFP growth originates from innovation by leading firms, and adoption of better, more efficient existing technologies and management practices by lagging firms (productive efficiency within firms). In turn, innovation and adoption generally require investments in tangible (physical) and intangible (research and development [R&D], human) capital. Improvements in aggregate TFP growth can also result from reallocation of capital and labor toward firms that use these resources most productively at the margin (allocative efficiency). This is achieved when resources move away from less productive to more productive businesses, and through the entry and exit of firms.

Figure 5. Mechanisms of Aggregate Total Factor Productivity Growth



Source: IMF staff compilation.
Note: R&D = research and development, TFP = total factor productivity.

11. **The slowing of global productivity growth caused by the global financial crisis and secular forces has occurred through the following mechanisms:**

- **Legacies of the global financial crisis**. As in previous deep recessions and financial crises, financial market dislocation, policy uncertainty, and weak investment in the aftermath of the global financial crisis had visible implications for productivity growth, affecting within-firm productivity gains (through slower capital-embodied innovation and intangible investment) as well as resource allocation across firms.

- **Secular drivers**. The fading effects of the ICT revolution, population aging, and other demographics forces, as well as slowing global trade—some of which were in part already visible in the run-up to the global financial crisis—have exerted continuous downward pressure on global TFP. In emerging and

developing economies, the waning effects of earlier structural reforms and structural transformation have also been playing a role.[7]

These forces have affected TFP growth by weakening technological adoption or innovation by existing firms or by hampering the optimal allocation of resources between them. In some cases, the analysis in the note identifies which of these channel(s) have been at play—for example, when studying the role of weak balance sheets and credit constraints. In other cases, the note only provides evidence of the direct TFP growth impact of the driver of interest without investigating the precise transmission mechanism—for example, when analyzing the effect of ageing. The contributions of the legacies of the global financial crisis and the secular forces mentioned above are discussed next.

A. Legacies of the Global Financial Crisis

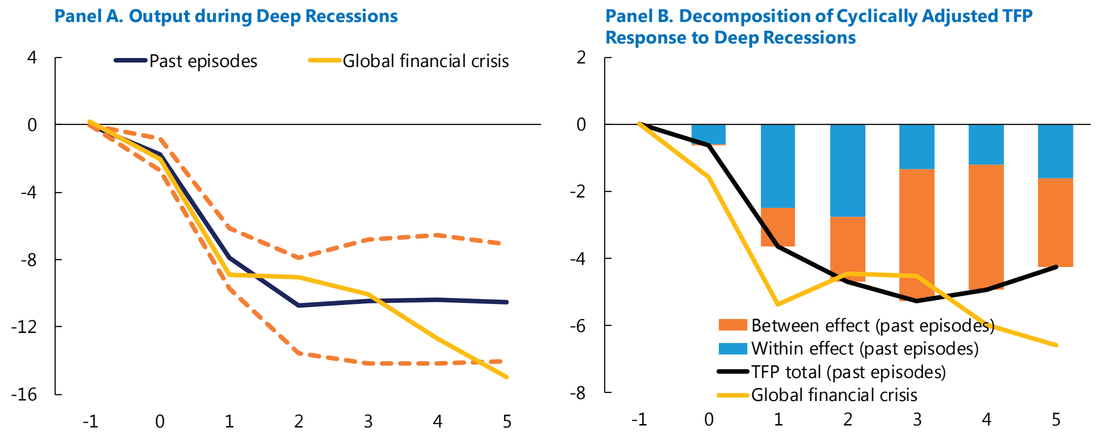
12. Lasting effects of deep recessions. Unlike normal growth slowdowns, deep recessions—often, albeit not always, associated with financial crises—have been shown to entail large and persistent output losses (Cerra and Saxena 2008; and Blanchard, Cerutti, and Summers 2015). New empirical analysis of past episodes of deep recessions in advanced economies—which, on average, displayed initial contractions comparable to those observed during the global financial crisis—shows that such output losses reflect not just persistent declines in employment—so-called employment hysteresis—or investment, but also significant and protracted losses in TFP (Figure 6, and Appendix I). This effect holds even when adjusting for factor utilization. Moreover, a sectoral decomposition indicates that these aggregate TFP losses are the result of both within-firm productivity losses and resource reallocation across industries (that is, disproportionately larger contractions of high-productivity sectors).[8] The negative reallocation (between) effect is small for regular recessions (see Appendix I), and initially during deep recessions. But in the latter case, the between component tends to increase over time, possibly reflecting greater market dislocation. Consistent with this evidence, and despite the deployment of extraordinary fiscal and monetary stimuli by major advanced economies, the global financial crisis displayed a fairly similar pattern in its aftermath, with both within and between effects driving down aggregate TFP. These crisis-related TFP losses appear to reflect a number of factors, including the effect of the tightening credit conditions for corporates with vulnerable balance sheets, weak investment, increased resource misallocation across sectors, and, more broadly, the effect of heightened economic and policy uncertainty. These are discussed in detail next.

[7] Earlier IMF work highlighted the fading role of structural transformation in advanced economies, reflecting secular reallocation of resources towards slow-growing services sectors (Dabla-Norris and others 2015). This mechanism is not studied in this note.

[8] While within-sector reallocation and firm-level innovation generally explain the bulk of aggregate productivity gains (Denis and others 2014; Dabla-Norris and others 2013a), the new analysis presented here suggests that cross-sectoral reallocation may play an important role during deep recessions. The latter are associated with a disproportionate contraction of manufacturing, wholesale and retail trade, and transportation sectors, in favor of service sectors (such as public administration, defense, education, health and social work, entertainment, recreation, and so on).

Figure 6. Lasting Effects of Deep Recessions on Total Factor Productivity

(Percent)



Sources: Penn World Table 9.0; EU KLEMS and WORLD KLEMS data; Blanchard, Cerutti, and Summers (2015); and IMF staff calculations.
Note: Years after the shock on the x-axis, t = 0 is the year of the shock. TFP = total factor productivity. The effect of past episodes is estimated using local projections method (Jordà 2005), controlling for past growth, lagged recessions and country-specific trends, and including a bias correction suggested by Teulings and Zubanov (2014). For the global financial crisis, output and unadjusted total factor productivity average deviation from precrisis trends are reported. Dashed lines denote 90-percent confidence bands. The TFP decomposition is based on McMillan and Rodrik (2011). *Within* effect refers to the contribution of sectoral productivity growth to aggregate productivity growth. *Between* effect refers to contribution of inter-sectoral reallocation of resources. See further details in Appendix I.

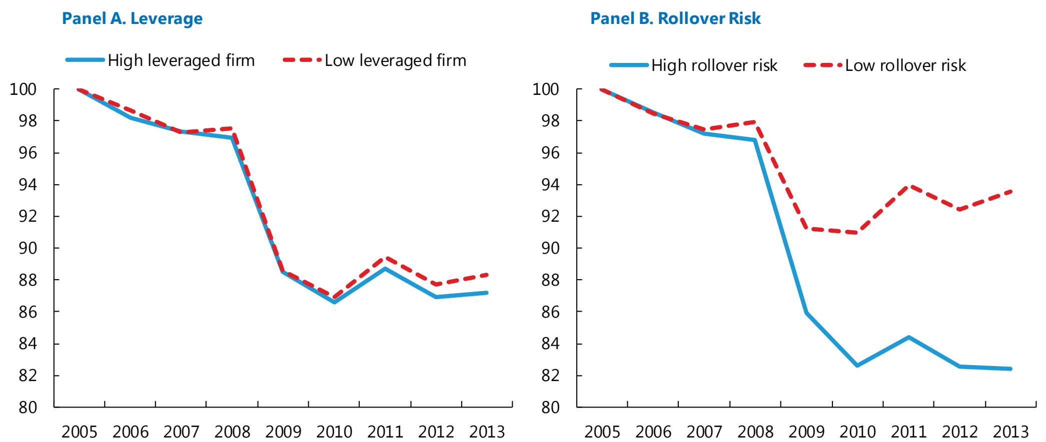
13. Tight credit conditions and corporate balance sheet vulnerability. Credit conditions tightened sharply after the collapse of Lehman Brothers in September 2008 and, despite the extraordinary monetary stimulus that followed, access to credit remained durably restricted for many small and medium-size enterprises, particularly in countries most affected by the euro area crisis. This partly reflected the persistence of asset legacy issues and capita shortfalls in the banking sector. Empirical analysis based on a large panel of advanced economies firms (Appendix II) indicates TFP growth fell more in companies with weaker balance sheets prior to the global financial crisis than their counterparts with stronger balance sheets (Figure 7).[9,10] Two distinct sources of firm vulnerability appear to have played a role, namely leverage (debt overhang) and, even more so, debt rollover risk (short-term financing). Neither of these is found to have affected TFP after the (milder) recession of the early 2000s, suggesting that the global financial crisis was different. Furthermore, since TFP gains for these two groups of firms were similar, on average, during the precrisis (2002–07) period, the post-crisis sub-par performance of more vulnerable firms was most likely a driver for the aggregate productivity slowdown—rather than reflecting a "cleansing" effect of less productive firms.

[9] Likewise, firms whose profits were lower relative to their interest payments experienced a sharper slowing of productivity See Duval, Hong and Timmer (forthcoming) for details.

[10] High- and low-leverage levels are defined as those corresponding to the 75th and 25th percentiles of the distribution of firm leverage across all countries and firms over the sample period.

Figure 7. Total Factor Productivity Level Path for Firms with Different Precrisis Balance Sheet Vulnerabilities

(Index, 2005 = 100)



Source: Duval, Hong, and Timmer (forthcoming).
Note: TFP = total factor productivity. High/low leverage and high/low rollover risk correspond to the 75th and 25th percentiles of the cross-country cross-firm distribution of leverage and rollover risk in the sample. Rollover risk is measured as debt maturing within a year in 2007, as a percent of total sales. Leverage is measured as total debt to total assets. For details, see Appendix II and Duval, Hong, and Timmer (forthcoming).

14. Credit conditions and investment in intangible assets. One key feature that sets the global financial crisis apart from past recessions was the sharp tightening of credit conditions, despite extraordinarily loose monetary policy, after the Lehman Brothers failure, and later during the euro area crisis. The evidence indicates that the interaction of vulnerable balance sheets and tightening credit conditions has a visible impact on TFP. Indeed, the effect discussed above—firms with weaker balance sheets experiencing a larger post-global financial crisis TFP slowdown—was particularly acute in countries whose banking sectors were more affected by the global financial turbulence. On average across countries, the post-crisis decline in advanced economies' annual TFP growth was about 1.01 percentage points greater for high-leverage than for low-leverage firms, while the gap was over 1.31 percentage point in countries where bank credit default swap spreads rose more sharply (Figure 8, Panel A). One channel through which the global financial crisis may have persistently weakened TFP growth is lower investment in intangible capital, such as R&D, in vulnerable firms. Aghion and others (2012) show that when firms face credit constraints after severe downturns, R&D expenditure becomes pro-cyclical, impairing future productivity growth. The post-global financial crisis evidence analyzed here is consistent with this finding.[11] Firms with weaker balance sheets are found to have reduced their investment rate in intangible assets—measured as a share of total value added—by 0.5 percentage points more than their less vulnerable counterparts (Figure 8, Panel B). This difference increases to 0.81 percentage points in countries where credit conditions tightened more. Compared with high leverage, high *ex-ante* rollover risk seems to have led to even greater declines in TFP growth; the sudden liquidity squeeze and the associated difficulty in

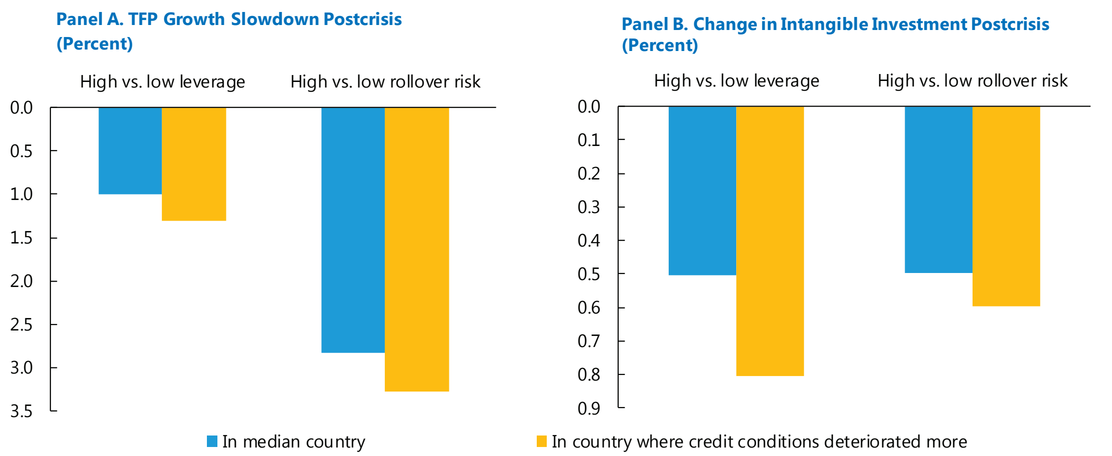
[11] See also recent related work by Garcia-Macia (2015) and de Ridder (2016).

(continued)

financing working capital may have forced distressed firms into asset fire sales, layoffs and cuts in intangible investment, with persistent adverse effects on productivity.[12]

Figure 8. Estimated Impact of Balance Sheet Vulnerabilities and Credit Conditions on Postcrisis Total Factor Productivity Growth and Intangible Investment

(Difference between 2002–07 and 2008–13 average TFP growth rates, percent)



Source: Duval, Hong, and Timmer (forthcoming).
Note: TFP = total factor productivity. High/low leverage and high/low rollover risk correspond to the 75th and 25th percentiles of the cross-country cross-firm distribution of leverage and rollover risk in the sample. The illustrative country where credit conditions deteriorated more corresponds to 75th percentile of the cross-country distribution of changes in average bank credit default swap spreads between the first and the second halves of 2008. Estimates are obtained from firm-level regressions of the change in average TFP growth between pre and postcrisis periods on firm-level leverage and rollover risk as well as their interactions with the country-level change in credit conditions—as measured by the average bank credit default swap spreads between the first and the second halves of 2008—controlling for various firm characteristics and country-sector fixed effects. For details, see Appendix II and Duval, Hong, and Timmer (forthcoming).

15. Misallocation of capital across firms. The financial crisis, and the credit boom that preceded, it may have not only undermined TFP growth within firms, but also the efficiency of capital allocation across firms, further weakening aggregate productivity growth. Misallocation of capital and labor can be measured as the dispersion of their marginal revenue product across firms within each sector in each advanced country, following the framework proposed by Hsieh and Klenow (2009). On average across business sectors in advanced economies, measured capital misallocation seems to have increased both before and after the global financial crisis (Figure 9). This, along with stable labor misallocation, point to a greater increase in frictions in capital than in labor markets.[13] Growing misallocation during the pre-global-financial-crisis financial boom is consistent with results for the Spanish manufacturing sector in Gopinath and others (2015), who link the increased misallocation of capital in Southern Europe to the sharp rise in poorly intermediated capital inflows following the inception of the euro (see also Reis 2013; Borio and others 2016; and Dias, Marques, and Richmond 2016). The global financial crisis might have worsened capital allocation further by impeding the growth of financially constrained firms relative to their less constrained counterparts. Indeed, the divergence in TFP paths between both types of firms shown in Figure 7 was accompanied by a growing gap in their marginal revenue product of capital, as factors of production were adjusted and reallocated across firms only slowly. Possibly slowing this reallocation further has been

[12] Distressed firms may also have exited altogether. Due to the rather poor quality of exit data that can be derived from Orbis, the analysis focuses only on surviving firms.

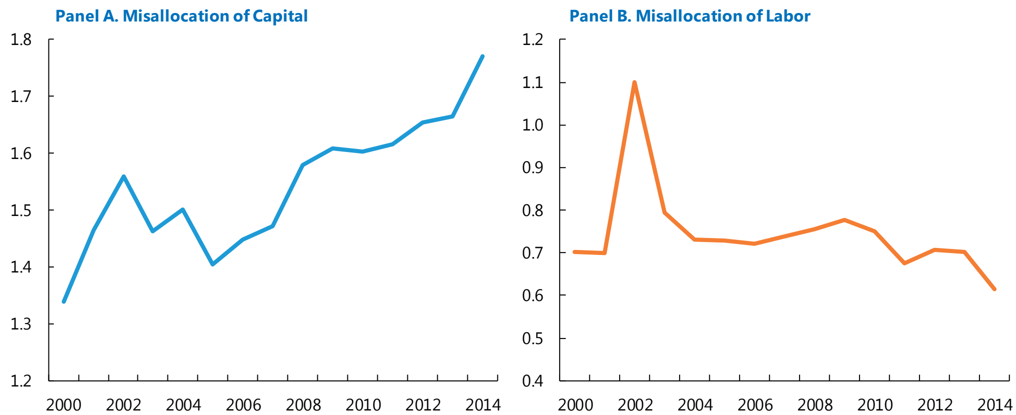
[13] Consistent with the findings in Gopinath and others (2015), stable labor misallocation indicates that, conditional on the observed allocation of capital, labor was allocated as efficiently as historically.

(continued)

that banks may have "evergreened" loans to weak firms to delay loan-loss recognition and the need to raise capital—particularly in continental Europe where progress toward addressing banking sector problems has been slower than in some other advanced economies such as the United States. Together, these forces may have fostered the emergence of some "zombie firms" and thereby further increased misallocation of capital.[14]

Figure 9. Rising Capital Misallocation in Advanced Economies

(Standard deviation of factor return, median across countries and industries)



Source: Duval, Hong, and Timmer (forthcoming).
Note: The calculation of marginal returns to capital and labor and their dispersion follows the approach proposed by Hsieh and Klenow (2009). For details, see Duval, Hong, and Timmer (forthcoming).

16. Feedback loop between weak investment in physical capital and productivity. Private fixed investment fell sharply in advanced economies in the aftermath of the global financial crisis—and weakened more gradually in emerging market economies and low-income countries—largely as a result of weak aggregate demand (IMF 2015a).[15] This drop is likely to have contributed to subdued labor productivity growth not only by weakening the contribution of capital deepening, but also by affecting TFP growth itself through a slower adoption of capital-embodied new technologies.[16] Indeed, new empirical estimates of this effect at the country level, based on data for 112 countries over 1970–2014 (see Appendix III) suggests that falling investment may be responsible for lowering TFP growth by nearly 0.2 percent points per year in advanced economies over the post-crisis period (Figure 10). Bleak prospects for TFP growth, in turn, appear to have fed back into weak demand and investment.[17] In emerging market economies, this effect has arguably materialized more gradually, following a less abrupt weakening in the pace of capital

[14] Adalet McGowan and others (2017) indeed document a rise in zombie firms in the post-global-financial-crisis period and find an adverse effect on the growth of healthy firms. The implied impact on TFP is not found to be large, however. Assuming all weak firms to be zombies, and reducing their share to the minimum level observed in each industry, would yield a one-off TFP level gain of about 0.6 percent on average across a sample of (mostly European) advanced economies.

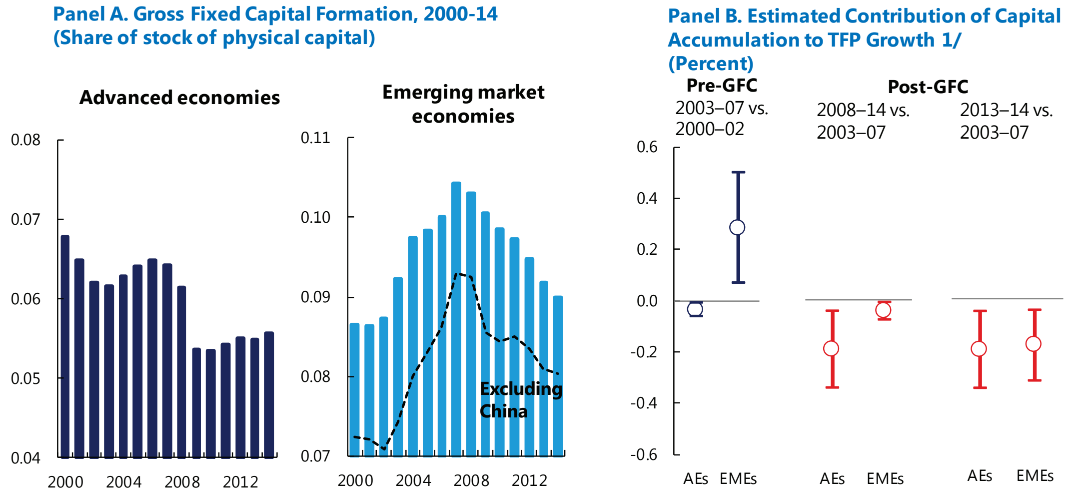
[15] Re-running the analysis underpinning Panel B of Figure 8 for investment in physical capital rather than in intangible assets also points to some—albeit only weakly significant statistically—role of the interplay of tighter credit conditions and weak corporate balance sheets in the investment slowdown.

[16] New capital equipment enables some innovations to find their way into actual production (Solow 1959). For example, in the late 1990s and early 2000s technological change such as internet use was "embodied" in new and increasingly powerful computers. New investment may also facilitate TFP-enhancing organizational innovations—for instance, just-in-time manufacturing and supply chain management emerged during the 1980s–1990s thanks to new information technology equipment and software. See further discussions in Wolff (1991) and Greenwood, Hercowitz, and Krusell (1997).

[17] See Blanchard, Lorenzoni, and L'Huillier (2017).

accumulation. For commodity exporting emerging and developing economies, the large fluctuations in commodity prices have also been a key factor in the fall in investment (Box 2) (See IMF (2015a and 2015c).

Figure 10. Investment and Its Impact on Capital-Embodied Technological Innovation



Sources: Penn World Table 9.0; IMF, *World Economic Outlook*; and IMF staff estimates.
Note: AEs = advanced economies, EMEs = emerging market economies, TFP = total factor productivity, and GFC = global financial crisis. Purchasing power parity GDP weighted average of largest 20 economies in each income group is reported.
1/ Estimated contribution of capital accumulation to the change in TFP growth between stated periods. 90-percent confidence bands are reported. See details in Appendix III.

Box 2. Productivity Growth in Commodity-Exporting Countries*

Since the global financial crisis, productivity growth in emerging market economies, and especially commodity-exporting ones, has slowed sharply. Can some of this be attributed to the post-crisis drop in commodity prices, or are there other factors at play? Economic theory suggests the process of productivity growth in commodity extracting sectors may be distinctly different from other sectors, with structural and cyclical factors playing a role.

Structural drivers. Higher quality commodity deposits are generally the first to be developed, with subsequent development targeting lower quality deposits—this is particularly true in the mining sector. Over time, commodities become harder to extract, and are of lower grade, so the inputs required to extract the same amount of output (volume) increases, resulting in weaker total factor productivity (TFP) (Aguirregabiria and Luengo 2015; Parham 2012). This sector-specific phenomenon would tend to exert downward pressure on aggregate TFP growth in commodity-producing countries.

Cyclical shifts. High commodity prices may affect TFP in conflicting ways. Elevated prices can induce increased capital investment to extract more of the commodity (or more rapidly) to take advantage of high prices. This process takes time to complete, implying that capital is not fully utilized during the initial investment phase, thereby driving down (measured) productivity growth (Parham 2012). Higher commodity prices can also induce capital investment in new, less productive mines, as they become profitable with higher prices, also pushing down TFP. At the same time, higher income associated with rising commodity prices may help relax budget and credit constraints, facilitating investment in technology and human capital, potentially boosting TFP growth in the medium term. Finally, for oil exporters, production can be driven by "non-technical" factors, such as production quotas—such an output change would be attributed to a shift in measured productivity in these countries.

Empirical evidence is consistent with a secular decline in mining-sector TFP growth—a sectoral breakdown for 11 advanced economies indicates that TFP growth in mining has been about half the rate of other industries during 1990–2007 (Figure 2.1). In addition, Blagrave and Santoro (2016) show that mining sector TFP growth has been persistently negative in Chile over the past decade or more.

Looking at the evidence on cyclical forces in Chile's mining sector, Blagrave and Santoro (2016) find suggestive evidence that during the recent copper-price boom, capital accumulation in the mining sector picked up during 2005–12, with limited changes in mining output, resulting in falling TFP growth. Taking a broader look at the economy, Aslam and others (2016) provide evidence that TFP growth in commodity-exporting countries tends to co-move positively with commodity prices. This is also visible when comparing pre- and post-global-financial-crisis TFP growth between commodity-exporting and other economies—especially across emerging market economies (Figure 2.2). Overall, the evidence suggests that the dynamics of commodity prices in recent years may have been a driving force of the recent TFP slowdown.

Figure 2.1. Average TFP Growth by Sector, 1990-2007 1/
(Annual average, percent)

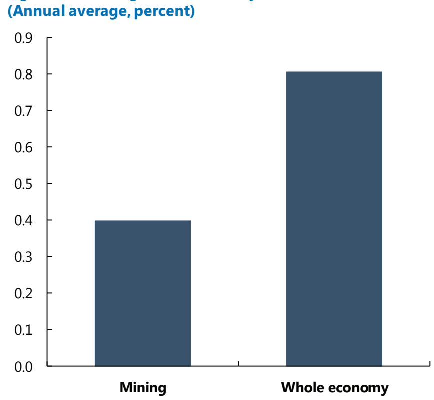
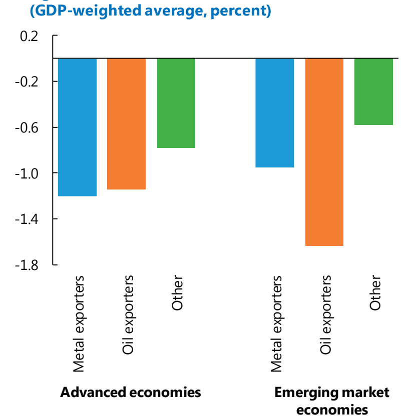


Figure 2.2. Pre- to Post-GFC TFP Slowdown 2/
(GDP-weighted average, percent)



Sources: EU KLEMS and WORLD KLEMS data; Penn World Table 9.0; IMF, *World Economic Outlook*; and IMF staff calculations.
1/ Average for a sample of 11 advanced economies (for which sectoral total factor productivity data is available)
2/ 2008–15 versus 1990–2007 average aggregate total factor productivity growth.

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* Prepared by Patrick Blagrave.

17. Protracted uncertainty. Elevated economic and policy uncertainty in the post-global-financial-crisis environment, more generally, appears to have played a significant role in driving down investment and productivity. While conventional measures of market uncertainty, such as stock market volatility, largely returned to precrisis levels after a temporary spike during the global financial crisis, indicators of policy-

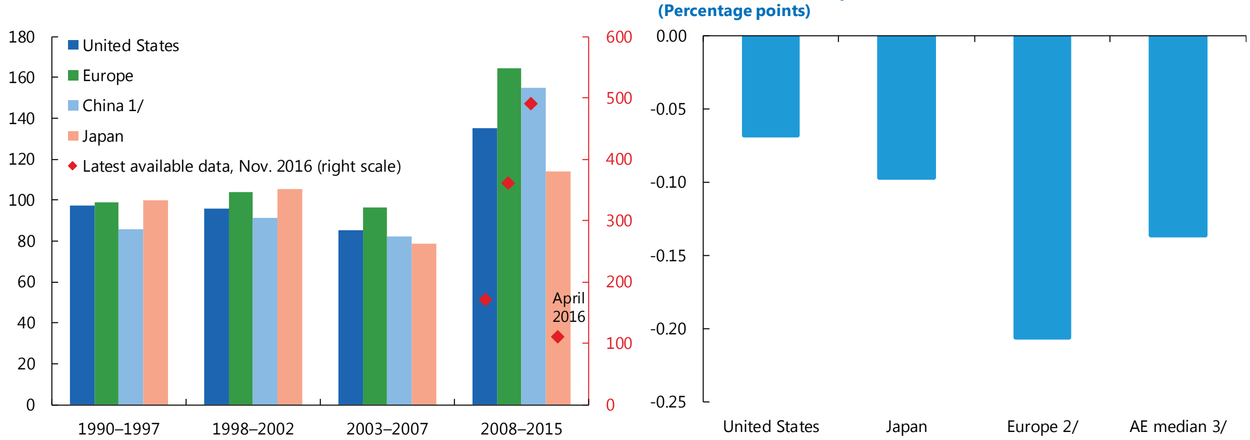
related economic uncertainty (Baker, Bloom, and Davis 2016) have remained high in key systemic economies—such as the euro area or Japan, and more recently the United States (Figure 11). Higher uncertainty induces firms to "wait and see", slowing the expansion of more productive firms at the expense of less productive ones, and leading firms to cut investment and shift its composition toward shorter-term, lower-risk/lower-return projects (Bloom and others 2014).

18. New IMF work (Choi and others 2016) for a panel of 25 industries and 18 countries over 1985–2010 finds that the adverse productivity impact of higher economic and policy uncertainty has been significantly larger in industries that face tighter credit constraints, due to their greater dependence on external finance for capital expenditure.[18] Further empirical analysis based on Choi and others (2016) points to a change in the investment mix as a possible channel through which higher uncertainty may have affected productivity. Indeed, higher uncertainty is found to lower the *share* of ICT in total capital in industries that depend more on external finance.[19] Under conservative assumptions (such as that only financially-dependent industries have been affected by the rise in policy-related uncertainty), these estimates imply a contribution of increased policy uncertainty to the TFP slowdown between the precrisis and 2012–14 periods of about 0.2 percent per year on average for Europe, 0.1 for Japan, and 0.07 for the United States.[20]

Figure 11. Policy-Related Economic Uncertainty and Estimated Impact on Total Factor Productivity Growth

Panel A. Economic Policy Uncertainty
(Index, red dots on right scale)

Panel B. Implied Effect of Policy Uncertainty on Annual Average Total Factor Productivity Growth, 2008-16/2000-07 1/
(Percentage points)



Sources: Baker, Bloom, and Davis (2016); IMF staff calculations.
Note: Index for each country/region normalized to a mean of 100 corresponding to different time periods: the United States from January 1985 through December 2009, Europe from January 1985 through December 2010, China from January 1995 through December 2011, Japan from June 1988 through December 2013.
1/ Data starts from 1995.

Sources: Baker, Bloom, and Davis (2016); EU KLEMS and WORLD KLEMS data; Organisation for Economic Co-operation and Development; and IMF staff estimations.
1/ 2016 is an average of January – November monthly data, except Japan, which is an average of January – April.
2/ Includes France, Germany, Italy, Spain, and the United Kingdom.
3/ 10 advanced economies included in the sample: Canada, France, Germany, Italy, Japan, Korea, the Netherlands, Spain, the United Kingdom, and the United States.

B. Long-Term Forces

Crisis legacies have dragged on productivity growth since the late 2000s. But this has occurred on the back of a secular slowdown already in train before the crisis—especially in advanced economies—driven in part

[18] Macroeconomic shocks such as higher uncertainty induce credit-constrained firms to prioritize investment projects that contribute to output and liquidity quickly but may not deliver the highest returns (Aghion and others 2010, Aghion, Hemous, and Kharroubi 2014).

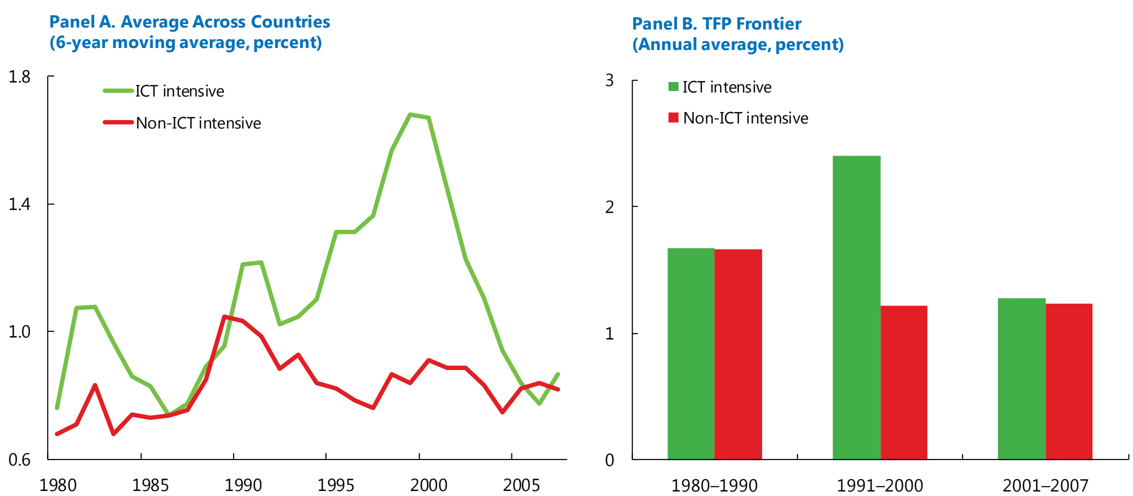
[19] This analysis is not reported in the technical appendix, but is available upon request.

[20] See also Arbatli and others (forthcoming) for an exploration of the effect of uncertainty on investment in Japan.

by the waning of the ICT revolution and slower innovation, population aging, and slowing global trade. In emerging and developing economies, the fading effects of earlier structural reforms and structural transformation may have also played a role. These forces are discussed next.

19. **Waning gains from ICT and the slowing pace of innovation at the technological frontier**. A fading ICT-related boom and slowing TFP growth at the technological frontier had been a significant driving force of the TFP slowdown in advanced economies even before the global financial crisis. Indeed, after a temporary boom associated with the ICT revolution in the late 1990s-early 2000s, TFP in ICT-intensive sectors slowed significantly starting in the early 2000s (Figure 12, Panel A). This process was also visible at the ICT frontier (Figure 12, Panel B). Meanwhile, while still a subject of much debate,[21] the pace of innovation at the frontier in other sectors may have slowed earlier, and remained more stable (although significantly lower than ICT) more recently. This is consistent with the aggregate pattern of frontier slowdown found in Dabla-Norris and others (2015). For the United States, which remains the technological leader in several industries, including ICT, the ICT slowdown partly reflects the well-documented loss of business dynamism, which also extends to other sectors, since the early 2000s (Cardarelli and Lusinyan 2015; Decker and others 2016; Haltiwanger, Hathaway and Miranda 2014).

Figure 12. Total Factor Productivity Growth in ICT- and Non-ICT-Intensive Sectors in Advanced Economies



Sources: Furceri, Çelik, and Schnucker (2016); Dabla-Norris and others (2015); EU KLEMS and WORLD KLEMS data; and IMF staff estimations.
Note: ICT = information and communications technologies, TFP = total factor productivity. Top and bottom 5th percentiles of the distribution across country-industries are excluded as outlier treatment for Panel A. Total factor productivity frontier in Panel B is defined as the average of the three highest total factor productivity levels across countries, for each industry and year. See further details in Appendix IV.

20. **Adverse productivity spillovers from a slowing frontier.** While the true extent, causes, and future persistence of slower innovation remain the subject of intense research,[22] the TFP slowdown at the

[21] See Andrews, Criscuolo, and Gal (2015), and Decker and others (2016).

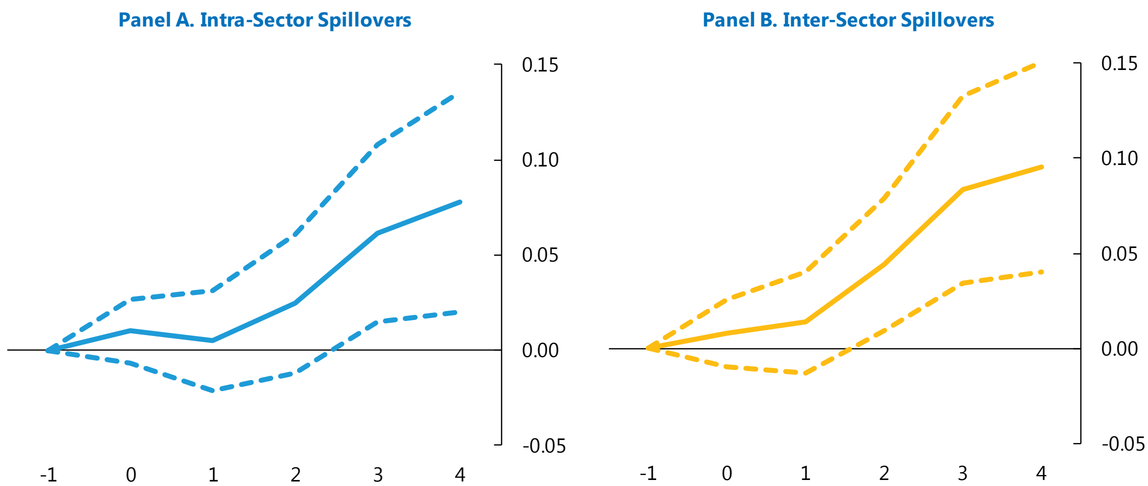
[22] Leaving aside the possible measurement issues discussed in Box 1, a few recent papers using firm-level data suggest that TFP growth may actually have remained steady within global frontier firms, with slowing TFP at the sector level reflecting primarily weaker diffusion to lagging firms—including within countries that host global frontier firms in a particular sector (see in particular Andrews, Criscuolo, and Gal 2015). Some argue that the slowdown in innovation is likely to be permanent (Gordon 2016) while others foresee a productivity revival connected to advances in artificial intelligence (Brynjolfsson and McAfee 2014).

(continued)

frontier observed thus far has spilled over across advanced economies industries, helping to explain the global TFP slowdown. New analysis using cyclically adjusted TFP growth rates at country-industry-level for a group of 17 advanced economies over 1970–2010 (see Appendix IV) shows that spillovers from TFP shocks in the United States—and more broadly at the technological frontier—are significant, both through intra-sector (such as competition and learning in the same sector) and inter-sector (such as improvement in the quality and variety of inputs available to other sector) spillovers. A 1 percent positive TFP level shock in an average U.S. sector leads, on average, to a TFP level increase of about 0.1 percent in other economies in that same sector over the medium term (Figure 13, Panel A).[23] Such a shock leads to a further 0.1 percent average TFP increase in other industries of foreign countries through their use of imported inputs from the United States (Figure 13, Panel B). Taken together, the two effects indicate that a 1 percent drop in TFP at the technological frontier in each industry lowers TFP by about 0.2 percent on average across all advanced economies over the medium term. These magnitudes are significantly larger for countries with relatively high exposure to the frontier through trade linkages.[24]

Figure 13. Spillovers from a One Percent U.S. Total Factor Productivity Shock

(Percent)



Sources: EU KLEMS and WORLD KLEMS data; IMF staff estimations.
Note: Years after the shock on the x-axis, t = 0 is the year of the shock. Estimates based on local projections method. Dashed lines denote 90-percent confidence intervals. See details in Appendix IV.

21. Population aging. Workforce aging is another secular force that seems to have weakened productivity growth since the late 1990s in advanced economies, and more recently in emerging and developing economies (Figure 14).[25] A worker's productivity varies over her working life, for reasons such as

[23] See also previous analysis in Dabla-Norris and others (2015).

[24] In the input channel, for example, the medium-term TFP impact of a one percentage point shock to U.S. TFP rises from 0.1 (the average effect across the sample) to 0.3 in a country-sector with relatively strong links to the United States (at the 75th percentile of the distribution across all country-sectors of the intensity of input imports from the United States), and declines to 0.05 in a country-sector with low input trade with the United States (25th percentile of the distribution). It should also be noted that an average 0.2 percentage point effect of a 1 percentage point TFP shock at the frontier after five years implies that about 4 percent of the gap between the frontier and lagging countries is closed this year. This is about twice as much as the typical speed of resorption of GDP per capita gaps found in the empirical growth literature (such as Barro and Sala-i-Martin 2004).

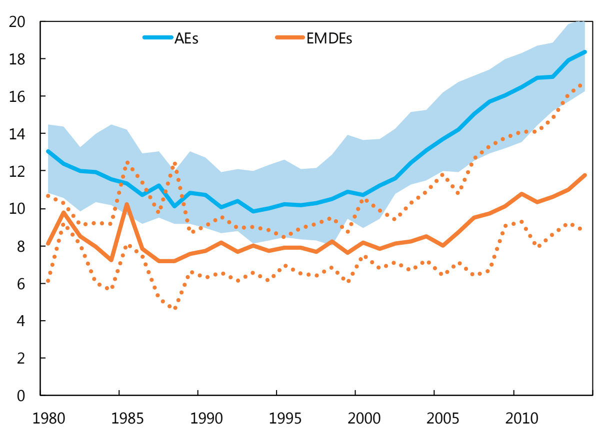
[25] While difficult to separate from aging, the overall slowing of population growth could also have an independent adverse effect on TFP, for example by lowering investment needs and slowing embodiments of technological progress (Greenwood

(continued)

the accumulation of experience over time, depreciation of knowledge, and age-related trends in physical and mental capabilities. A mature labor force will have higher average levels of work experience, with positive effects on productivity (Disney 1996). On the other hand, workforce skills also depend on the stock of knowledge acquired through formal education before entering the labor market and on the job in the early stages of individuals' careers. As such, skills are likely to peak and start declining later in the career, leading to a decline in innovation and productivity (Aksoy and others 2015; Dixon 2003; Feyrer 2008; Jones 2010; Liu and Westelius forthcoming; Maestas, Mullen, and Powell 2016).[26] Building on previous work,[27] new analysis explores the relationship between changes in the age structure of the working population and TFP growth using a new panel dataset composed of selected advanced economies and emerging and developing economies over 1985–2014 (see Appendix V). The estimates suggest that aging (that is, changes in the age structure) can indeed affect TFP growth and, all else equal, may have played a role in slowing TFP gains—perhaps by as much as 0.2–0.5 percentage point per year on average across advanced economies, and about 0.1 percentage point on average across emerging and developing economies, from the 1990s through the 2000s.

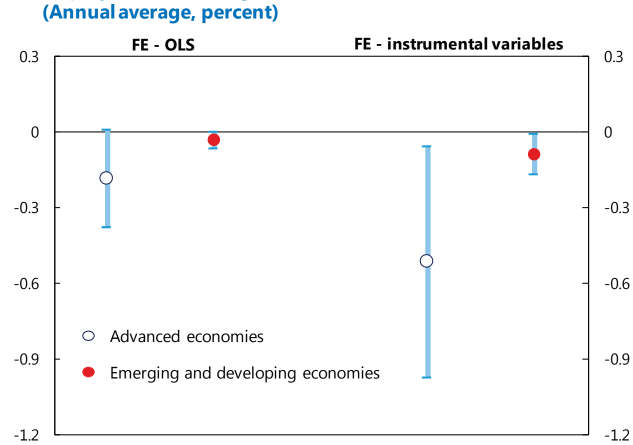
Figure 14. Population Aging and Its Impact on Total Factor Productivity
(Percent)

Panel A. Share of Old (ages 55–64) to Total Labor Force Participation
(Percent)



Sources: International Labour Organization Labour Statistics; IMF staff estimations.
Note: Medians and interquartile ranges are reported.

Panel B. Effect on TFP Growth of Change in Share of Old Employed Workers (Ages 55–64) to Total Labor Force, 2000s
(Annual average, percent)



Sources: International Labour Organization Labour Statistics; IMF staff estimations.
Note: TFP = total factor productivity, FE= fixed effects, and OLS = ordinary least squares. Vertical lines indicate the 90-percent confidence bands. Average effects for each income group are based on observed changes in the share of old employed workers, and the estimated effects on TFP growth. See details in Appendix V.

22. Global trade slowdown. Anemic global productivity growth has coincided with a global trade slowdown. International trade barely kept pace with global GDP after 2012, while it grew twice as fast in the two decades preceding the global financial crisis. While the trade slowdown is first and foremost the result

Hercowitz, and Krusell 1997). Another mechanism might be the disincentive of incurring sunk costs of innovation when markets grow more slowly.

[26] Furthermore, increased penetration of information technologies might place older workers at a disadvantage (Dixon 2003). Also, younger managers tend to lead firms towards greater innovation as they are more open to product destruction (Acemoglu, Akcigitz, and Celik 2014).

[27] See Aiyar, Ebeke and Shao (2016), Feyrer (2007), Jaimovich and Siu (2009), and Wong (2007) for previous findings on the link between aging and productivity. A recent paper by Acemoglu and Restrepo (2017) casts doubts about the theoretical and empirical impact of aging on productivity, highlighting the faster adoption of labor-saving technologies in rapidly ageing societies. See further details in Appendix V.

of weak economic activity, waning trade liberalization efforts and the maturation of global supply chains have also contributed (IMF 2016a). These supply-side forces can have strong implications for productivity growth through two broad channels: (1) *Import penetration*—greater foreign competition increases pressure on domestic firms to produce more efficiently or to innovate; and imported inputs expand the variety, and enhance the quality of intermediate goods to which firms have access (such as Romer 1994); (2) *Export penetration* can improve firm-level productivity through learning from foreign markets both directly (through buyer-seller relationships) and indirectly (through exposure to competition). These channels can operate both at the firm level— by inducing firms to adopt more efficient production processes, improve product quality, or undertake specific investments—and at the sectoral level, by inducing a reallocation of resources towards more productive firms within a sector (such as Criscuolo, Timmis, and Johnstone 2016). All else equal, slowing import and export penetration should reduce productivity growth.

23. China's integration into world trade. New analysis quantifies the impact of both the import and export channels in a panel setting of 18 advanced economies and 18 sectors spanning over one decade before the global financial crisis (see Appendix VI). The focus is on the effects of growing trade exposure to China and using instrumental variable techniques to address measurement issues and concerns of reverse causality running from growth to trade liberalization. The estimated effects on TFP in advanced economies from China's integration into world trade in the 1990s and 2000s are sizeable, although they also coincide with adverse effects on domestic employment in sectors with greater exposure to China (see Ahn and Duval forthcoming). Results imply that the trend increase in trade with China alone may have accounted for as much as 10 percent of the overall TFP increase in the median advanced economies country-sector over 1995–2007. More broadly, these findings suggest that stagnating trade intensity because of China's maturing integration into world trade will imply lower productivity gains going forward, while outright trade restrictions in advanced economies would mean reversing some of the earlier sizable gains.

24. Slowing human capital accumulation. A fourth global headwind for productivity growth has been slowing human capital accumulation. Individuals reap high returns from schooling in the form of increased productivity and wages (Mincer 1974), and returns to society may be even higher (Cohen and Soto 2007; De la Fuente and Domenech 2006). Reflecting this, the secular improvement in educational attainment in advanced economies and emerging and developing economies alike made an important contribution to aggregate labor productivity growth in past decades. However, such human capital accumulation has slowed across both country income groups during the 2000s (Barro and Lee 2013; Morrisson and Murtin 2013). An illustrative calculation based on the approach of Hall and Jones (1999) and broadly accepted estimates of social returns to education suggests that about a 0.3 percentage point per year of the slowing labor productivity in the average advanced economy and emerging market economy during the 2000s can be attributed to the falling pace of human capital accumulation (Figure 15).[28,29] Part of this slowdown may

[28] Estimates presented here assume declining marginal returns from educational attainment, with highest (lowest) returns primary (tertiary) education, as specified in Morrisson and Murtin (2013) based on Psacharopoulos and Patrinos (2002). Recent papers provide new evidence in favor of non-decreasing, and perhaps increasing, returns (such as Montenegro and Patrinos 2014). Under constant returns—a conservative assumption—the slowdown in human capital stock growth between the 2000s and the 1990s would be about 0.25 instead of 0.3 percentage points for advanced economies, while the estimates for emerging market economies would be essentially unchanged.

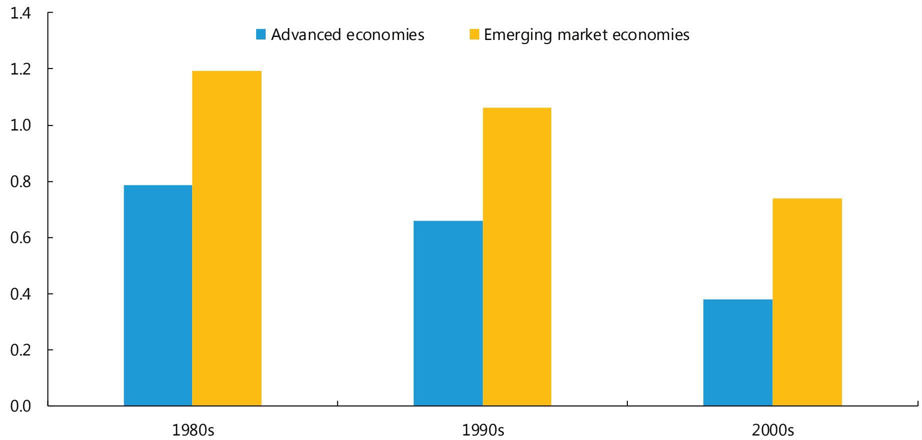
[29] There is wide dispersion across countries within each group, in the level and the change of the contribution of human capital to labor productivity growth. For example, the United States enjoyed stable but very low human capital accumulation—0.1–0.2 percent per year—during the 2000s, reflecting the previous levelling off of secondary schooling in the 1970s and slow progress on tertiary education attainment. China, on the other hand, experienced a slowdown but still fast

(continued)

show up in weaker measured TFP growth depending on how human capital is accounted for when calculating TFP, and whether human capital entails positive externalities.

Figure 15. Contribution of Human Capital to Labor Productivity Growth

(Simple average by decade for both country income groups, percent)

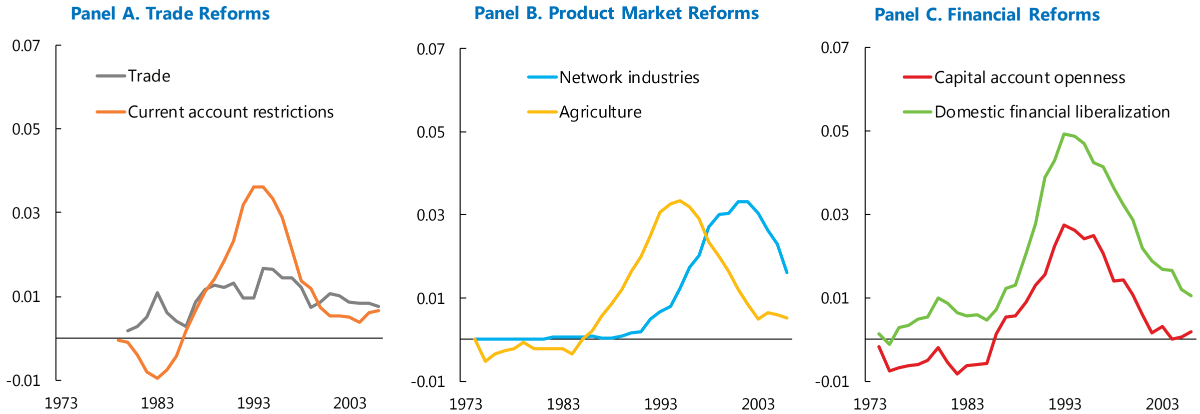


Sources: Murtin and Morrisson (2013); Organisation for Economic Co-operation and Development; and IMF staff calculations.
Note: The calculation follows the approach of Hall and Jones (1999), only departing from them by allowing for diminishing rather than constant returns to schooling as estimated by Morrisson and Murtin (2013), and consistent with Psacharopoulos and Patrinos (2002). Advanced economies include Australia, Austria, Belgium, Canada, Czech Republic, Denmark, Estonia, Finland, Germany, Greece, Iceland, Ireland, Israel, Italy, Japan, Korea, Luxembourg, Netherlands, New Zealand, Norway, Portugal, Slovak Republic, Slovenia, Spain, Sweden, Switzerland, the United Kingdom, and the United States. Emerging market economies include Argentina, Brazil, Chile, China, Hungary, India, Indonesia, Mexico, Poland, Saudi Arabia, South Africa, and Turkey.

25. Fading structural reform efforts in emerging and developing economies. TFP growth in emerging and developing economies may have also been affected by a slowing pace of structural reform. Significant progress on both real and financial sector reforms was achieved during the late 1980s and the 1990s—partly in the aftermath of financial crises—paving the way for fast emerging and developing economies growth during the 2000s. Indeed, past research has found positive TFP and growth impacts of these reforms, while also highlighting that these effects vary across types of reforms and depends on the overall institutional environment (Christiansen, Schindler, and Tressel 2013; Prati, Onorato, and Papageorgiou 2013). However, with a few exceptions, reform efforts faded across a broad range of areas over the decade (Figure 16). In advanced economies, the pace of product market reform also appears to have slowed after the wave of liberalization of network industries during the 1990s and early 2000s, while progress on labor market reform has been uneven (Duval and others forthcoming; IMF 2016d).

average growth—about 0.9 percent per year—over that decade, mainly reflecting cohort effects (as older, less educated cohorts were replaced by younger, more educated ones)—and continued increases in tertiary education attainment among new generations.

Figure 16. Fading Structural Reform Efforts in Emerging and Developing Economies
(Average annual index change, 5-year moving average)



Sources: Prati, Onorato, and Papageorgiou (2013); IMF staff calculations.
Note: The average annual index change uses reform indices data from Prati, Onorato, and Papageorgiou (2013). All indices are rescaled to range between 0 and 1, with higher values corresponding to higher degree of liberalization. Indices are comparable across countries and time for each sector, but are not directly comparable across sectors because different methodologies are used to construct each index.

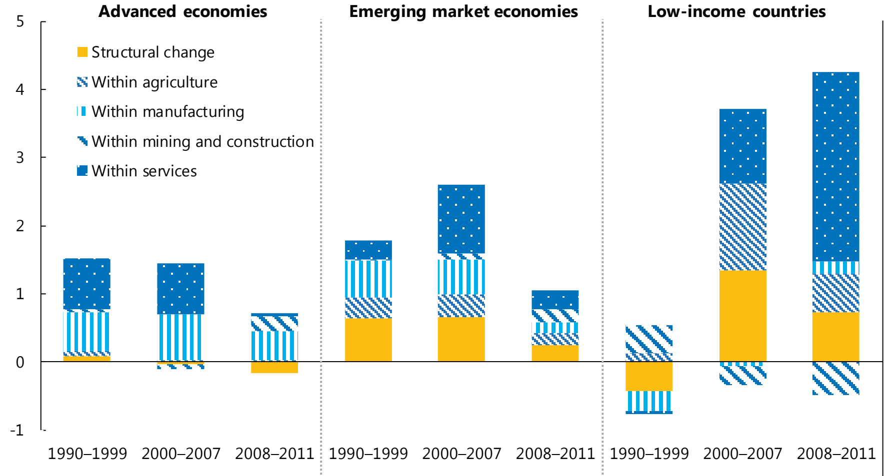
26. Structural transformation. Reallocation of resources away from low-productivity and toward high-productivity industries can also be an important driving force of aggregate productivity (labor productivity and TFP), especially in developing countries transitioning from agriculture to manufacturing. Sector-level analysis of labor productivity growth updating earlier IMF work (Dabla-Norris and others 2013b and 2015) indeed indicates that resource reallocation has been an important driver of productivity in emerging market economies and low-income countries over the last two decades, and especially before the global financial crisis (Figure 17). However, post-crisis evidence—although limited to 2008–11 due to lack of more recent data—suggests that benefits from structural transformation have declined for emerging market and low-income countries alike, partly as some of them, especially emerging market economies, have increasingly moved toward services.[30,31]

[30] China is not included in the sample for this analysis due to lack of manufacturing value-added data at the beginning of the sample.

[31] A decline in labor productivity growth *within* both manufacturing and services has also contributed significantly to the post-global-financial-crisis productivity slowdown in advanced economies and emerging market economies. In low-income countries labor productivity growth has picked up within both sectors, offsetting the drag from the declining contribution of structural transformation. These patterns, however, should be interpreted cautiously, given the heavy weight of the global financial crisis during the short time span (2008–11) for which data are available.

Figure 17. Structural Transformation, 1990–2011

(Contribution to annual labor productivity growth, percent)



Sources. Groningen Growth and Development Centre; World Bank, World Development Indicators; United Nations National Accounts database; Penn World Table 9.0; Dabla-Norris and others (2013); and IMF staff calculations.
Note: The decomposition is based on McMillan and Rodrik (2011). *Within* effect refers to the contribution of sectoral productivity growth to aggregate productivity growth, weighted by the initial value-added share of each sector. *Structural change* refers to the contribution of inter-sectoral reallocation of resources, measured by the change in the sector's employment share weighted by its relative productivity level at the end of the period. Countries are weighted by their purchasing power parity GDP at the beginning of each period.

REMEDIES

It is conceivable that innovation will gain pace in the future (see introduction), but, meanwhile, trend productivity growth remains sluggish. Ensuring that productivity continues to play its role in boosting living standards will require immediate policy action to address the legacies of the global financial crisis, along with a gradual implementation of structural policies to address secular drivers of slowing TFP growth.

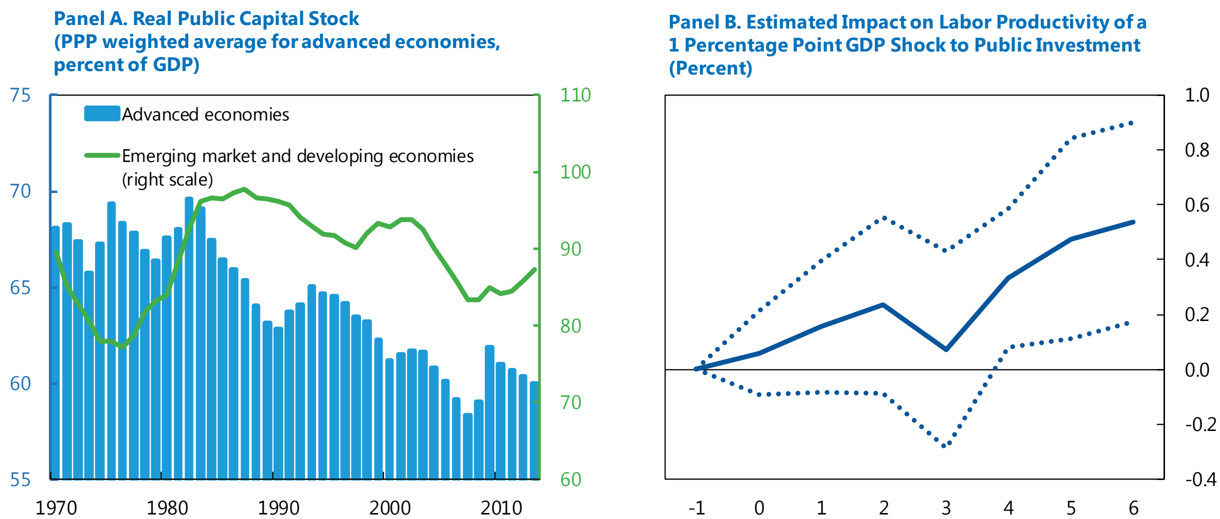
A. Short-Term Remedies

27. Boosting demand—primarily private investment—where it remains too weak. Demand support would not only help close output gaps but, especially if geared towards stronger investment, would also support capital deepening and further adoption of technologies embodied in new physical capital, helping to reverse the adverse feedback loop between weak investment and productivity. Recent IMF work discusses policy options to boost demand when macroeconomic policy space is constrained, as it now is in many advanced economies. Crucial under such circumstances is to exploit all existing synergies between monetary, fiscal, and structural policies (Gaspar and others 2016).

28. Efficient spending on infrastructure. Over the last two decades, the stock of public capital has fallen continuously relative to GDP in many advanced and emerging and developing economies (Figure 18, Panel A). In countries facing very low long-term borrowing costs and, in many cases, significant infrastructure needs, the social benefits of carefully selected public investment projects—including maintaining existing infrastructure—are likely to be high (see IMF 2016b). An efficient public infrastructure spending boost would raise labor productivity directly through higher infrastructure capital, and possibly TFP as well, by making existing private capital more productive—so-called spillover externalities. As an illustration, Figure 18, Panel B, estimates the dynamic impact on labor productivity of an increase in public investment equivalent to one percentage point of GDP across a panel of 17 advanced economies over

1985–2013. Following IMF (2014), infrastructure spending shocks are computed as the forecast error of public investment relative to GDP, using *OECD Economic Outlook* forecasts.[32] On average, labor productivity rises by 0.5 percent over the medium term, although primarily through higher physical capital intensity. Ensuring efficient spending can deliver larger effects than this historical average. IMF (2015b) finds that public investment in countries with the most efficient public spending leads to twice the growth impact as that seen in the least efficient. By contrast, infrastructure development designed to support particular sectors with chronic and growing excess capacity may delay necessary long-term adjustments and boost output only in the short term.

Figure 18. Stock of Public Capital and Productivity Effect of Infrastructure Spending



Sources: IMF, Investment and Capital Stock database; IMF staff calculations.
Note: PPP = purchasing power parity. For Panel B, years after the shock on the x-axis, t = 0 is the year of the shock. The methodology follows that used in the October 2014 IMF, *World Economic Outlook* to identify reform shocks and estimate their dynamic impact on output.

29. Strengthening balance sheets. Weak balance sheets still constrain access to credit, investment in intangibles, and productivity growth in some countries. Speeding up balance sheet repair—especially in Europe—would help boost labor productivity through both higher capital deepening and TFP growth, the latter by facilitating the implementation of innovations embodied in, or complementary to, new capital vintages. Facilitating corporate restructuring, including by lifting legal impediments, and strengthening banking sector supervision, could help in some cases to improve capital allocation across firms by inducing the exit of low-productivity/loss-making firms.

30. Reducing economic policy uncertainty. Providing greater certainty about future economic policy would also support investment and its shift toward higher-risk/higher-return projects, such as in Europe, where economic policy uncertainty remains substantially above precrisis levels. Particularly important is adopting a consistent dynamic framework to guide economic policies (Gaspar and others 2016). In fiscal policy, sound medium-term fiscal frameworks to manage public sector balance sheet risks can be

[32] This approach identifies plausibly exogenous shocks, whose dynamic impact is then traced out using the local projection method described in IMF (2014).

particularly helpful. Similarly, greater clarity about prospects for regulatory and trade policies would lower uncertainty and support investment decisions across the board.

B. Longer-Term Remedies

31. Innovation policies to boost technological progress. Slower advancement at the technological frontier in some industries suggests there may be scope for policies to further stimulate R&D, entrepreneurship, and technology transfer. Recent IMF analysis indicates that, given its positive externalities, current global R&D spending remains suboptimal by a significant margin (IMF 2016c). In advanced economies, a socially desirable level of R&D that accounts for positive knowledge spillovers would entail a 40 percent increase from current levels—which in turn could have a large positive effect on the long-term level of GDP in those countries. Well-designed R&D tax incentives, policy reforms aimed at limiting legal and market impediments to venture capital financing, and a strong framework for intellectual property rights that incentivizes investment in innovation while facilitating technological diffusion and follow-on research, can all play an instrumental role in this regard. R&D incentives targeted to young firms may be particularly effective in countries where these firms still face tight credit constraints, such as in a number of continental European countries. In emerging and developing economies, R&D can also support productivity growth, provided a sufficiently strong human capital base is available. In these countries, investment in education and infrastructure can strengthen capacity to absorb technologies from abroad. Simplifying tax regimes for small businesses could facilitate firm entry and reduce informality, also raising productivity.

32. Policies to mitigate the effects of aging. Continuing current trends, workforce aging will drag on productivity growth in advanced economies over the next three decades—roughly comparable in magnitude to that seen since over the past three decades—and will increasingly affect emerging market economies as well, albeit to varying degrees. This negative effect could be dampened by improving health support and affordability for mature workers, who are disproportionately affected by health risk, and facilitating human capital upgrading and retraining (Aiyar, Ebeke, and Shao 2016). Active labor-market policies and pension reforms that eliminate disincentives to continue work at older ages, can give older workers the means and incentives to acquire new skills.

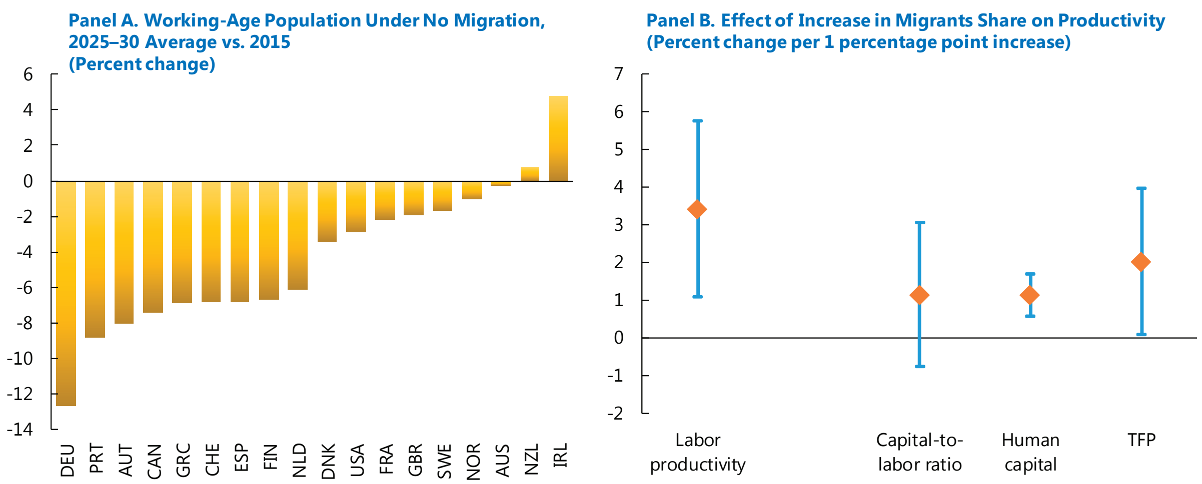
33. Migration policies. Workforce aging itself can be mitigated by higher fertility and, importantly, immigration. Between 1990 and 2010, immigrants contributed about half of total working-age population growth in many advanced economies, and may continue to play an important role in counteracting declining labor forces in advanced economies in the coming years. Immigrants are typically younger than natives, and can bring further productivity gains to the host economy through other channels. New analysis of the effects of immigration on the host country indicates that the gains from immigration may be sizeable (see Appendix VII).[33] A 1 percentage point increase in the share of migrants in adult population is found to raise labor productivity in the host economy by up to 3 percent in the long term through both higher human capital and improved TFP (Figure 19).[34] These effects do not come solely from high-skilled migrants,

[33] The analysis builds on Jaumotte, Koloskova, and Saxena (2016). It controls for the age structure of the working-age population, and thereby recognizes that migrants may increase productivity simply because they are younger than natives. As a result, the productivity gains discussed in this paragraph operate through channels different than age.

[34] The effect is not driven by the increase in the capital-to-labor ratio, because, in the long term, the level of capital adjusts to the larger labor force.

who bring diverse skills and innovation to their new home countries. Low-skilled migrants appear to contribute as well, likely reflecting their skill complementarity with higher-skilled natives (for example, Peri 2016). Moreover, the long-term benefits of migration appear to be broadly shared. The average per capita incomes of both the top 10 and of the bottom 90 percent of earners increase as a result of immigration, although high-skilled immigration benefits top incomes more strongly (possibly due to stronger synergies among high-skilled migrants and high-skilled natives). Key to harnessing these long-term gains, however, is preventing social and political disruptions associated with sizable immigration. Clear and widely accepted immigration policies are essential, as are labor market institutions and active policies that facilitate immigrants' labor market integration. This includes language training and assistance in job search, better recognition of migrants' skills through credential recognition, and lower barriers to entrepreneurship. Challenges in integrating refugees can be particularly acute, as uncertainty about their legal status can delay their employment, potentially resulting in worse labor market outcomes (IMF 2016f).

Figure 19. Projected Working-Age Population and Productivity Gains from Immigration



Sources: United Nations, World Population Prospects, 2015 Revision; Jaumotte, Koloskova, and Saxena (2016); and IMF staff calculations.
Note: Data labels in Panel A use International Organization for Standardization (ISO) country codes. Estimated effect of migration is based on a two-stage least squares approach, where the migration share is instrumented using a gravity-type model of bilateral migration flows. See further details in Appendix VII and Jaumotte, Koloskova, and Saxena (2015).

34. Advancing an open global trade system. Multilateral trade liberalization could provide a productivity boost for all through the same channels that have made the global trade slowdown harmful. IMF research using a historical database of effective tariffs in 18 sectors across 18 advanced economies finds significant productivity gains from liberalization—a 1 percent reduction in input tariffs is found to raise TFP levels by about 2 percent (see Ahn and others 2016; and Dabla-Norris and Duval 2016). Consequently, the increase in TFP from eliminating existing tariffs could be in the order of 1 percent, on average, across advanced economies and significantly larger in emerging and developing economies, where remaining tariffs are higher.[35] Eliminating nontariff barriers would add more sizable additional gains. Trade liberalization would also help boost spillover effects to other countries from innovation at the technological frontier.

[35] These calculations are likely to underestimate the potential gains from trade liberalization because they do not account for the gains that would arise from reallocation of resources across industries.

35. Exploiting synergies between trade, FDI, and other policies. Complementary policies can magnify the gains from trade liberalization. Productivity gains from tariff reductions tend to be higher in countries with less restrictive FDI regimes (Ahn and others 2016). More foreign firms facilitates knowledge diffusion across countries, while also magnifying the benefits of lower trade barriers (as foreign companies tend to use more and better imported inputs—see Halpern and others 2015). This is particularly relevant for the many emerging and developing economies that maintain comparatively strict barriers to foreign direct investment. Likewise, the effect of trade liberalization can be larger if domestic, "behind-the-border" product market regulations are reduced, and if labor market institutions are (re)designed in ways that facilitate swift reallocation of workers across jobs—reforms that, as shown above, would also lift productivity in and of themselves. Such reallocation often entails costs for certain categories of workers, however. Thus, pushing through an ambitious liberalization agenda will require forcefully addressing these adverse labor market and distributive impacts upfront. Tax-benefit systems and active labor market policies—such as job search support and (re)training—have a key role to play in this regard.

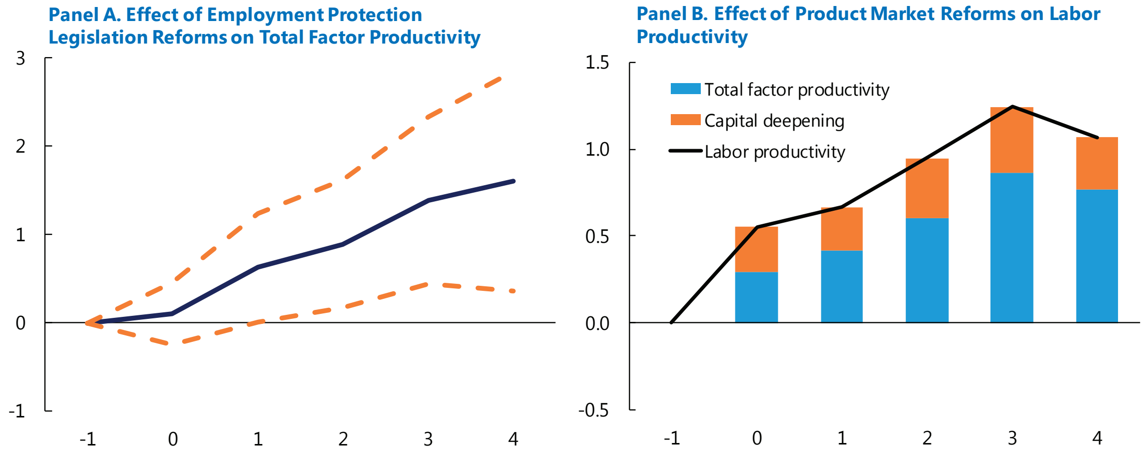
36. Structural reforms. More broadly, advanced economies and emerging and developing economies have considerable scope for pressing ahead with structural reforms. While priorities vary widely across and even within country-income groups, product and labor market reforms often rank high, for example across many European advanced economies and Asian and Latin American emerging markets. Building on the reform database and methodology developed in IMF (2016d), new analysis (see Appendix VIII) indicates that market deregulation in non-tradable sectors can meaningfully enhance labor productivity in the medium term through both higher TFP and capital intensity, with the former accounting for about two thirds of the total effect (Figure 20). Long-term effects are typically larger (see Duval and Furceri 2016). Such reforms do not only facilitate new firms' entry but can also stimulate employment and investment by incumbents (see Bouis, Duval, and Eugster 2016; Gal and Hijzen 2016), while exerting positive spillovers on downstream and upstream industries, including in manufacturing (see Duval and Furceri 2016; IMF 2016d). Services deregulation is even more important for emerging and developing economies, where services account for a growing share of resources and GDP (Dabla-Norris and others 2013b; Rodrik 2015) and regulation remains much stricter than in advanced economies.[36] Likewise, easing employment protection legislation for regular workers can lift TFP by improving allocation of labor across firms and sectors (Figure 20).[37] In addition, product and labor market reforms can help restore external competitiveness through internal devaluation, which might in itself enhance productivity in the presence of economies of scale. Fiscal structural reforms, aimed at improving efficiency in tax system, can also boost firm-level productivity by reducing resource misallocation (IMF 2017; and Banerji and others 2017).

[36] For a recent and broader discussion of the potential gains from structural reforms in Central and Eastern European emerging economies see IMF (2016e).

[37] Employment protection legislation reforms appear to be associated with a fall in the capital-to-labor ratio, however, reflecting lower labor costs and the consequent substitution of labor for capital.

Figure 20. Effect of Product and Labor Market Reforms

(Percent)



Sources: Penn World Table 9.0; Duval and others (forthcoming); and IMF staff calculations.
Note: Years after the shock on the x-axis, t = 0 is the year of the shock. Dashed lines denote 90 percent confidence bands. Capital deepening is defined as the difference between log labor productivity and log total factor productivity. The effects are estimated using local projections method (Jordà 2005), controlling for lagged growth, past reforms, crisis dummies and using a bias correction suggested by Teulings and Zubanov (2014). See further details in Appendix VIII.

37. **Raising the quantity and quality of human capital.** Finally, scope exists for mitigating or reversing the slowdown in human capital accumulation. In many emerging and developing economies, tax and public spending reforms could free up space for higher investment in education and health, adding to another form of capital and source of productivity growth (IMF 2015b). In advanced economies, still-high private returns to tertiary education (Boarini and Strauss 2010) continue to incentivize investment in human capital. Nonetheless, enrollment has slowed and access remains unequal in most countries, with high and rising tuition costs in a number of cases. Raising enrollment, including by maintaining moderate access costs, would benefit productivity and equity. In both advanced and emerging and developing economies, improving the quality of education is at least equally important. This calls for education policy reforms to enhance service delivery and policy actions to reduce the skills mismatch in the labor market (OECD 2016; World Bank, forthcoming).

FINAL REMARKS

38. **As the key source of progress in living standards over the long term, persistently sluggish TFP growth is an obvious source of concern.** While the debate about future productivity remains unsettled, and underlying forces in emerging market economies and low-income countries need to be better understood, our analysis indicates that the global slowing of productivity growth reflects not only structural factors, but also scars from the global financial crisis. The latter—weak corporate and bank balance sheets that are tilting investment away from high-return but high-risk projects, elevated economic policy uncertainty, persistently sluggish demand feeding into slower capital-embodied technological change—afflict many advanced economies, particularly in Europe. Some of these factors, such as policy uncertainty and weaker investment, may have also been at play more recently in some emerging market economies and low-income countries. It is conceivable that a new leap in innovation, driven by major breakthroughs in artificial intelligence or other general purpose technologies, will raise TFP growth in the medium term. If not, or until then, however, a return to a healthy pace of productivity growth appears difficult to achieve without policy action. Thus, renewed efforts to tackle the legacies of the global financial

crisis, especially in continental Europe, while simultaneously addressing the secular forces behind the longer trend of slowing productivity growth, are paramount to reviving growth.

39. Policies addressing crisis legacies and more secular headwinds can be mutually supportive. For example, lifting future potential growth—through R&D tax incentives, infrastructure spending, or migration and trade policies—would raise expectations of demand and investment returns, helping support current investment and capital-embodied technological innovation. Conversely, policies geared towards boosting domestic demand and investment in the short term—including through balance sheet repair—would create economic and political conditions more conducive to implementing structural reforms with high long-term productivity payoffs. A comprehensive approach is best suited for breaking the adverse feedback loops and addressing the current cycle of low output and productivity growth.

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IMF STAFF DISCUSSION NOTE

Gone with the Headwinds: Global Productivity

TECHNICAL APPENDICES I-VIII

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The Global Productivity Slowdown: Crisis Legacies and Other Headwinds

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APPENDIX I. THE IMPACT OF DEEP RECESSIONS ON AGGREGATE PRODUCTIVITY[2]

Previous literature has found that financial crises and large recessions can have sizable and persistent effects on output.[3] This note focuses on the specific effects of deep recessions on total factor productivity (TFP). Recessions can have an impact on aggregate productivity through two channels: (i) by affecting productivity at the firm level or, in the analysis below, at the sectoral level (the *within* effect); and (ii) by inducing inter-sectoral reallocation of resources (the *between* effect). This is explored here.

A. Methodology

Aggregate TFP is decomposed into two components, *within*- and *between*-sector productivity following the methodology by McMillan and Rodrick (2011), adapted to study TFP growth by Furceri, Selik, and Schnuker (forthcoming):[4]

$$tfp_{j,t+k} - tfp_{j,t-1} = \sum_{i=1}^{I} w_{i,j,t-1}\left(tfp_{i,j,t+k} - tfp_{i,j,t-1}\right) + \sum_{i=1}^{I} tfp_{i,j,t+k}\left(w_{i,j,t+k} - w_{i,j,t-1}\right)$$

where $tfp_{j,t}$ is the log of aggregate cyclically-adjusted TFP in country *j* at time t, $tfp_{i,j,t}$ is the log of the cyclically-adjusted TFP of sector *i* in country *j*, and $w_{i,j,t}$ is the share of sector *i's* value added.[5] The first right-hand side term is the *within* component—which captures the change in TFP in each sector, keeping the weight of each sector unchanged. The second right-hand side term is the *between* component, which captures the change in TFP resulting from reallocation of resources across different sectors. This *between* component is simply calculated as a residual between aggregate TFP growth and the *within* component, which alleviates the need to compute TFP levels as would be needed if we attempted to measure it directly.

We use the local projections method (Jorda 2005) to study the effect of deep recession on different variables of interest, including aggregate TFP, as well as the *within* and *between* components. Specifically, the following equation is estimated for each horizon $k = 0,1,2,3,4$:

$$x_{t+k,j} - x_{t-1,j} = \alpha_j + \gamma_t + \sum_{s=1}^{2} \delta_s^k \Delta y_{t-s,j} + \beta_k D_{t,j} + \sum_{s=1}^{2} \theta_s^k D_{t-s,j} + \sum_{s=0}^{k-1} \rho_s^k D_{t+k-s,j} + \varepsilon_{t,j}$$

---

[2] This technical appendix was prepared by Ksenia Koloskova.

[3] See, for example, Cerra and Saxena (2008).

[4] See also IMF (2015).

[5] These weights are those we also use to compute our aggregate measure of cyclically-adjusted TFP growth. Following the approach described in Basu and others (2006), the weights are given by w_i/(1-sm_i), in which w_i is the industry' share of gross output, and sm_i is the share of input payments in total costs. The rationale for dividing by 1-sm_i is to take into account productivity gains in intermediate sectors, following Domar (1961). Therefore, the TFP growth rates are weighted by the industry's share of aggregate value added (Basu and others 2006).

where $x_{t+k,j} - x_{t-1,j}$ is the cumulative change of the variable of interest for country *j;* α_j and γ_t are country and time fixed effects, respectively; *D* is a dummy variable which takes value of 1 for beginning of the deep recession, and zero otherwise. Other control variables include (i) past output growth (two lags), (ii) lagged recession dates (two lags), (iii) country-specific trends. The bias correction suggested by Teulings and Zubanov (2014) is followed, by controlling for forward values of the recession dummy between periods t and $t + k - 1$.

B. Data

Country-level data come from Penn World Tables version 9.0 (PWT). For the sector-level analysis, cyclically-adjusted TFP data come from Furceri, Selik, and Schnuker (forthcoming) and Dabla-Norris and others (2015). The cyclical adjustment is applied by extending the approach followed by Basu and others (2006) for the United States to 17 advanced economies for 1970–2010. The sample for our analysis is restricted to years before the global financial crisis. We focus on past recessions of comparable size—by output decline— to the global financial crisis. The countries in the sample include Australia, Austria, Canada, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Japan, Korea, the Netherlands, Portugal, Spain, the United Kingdom, and the United States.

The definition of *deep recessions* is based on the sample of recessions identified in Blanchard, Cerutti, and Summers (2015). Their original quarterly data set contains data on peak and trough dates, with all periods between these dates (inclusive) defined as recessions. Deep recessions are identified as those at the bottom 10 percent of the distribution of episodes, by cumulative output growth in the first eight quarters of the recession (starting from the peak). The deep recession dummy then takes value of 1 in the year of the start of the event,[6] and 0 in all other years. This selection allows us to study whether recessions with large initial output declines (comparable in size to that observed during the global financial crisis) have persistent effects on key macroeconomic variables such as TFP, as opposed to just transitory effects. As a robustness check, we also rerun our analysis with an identification of deep recession episodes based on output contraction in the first four—rather than eight—quarters after the peak.

C. Results

Aggregate Effect

Results for economy-wide variables using Penn World Tables are reported in Appendix Figure 1.1. Output declines by about 10 percent in the medium term during deep recessions. The decline in employment is somewhat delayed, resulting in a sharp fall in labor productivity. In the medium term, employment declines almost by as much as the output. The effects on output and employment appear to be very persistent. Medium-term recovery in labor productivity is driven by the evolution of the capital-to-labor ratio: physical capital declines significantly in the medium term, but by less

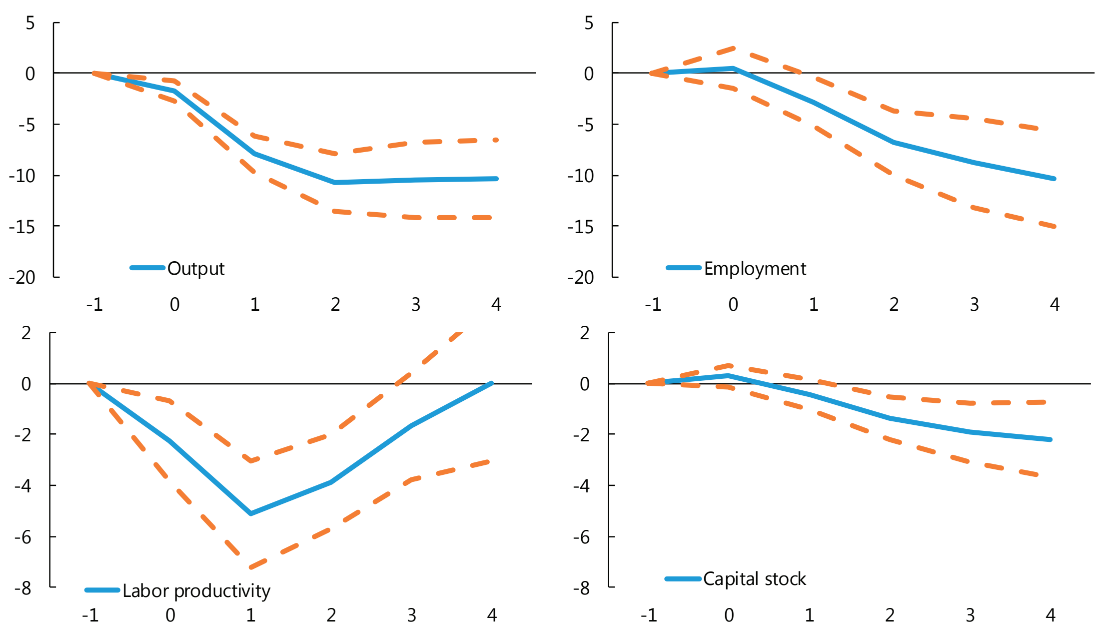
[6] In all identified episodes of deep recessions, the pre-recession peak occurred either in Q1 or Q2. This alleviates potential issue of incorrectly dating the start of a recession when moving from quarterly to annual frequency.

than employment. Since labor productivity goes back to, and the capital-to-labor ratio rises above, pre-recession levels over the medium term, TFP is durably reduced.

The next section reruns this analysis following an alternative approach, which is to estimate the economy-wide TFP loss using sector-level data from KLEMS and then decompose it into its within and between components. The use of sector-level data allows for cyclical adjustment of TFP at the sector level as in Basu, Fernald, and Kimball (2006), which is important to capture the underlying change in productivity since measured TFP fluctuations are typically driven in part by highly procyclical unobserved capacity utilization.

Appendix Figure 1.1. Effects of Recessions on Key Macroeconomic Variables

(Percent)



Sources: Penn World Table 9.0; EU KLEMS and WORLD KLEMS data; Blanchard, Cerutti, and Summers (2015); and IMF staff calculations.
Note: Years after the shock on the x-axis, t = 0 is the year of the shock. Dashed lines denote 90-percent confidence bands. The effects are estimated using local projections method (Jordà 2005), controlling for past growth, lagged recessions and country-specific trends, and including a bias correction suggested by Teulings and Zubanov (2014).

Sectoral Reallocation

Cyclically-adjusted TFP shows a strong protracted decline during deep recessions, averaging about 5 percent after four years (Appendix Figure 1.2—Panel A).[7] This is somewhat larger than in the

[7] These results contrast with those of Oulton and Sebastia-Barriel (2013), who found permanent output effects, but not permanent TFP impact, of financial crises. The difference owes to our focus on deep recessions rather than on financial crises. Some financial crises are associated with only mild recessions, and conversely some deep recessions are not associated with financial crisis. Rerunning the analysis focusing only on financial crises would yield no significant long-term impact on TFP, in line with Oulton and Sebastia-Barriel (2013).

aggregate analysis performed above, which uses data from Penn World Tables rather than KLEMS. The former encompasses all sectors of the economy, although it is not cyclically adjusted.

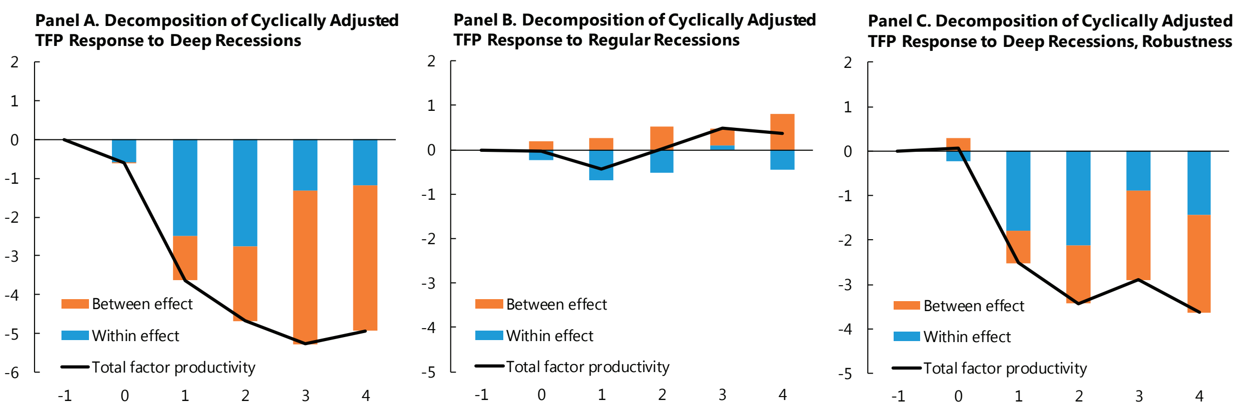
The effect comes from both the *within* and *between* components of TFP growth, with the latter being small initially but gaining prominence over time, possibly reflecting the impact of market dislocation. Complementary analysis of the change in weights of various sectors shows that deep recessions are associated with declining weights for high-productivity manufacturing sectors, such as electrical and optical equipment, machinery, and so on.

A comparison between deep and mild recessions shows that the former have a much larger effect on cyclically-adjusted TFP (Appendix Figure 1.2—Panel B)—the TFP decline is much smaller and short-lived in mild recessions. Moreover, in contrast to the large *between* component identified during deep recessions, the TFP decline during mild recessions is entirely due to the *within* effect. The *between* effect is small and goes in the opposite direction.

A robustness exercise identifying deep recessions on the basis of only their four-quarter cumulative output contraction confirms a large and persistent decline in cyclically adjusted TFP with a significant contribution of the *between* effect (Appendix Figure 1.2—Panel C).

Appendix Figure 1.2. Effects of Recessions on Cyclically Adjusted TFP and Its Components

(Percent)



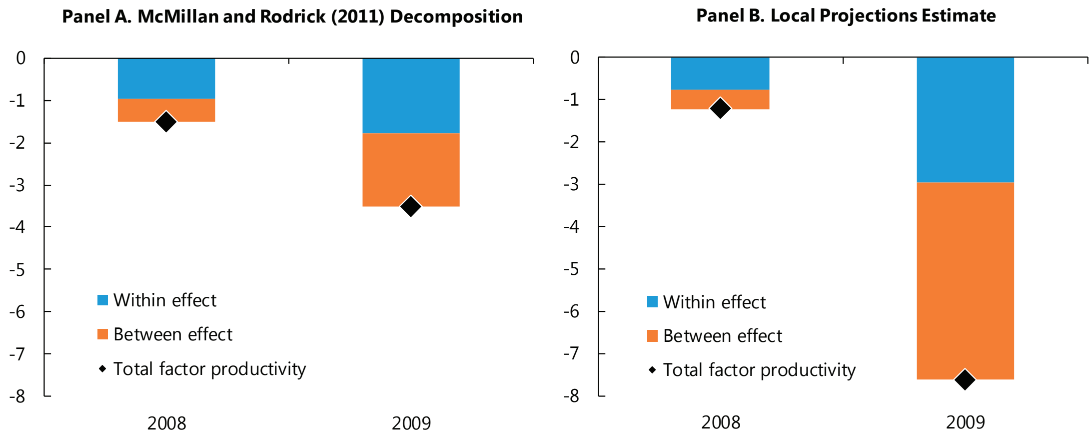
Sources: EU KLEMS and WORLD KLEMS data; Blanchard, Cerutti, and Summers (2015); and IMF staff calculations.
Note: Years after the shock on the x-axis, t = 0 is the year of the shock. TFP = total factor productivity. The decomposition is based on McMillan and Rodrik (2011). Within effect refers to the contribution of sectoral productivity growth to aggregate productivity growth. Between effect refers to contribution of inter-sectoral reallocation of resources. The effects are estimated using local projections method (Jordà 2005), controlling for past growth, lagged recessions and country-specific trends, and including a bias correction suggested by Teulings and Zubanov (2014). Panel C presents the decomposition based on an alternative definition of deep recessions, using growth in the first 4 quarters after the peak (instead of 8 quarters) to identify the 10 percent of the largest recessions.

A similar decomposition for the global financial crisis indicates that the productivity decline was even larger compared with past deep recessions, and sectoral reallocation (*between* effect) also played an important role (Appendix Figure 1.3). Since sector-level data used here end in 2009 for the most the countries in the sample, only the short-term impact of the global financial crisis can be explored. Both the results based on the above sectoral decomposition and those from a local projection estimation focusing only on the global financial crisis (where the *within* and *between* effects are also regressed on control variables) show a cumulative productivity decline of more than 3 percent, with a

significant contribution from the *between* effect, in the first two years. In this regard, the global financial crisis is comparable to previous deep recession episodes.

Appendix Figure 1.3. Cumulative Change in Cyclically Adjusted Total Factor Productivity

(Relative to 2007, percent)



Sources: EU KLEMS and WORLD KLEMS data; Blanchard, Cerutti, and Summers (2015); and IMF staff calculations.
Note: The decomposition is based on McMillan and Rodrik (2011). *Within* effect refers to the contribution of sectoral productivity growth to aggregate productivity growth. *Between* effect refers to the contribution of inter-sectoral reallocation of resources. The effects in the right hand side panel are estimated using local projections method (Jordà 2005), controlling for past growth and lagged global financial crisis dummy, and including a bias correction suggested by Teulings and Zubanov (2014).

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APPENDIX II. THE IMPACT OF FIRM BALANCE SHEET VULNERABILITIES AND CREDIT CONDITIONS ON THE POSTCRISIS PRODUCTIVITY SLOWDOWN[8]

One possible driver of the abrupt slowdown in total factor productivity (TFP) since the global financial crisis is the sharp tightening in credit conditions that took place after the collapse of Lehman Brothers in September 2008 and persisted in a number of countries afterward, not least in Southern Europe during the euro area crisis. Credit conditions may affect aggregate TFP through their impact on *both* firm-level TFP and the efficiency of resource allocation across firms. This appendix focuses on the former channel. Using an extensive cross-country firm-level data set, it investigates whether tighter access to credit postcrisis reduced TFP growth in firms with pre-existing balance sheet vulnerabilities, and thereby weakened aggregate TFP growth given that such "vulnerable" firms were not (on average) lower-productivity-growth firms. The analysis then explores one possible channel: the adverse impact of tighter credit conditions on intangible investment.

Key Variables and Data

The main dataset used for the firm-level analysis is ORBIS, a unique cross-country longitudinal database of both listed and unlisted firms provided by Bureau van Dijk. ORBIS features harmonized and rich information on firms' productive activities (for instance, value-added output, capital stock, employment) and financial situations based on balance sheets and income statements (for instance, debt, assets, tangible and intangible fixed assets, long-term debt).[9]

The main analysis draws from the latest vintage of data collected in 2015, which covers 10 years from 2004 to 2013.[10] We focus on 15 advanced economies for which we also have information on aggregate financial and credit conditions over this period: Austria, Belgium, Denmark, Germany, Spain, France, Greece, Italy, Japan, Korea, the Netherlands, Portugal, Slovenia, the United Kingdom, and the United States. We study firms in the nonfarm, nonfinancial business sector, which corresponds to the two-digit industry codes 5–82 in NACE Rev.2., covering both manufacturing and a number of services sectors including real estate, education, and profession/scientific/technical activities, to name a few.[11]

[8] This technical appendix was prepared by Romain Duval and Gee Hee Hong.

[9] See Gal (2013), Kalemli-Özcan and others (2015) and Gal and Hijzen (2016) for more detailed descriptions of the data set.

[10] The only exception is the placebo analysis around the time of the 2000 dot-com bubble burst (see below), for which one of the historical vintages of ORBIS containing information before and after 2000 is used.

[11] See Eurostat (2008) for information on the categorization and correspondence with other sector classifications (http://ec.europa.eu/eurostat/documents/3859598/5902521/KS-RA-07–015-EN.PDF).

To ensure consistency and comparability of monetary variables across countries and over time, we adopt the methodology followed by Gal and Hijzen (2016). First, the original data recorded in U.S. dollars are converted into local currency. Nominal variables are then turned into real variables by applying local currency deflators obtained from OECD STAN (ISIC4 version), which are rebased to 2005 U.S. dollars using country-industry level purchasing power parity data obtained from Timmer and Inklaar (2014). In addition, we exclude very small firms (less than three employees), a common practice in studies using firm-level data, due to concerns regarding the reliability of the data as well as the consistency of variables over time. Also, we restrict our analysis to firms that report at least four consecutive periods.

Matched with these firm-level variables are aggregate, country-level financial and credit conditions variables drawn from other sources. The main one is an economy-wide measure of spreads on bank credit default swaps (CDS) in each country in our sample, which is computed as the simple average of CDS spreads across the country's banks.[12] All else equal, banking systems whose CDS spreads rose more around the collapse of Lehman Brothers experienced a larger increase in perceived vulnerabilities and a more adverse shock to credit supply as banks sought to strengthen their balance sheets. We argue that greater exposure to the Lehman bankruptcy as reflected in a larger increase in domestic bank CDS spreads captures an exogenous tightening of credit conditions in the country considered.

The main dependent variable used in the analysis is firm-level TFP growth, which we compute using real value added, real capital stock, and the number of employees available in each firm's balance sheet, and applying the control function suggested by Wooldridge (2009).[13] The real capital stock for each firm is derived from the dynamic evolution of the capital stock following the perpetual inventory method (PIM), using information on depreciation and tangible fixed in the balance sheet (for more details, see Gal 2013, Gal and Hijzen 2016). In addition to identifying the possible channel(s) through which firm-level productivity growth may be affected by financial frictions, we explore their impact on intangible fixed assets as reported in balance sheets.

Two key explanatory variables are chosen that capture two different dimensions of firms' balance sheet vulnerabilities entering the global financial crisis. The first variable captures debt overhang. It is the precrisis average leverage ratio, measured as the ratio of the sum of current liabilities and long-term debt to total assets, averaged from 2003 to 2007. The second variable captures rollover risk, and is measured as the ratio of current liabilities (i.e. debt maturing within a year) to total sales in the 2007 balance sheet. A higher share of debt maturing in 2008 implies greater exposure to rollover risk before the failure of Lehman Brothers. Almeida and others (2009) argue that this variable provides exogenous variation in firms' financial vulnerabilities, as firms could not foresee in 2007 the timing and size of the September 2008 shock to global credit conditions.

[12] Results are robust to considering weighted averages instead.

[13] Wooldridge (2009) provides a single-equation instrumental variable approach to estimate unobserved multi-factor productivity, including intermediate inputs rather than investment as proxies as proposed by Olley and Pakes (1996) and Levinsohn and Petrin (2003).

Importantly, TFP growth did *not* systematically differ across firms along these two dimensions before the crisis (as shown in Figure 7 in the main text), which points to exogenous variation in firm vulnerabilities and will allow causal interpretation of the estimated effects. Our confidence in such a causal interpretation will be strengthened by a placebo test around the 2000 recession, which will show no effect of preexisting financial vulnerabilities on postrecession TFP growth.

Empirical Strategy and Findings

Our baseline regression follows a difference-in-differences strategy and compares precrisis and postcrisis TFP growth in more vulnerable versus less vulnerable firms, controlling for country-sector fixed effects to ensure the comparison is performed within each country-sector and the results are not driven by country-sector-specific factors (such as a sharp decline in the output and productivity growth of the construction sector, which was also more leveraged in some countries than in others). This identification strategy bears similarities with Giroud and Mueller (2017), who study the impact of the 2008 credit supply shock on employment in firms in the United States, using the pre-crisis leverage ratio as a measure of firm-specific vulnerability. We also use 2008 as the crisis year. To further assess whether the sharp unforeseen tightening of credit conditions after the collapse of Lehman Brothers reduced TFP growth more in firms that had greater ex-ante balance sheet vulnerabilities, we also exploit the variability in the tightening in credit conditions across countries. We do so by interacting an indicator capturing this degree of tightening, namely the change in average bank CDS spreads between the first and second halves of 2008, with our two measures of firm-specific financial vulnerabilities. By design, the focus is on firms still in business; tighter access to credit may have led some of the more vulnerable firms to exit. But this is not studied here for lack of reliable data on exit using Orbis.

Specifically, the estimated specification is:

$$\Delta TFP_{isc}^{growth} = \alpha_{sc} + \beta_1 Vulnerabilities_i^{PRE} + \beta_2 Vulnerabilities_i^{PRE} * \Delta CDS_c + \gamma' X_i + \varepsilon_{isc} \quad (1)$$

where $\Delta TFP_{isc}^{growth}$ denotes the change in average TFP growth between the five years before and five years after the crisis in firm *i*, in sector *s*, and country *c*, $Vulnerabilities_i^{PRE}$ is one of the two firm-specific measures of precrisis vulnerabilities (which may also enter the equation simultaneously), X_i is a set of firm-level controls including age, total assets and earnings (EBITDA) before the financial crisis and ΔCDS_c is the change in the average CDS spread across banks of country c between the first and second halves of 2008. Standard errors are double-clustered at the country-sector and firm levels in all firm-level regressions.

Appendix Table 2.1 reports the results. Both high leverage and high rollover risk are found to have had a large and statistically significant adverse effect on TFP growth postcrisis, as shown in columns (1) to (3). There is also significant interaction between each source of vulnerability and the degree of tightening in credit conditions as measured by the country-wide change in average bank CDS spreads around the collapse of Lehman Brothers, as shown in columns (4) to (6). This indicates that

firm-specific vulnerabilities weakened TFP growth more in countries where credit conditions tightened more.

Appendix Table 2.1. Pre-2008 Financial Vulnerabilities and the Change in TFP Growth Between the Precrisis and Postcrisis Periods

	(1)	(2)	(3)	(4)	(5)	(6)
	Δ Total factor productivity growth					
Leverage precrisis	-0.047***		-0.036***	-0.057***		-0.046***
	(0.008)		(0.006)	(0.009)		(0.010)
Leverage precrisis * Δ credit default swap spreads				-0.057***		-0.051***
				(0.015)		(0.021)
Debt maturing 2008		-0.094***	-0.091***		-0.111***	-0.108***
		(0.010)	(0.010)		(0.008)	(0.008)
Debt maturing 2008 * Δ credit default swap spreads					-0.068***	-0.064***
					(0.017)	(0.017)
R-squared	0.149	0.151	0.151	0.163	0.167	0.167
N	134838	134838	134838	104275	104275	104275
Country* sector fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Firm-level controls	Yes	Yes	Yes	Yes	Yes	Yes

Source: IMF staff estimate.
Note: TFP = total factor productivity, CDS = credit default swap spreads. The dependent variable ` ΔTFP growth' is the difference in the TFP growth rate postcrisis versus `Leverage precrisis' is the average precrisis debt-to-assets ratio. `Debt maturing 2008' is the amount of debt maturing in 2008 divided by average total sales precrisis. Postcrisis starts in 2008. `ΔCDS' is the difference in the average CDS spread of banks in each country two quarters before and two quarters after the Lehman Brothers bankruptcy. Standard errors in parentheses are clustered at the country-sector and firm levels. * = significant at 10% level; ** = significant at 5% level; *** = significant at 1% level.

The magnitudes of these effects are rather large. The estimates in column 3 imply that a firm with a 10 percentage points higher leverage ratio than its less leveraged counterpart experienced a 0.36 percentage point larger drop in TFP growth after the crisis. Likewise, a 10 percentage points higher share of debt maturing in 2008 was associated with a 0.91 percentage point postcrisis decline in TFP growth. This relationship is stronger in countries whose banking sectors were hit harder by the financial crisis and where credit conditions tightened more as a result. Using the estimates in column 6,[14] in the average country a firm with a 10 percentage point higher share of debt maturing in 2008 experienced on average a 1.08 percentage point stronger decline in TFP growth than its less exposed counterpart, but this difference was 1.72 percentage points in a country where the CDS spread rose by 100 basis points more than in the average country.

A crude back-of-the-envelope calculation can help assess the extent to which financial vulnerabilities accounted for the postcrisis drop in within-firm productivity growth. To this end, we

[14] The difference in the coefficient between columns (6) and (3) is due to column (3) reflecting the average firm (not necessarily in the average country) and column (6) reflecting the average firm in the average country.

use the coefficient on the debt maturity variable in column (3) and estimate the loss of TFP growth postcrisis for each firm compared to a hypothetical firm that did face any roll-over risk (had zero short-term debt in 2007) and is conservatively assumed not to have faced financial frictions. We then aggregate up this loss across all firms using their TFP levels as weights. This yields an overall loss that is about one third of the total loss in aggregate within-firm TFP growth after the financial crisis (five years after versus five years before 2008).

As a robustness check for our findings, we run a placebo test. If the effects estimated in Appendix Table 2.1 do indeed reflect the role of the sharp tightening of credit supply conditions during the global financial crisis, they should not show up if one focused instead on regular recessions that were not accompanied by a financial crisis. With this in mind, we use the historical vintages of ORBIS to conduct similar analysis using the year 2000, which saw the burst of the dot com bubble and marked the start of a mild recession in advanced economies. We reestimate specification (1), using as measures of vulnerabilities the average leverage ratio before 2000 and the current liabilities reported in 1999 balance sheets. We find no evidence that financial vulnerabilities before the 2000 recession had any significant impact on TFP growth after the recession (Appendix Table 2.2). This confirms that the results in Appendix Table 2.1 reflect the peculiar nature of the recent global financial crisis.

Appendix Table 2.2. Placebo Test: The Dot Com Bubble

	(1)	(2)	(3)
		Δ Total factor productivity growth	
Leverage prerecession	-0.00383		0.00620
	(0.015)		(0.017)
Debt maturing 2000		-0.0657	-0.0690
		(0.046)	(0.050)
R-squared	0.157	0.157	0.157
N	53200	53200	53200
Country * sector fixed effects	Yes	Yes	Yes
Firm-level controls	Yes	Yes	Yes

Source: IMF staff estimates.
Note: TFP = total factor productivity. The postrecession period covers 2000–2005. The dependent variable `ΔTFP growth' is the difference in the TFP growth rate postrecession versus prerecession. `Leverage prerecession' is the average prerecession debt-to-assets ratio. `Debt maturing 2000' is the amount of debt maturing in 2000 divided by average total sales before the recession. Standard errors in parentheses are clustered at the country-sector and firm levels * = significant at 10% level; ** = significant at 5% level; *** = significant at 1% level.

Finally, we explore one potential channel through which financial vulnerabilities could have led to a protracted TFP slowdown, which is by pushing distressed firms to cut their investment in intangibles. A wide range of recent studies have linked investments in intangible assets with productivity since the influential work of Corrado, Hulten and Sichel (2005, 2009). When hit by a financial shock, firms may adjust various types of investment differently depending on expected returns, risks and gestation periods (Holstrom and Tirole 1997; Matsuyama 2007; Garcia-Macia 2016). While most forms of physical capital can be pledged as collateral to get a loan, intangible assets such as R&D or workforce training cannot. Furthermore, investments in intangible assets

tend to translate more slowly into sales and to be riskier. Therefore, our hypothesis is that vulnerable firms are more likely to cut investment in intangible assets than physical capital investment when access to financing suddenly tightens.

We use the same difference-in-differences strategy, using as dependent variable the investment in intangible assets as a share of total value added. The specification is as follows:

$$\Delta Inv\_Intan_{isc} = \alpha_{sc} + \beta_1 Vulnerabilities_i^{PRE} + \beta_2 Vulnerabilities_i^{PRE} * \Delta CDS_c + \gamma' X_i + \varepsilon_{isc} \qquad (2)$$

We find that more vulnerable firms indeed reduced their investment in intangible assets more than their less vulnerable counterparts after the crisis, and this gap was again larger in countries where credit conditions tightened more (Appendix Table 2.3).[15]

Appendix Table 2.3. Investment in Intangible Assets

	(1)	(2)	(3)
		Δ Investment in intangible assets	
Leverage precrisis	-0.025***		-0.023***
	(0.004)		(0.004)
Leverage precrisis * Δ credit default swap spreads	-0.047***		-0.043***
	(0.009)		(0.009)
Debt maturing 2008		-0.02***	-0.019***
		(0.002)	(0.002)
Debt maturing 2008 * Δ credit default swap spreads		-0.018***	-0.014***
		(0.004)	(0.004)
R-squared	0.041	0.041	0.045
N	97487	97487	97487
Country * sector fixed effects	Yes	Yes	Yes
Firm-level controls	Yes	Yes	Yes

Source: IMF staff estimates.
Note: CDS = credit default swap spreads. The dependent variable `Δ Investment in intangible assets' is the difference in the investment in intangible assets as a ratio of value added postcrisis versus precrisis. `Leverage precrisis' is the average precrisis debt-to-assets ratio. `Debt maturing 2008' is the amount of debt maturing in 2008 divided by average total sales precrisis. Postcrisis starts in 2008. `ΔCDS' is the difference in the average CDS spread of banks in each country two quarters before and two quarters after the Lehman Brothers bankruptcy in 2008. Standard errors in parentheses are clustered at the country-sector and firm levels. * = significant at 10% level; ** = significant at 5% level; *** = significant at 1% level.

As a complement, we explore whether distressed firms cut intangible investment more than physical capital investment. To do so, we replace the dependent variable with the share of intangible fixed assets out of total fixed investment, which is the sum of physical (or tangible fixed) assets and intangible fixed assets. Appendix Table 2.4 shows that, relative to their less vulnerable counterparts after the 2008 financial shock, more vulnerable firms reduced intangible

[15] This is consistent with the results of Aghion and others (2012), who find evidence of procyclical R&D spending among financially constrained firms, using French firm-level data.

asset investment to a greater degree than tangible asset investments—the share of intangible assets in total investment declined. Again, this difference was larger in countries where credit conditions tightened more.

Appendix Table 2.4. Share of Intangible Assets

	(1)	(2)	(3)
		Δ Share of intangible assets	
Leverage precrisis	-0.136***		-0.129***
	(0.018)		(0.018)
Leverage precrisis * Δ credit default swap spreads	-0.277***		-0.265***
	(0.043)		(0.043)
Debt maturing 2008		-0.069***	-0.061***
		(0.009)	(0.009)
Debt maturing 2008 * Δ credit default swap spreads		-0.103***	-0.075***
		(0.017)	(0.016)
R-squared	0.382	0.380	0.384
N	101150	101150	101150
Country * sector fixed effects	Yes	Yes	Yes
Firm-level controls	Yes	Yes	Yes

Source: IMF staff estimates.
Note: CDS = credit default swap spreads. The dependent variable ` Δ Share of intangible assets' is the difference in the share of intangible assets in total capital postcrisis versus precrisis. `Leverage precrisis' is the average precrisis debt over assets ratio. `Debt maturing 2008' is the amount of debt maturing in 2008 divided by average total sales precrisis. Postcrisis starts in 2008. `ΔCDS' is the difference in the average CDS spread of banks in each country two quarters before and two quarters after the Lehman Brothers bankruptcy in 2008. Standard errors in parentheses are clustered at the country-sector and firm levels. * = significant at 10% level; ** = significant at 5% level; *** = significant at 1% level.

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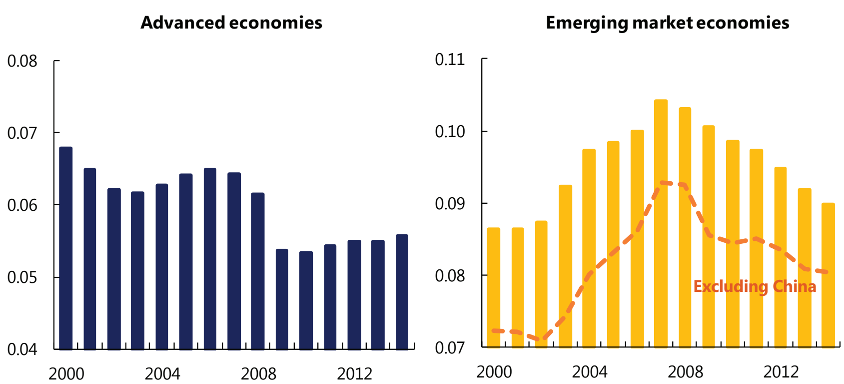
APPENDIX III. INVESTMENT AND CAPITAL-EMBODIED INNOVATION[16]

The post-global financial crisis period has been characterized by weak investment across the spectrum of countries—although with different patterns across income groups, meaning a marked level shift in advanced economies and a more gradual weakening in emerging market economies (Appendix Figure 3.1). Weak investment is likely have contributed to the accompanying sluggish output growth not only through its effect on capital accumulation, but also through its effect on total factor productivity (TFP). The notion that capital can affect TFP goes back to Solow (1959), who argued that new capital equipment may enable some innovations to find their way into production. An example of this in the late 1990s and early 2000s is that technological change such as internet use was "embodied" in new and increasingly powerful computers. New investment may also facilitate TFP-enhancing organizational innovations—for instance, just-in-time manufacturing and supply chain management emerged during the 1980s–1990s because of new IT equipment and software.[17] This appendix explores the role that capital embodied technological innovation may have played in the postcrisis global TFP slowdown.

Appendix Figure 3.1. Gross Fixed Capital Formation, 2000–14

(Share of stock of physical capital)



Sources: Penn World Table 9.0; IMF, *World Economic Outlook*; and IMF staff estimates.
Note: Purchasing power parity GDP weighted average of largest 20 economies in each income group is reported.

A. Empirical Approach

The empirical approach to explore the relationship between investment and TFP growth is broadly similar to Wolff (1991),[18] and entails estimating the following simple linear specification in a panel setting:

[16] This technical appendix was prepared by Gustavo Adler.

[17] See further discussions in Wolff (1991) and Greenwood, Hercowitz, and Krusell (1997).

[18] There are two key differences to the work by Wolff (1991): the exercise here focuses on investment as a share of the stock of capital (as opposed to the capital-to-labor ratio); and, more importantly, it seeks to address the likely endogeneity bias with a two-stage least square instrumentation approach.

$$\widehat{TPF_{i,p}} = \alpha + \beta_0 TFP_{i,p_0} + \beta_1 IK_{i,p} + \gamma_i + \delta_p + \varepsilon_{i,p}$$

where $\widehat{TPF_{i,p}}$ denotes average aggregate TFP growth in country i during period p; TFP_{i,p_0} is country i's TFP gap vis-a-vis the United States at the beginning of the period (meant to control for the average rate of productivity catch-up); $IK_{i,p}$ is the average rate of investment (gross fixed capital formation) as a share of the stock of capital; γ_i is a country fixed effect meant to control for relatively time-invariant country characteristics that may affect the rate of technological innovation, such as institutions, trade openness, culture, and so on; and δ_p is a period fixed effect meant to control for common shocks—for example, frontier innovations that affect all countries alike. β_1 is the coefficient of interest, indicating the effect during the period of the average rate of capital accumulation on the average TFP growth rate. To avoid capturing TFP variations arising from the economic cycle, estimations are conducted using low frequency data (that is, averages over relative long time periods). Specifically, individual observations for each country are averages over annual data for the periods 1970–79, 1980–89, 1990–99, 2000–07 and 2008–14.[19]

To address possible endogeneity bias arising from reverse causality (investment responding to TFP shocks), a Two-stage Least Squares (2SLS) approach is implemented. The investment rate is instrumented by population growth and the initial physical capital per capita (measured in comparable purchasing power parity terms). These two variables are likely to drive growth in capital accumulation, but are unlikely to be correlated with TFP growth. As predicted by a standard growth model, population growth should correlate positively with investment—that is, higher population growth should lead to higher investment rates to sustain a constant capital-to-labor ratio—independent of the pace of TFP. On the other hand, the initial stock of capital should correlate negatively with the investment rate, from a convergence perspective, and also be independent of the pace of TFP growth.

Two robustness checks are implemented, by excluding low-income countries—for which data issues can make TFP measures less reliable—and controlling for population aging, given that population growth may be correlated with population aging, which in turn may directly affect TFP growth, as discussed in the main text and Appendix V.

B. Data

The sample encompasses 112 countries—for which there is available data for the proposed instrumentation—over 1970–2014.[20] Data on aggregate TFP (growth and levels) and stock of physical capital come from Penn World Tables 9.0; data on gross fixed capital formation are extracted from the IMF World Economic Outlook database, and population series are from the UN Population Statistics.

C. Results

Appendix Table 3.1 presents the main results, displaying both the results of the first- and second-stage regressions. The instruments are highly statistically significant with the expected

[19] The period 2000–14 is split at 2007 to better control for global financial crisis effects with the period fixed effect.

[20] When controlling for population aging, the sample of countries is reduced to 104.

signs in the first stage. The instrumented investment-to-capital ratio displays both statistically significant and economically meaningful second-stage coefficients. Results for the baseline specification (columns 3 and 4) suggest that a 1 percentage point increase in the investment rate leads, on average, to a TFP increase of about ¼ percent. Moreover, this effect appears to have increased over time, as shown by the results for 1990–2014 (columns 5 and 6). Results are robust to excluding low-income countries from the sample and controlling for population aging. In line with Wolff (1991), these findings provide support to the notion that capital accumulation contributes to output growth not only through capital deepening but also through capital-embodied technological change.

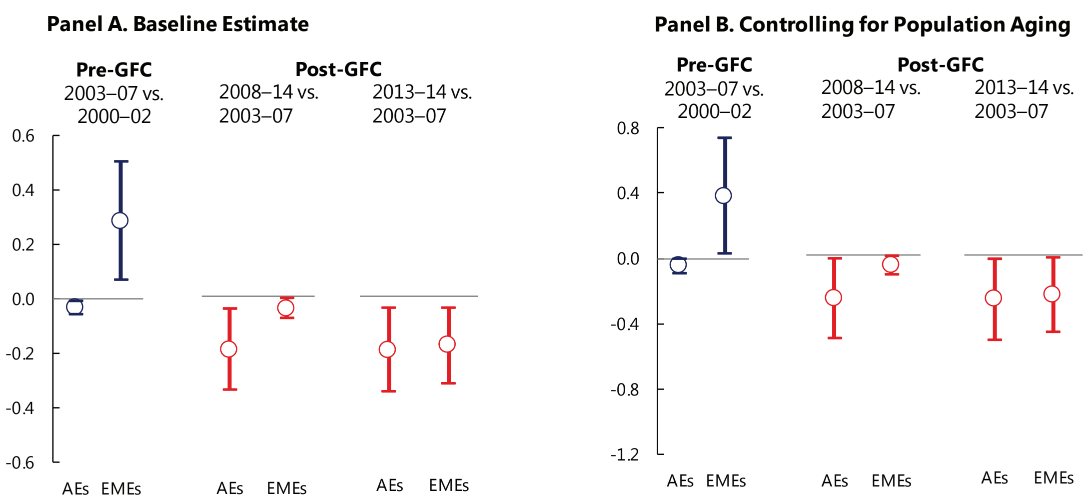
D. Contribution to Recent TFP Growth

Applying these rough estimates to the recent data suggests that weak investment may have been a meaningful driving force behind variations in the pace of TFP growth. As shown in Appendix Figure 3.2, falling investment may have lowered annual TFP growth in advanced economies by as much as 0.2 percent points on average during the period following the global financial crisis. For emerging market economies—which displayed a more gradual weakening in investment over the postcrisis period—the contribution of this channel is muted for the whole post-crisis period but reaches about 0.2 percentage points per year toward the end of the period (again, relative to precrisis TFP growth). This marks a shift from the pace of TFP growth in the years preceding the crisis, when the rise in the investment rate appears to have been an important driver behind the productivity boost in these economies.

Appendix Figure 3.2. Investment and Estimated Impact on Total Factor Productivity Growth Around the Global Financial Crisis

In

(Percent)



Sources: Penn World Table 9.0; IMF, *World Economic Outlook*; and IMF staff estimates.
Note: AEs = advanced economies, EMEs = emerging market economies, and GFC = global financial crisis. Purchasing power parity GDP weighted average of largest 20 economies in each income group is reported.
1/ Estimated contribution of capital accumulation to the change in total factor productivity growth between stated periods. 90-percent confidence bands are reported.

Appendix Table 3.1. Effect of Capital Accumulation on TFP Growth

	Baseline Estimation						Controlling for Population Aging				Excluding Low-Income Countries			
Time period:	1970–2014				1990–2014		1970–2014		1990–2014		1970–2014		1990–2014	
Sample of countries:	All countries				All countries		All countries		All countries		AE and EMEs		AE and EMEs	
			2SLS		2SLS		2SLS		2SLS		2SLS		2SLS	
Method:	OLS		1st stage	2nd stage	1st stage	2nd stage	1st stage	2nd stage	1st stage	2nd stage	1st stage	2nd stage	1st stage	2nd stage
Dependent variable:	Avg. TFP growth	Avg. TFP growth	Avg. I/K	Avg. TFP growth	Avg. I/K	Avg. TFP growth	Avg. I/K	Avg. TFP growth	Avg. I/K	Avg. TFP growth	Avg. I/K	Avg. TFP growth	Avg. I/K	Avg. TFP growth
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
Initial TFP relative to the U.S.	-0.015***	-0.034***	-0.001	-0.034***	-0.010	-0.063***	0.004	-0.036***	0.003	-0.102***	0.002	-0.033***	-0.005	-0.060***
	(0.002)	(0.005)	(0.006)	(0.003)	(0.008)	(0.008)	(0.005)	(0.004)	(0.015)	(0.016)	(0.006)	(0.004)	(0.008)	(0.007)
I/K (average)	0.006	0.088*												
	(0.027)	(0.048)												
I/K (average; instrumented)				**0.243****		**0.428*****		**0.326***		**0.721****		**0.229**		**0.506****
				(0.112)		(0.156)		(0.184)		(0.347)		(0.195)		(0.206)
Instruments														
Population growth			1.038***		0.853***		0.867***		0.875***		0.791***		0.741***	
			(0.237)		(0.203)		(0.215)		(0.244)		(0.271)		(0.208)	
Initial capital per capita			-0.003***		-0.003***		-0.004***		-0.004**		-0.001*		-0.002***	
			(0.001)		(0.001)		(0.001)		(0.002)		(0.001)		(0.001)	
Country fixed effects	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Time fixed effects	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Controlling for population aging	No	No	No	No	No	No	Yes	Yes	Yes	Yes	No	No	No	No
Constant	0.013***	0.015***	0.078***	0.004	0.089***	0.010	0.075***	0.013	0.078***	0.028	0.070***	0.008	0.083***	0.009
	(0.003)	(0.005)	(0.006)	(0.008)	(0.006)	(0.012)	(0.005)	(0.013)	(0.009)	(0.026)	(0.007)	(0.013)	(0.007)	(0.014)
Number of observations	487	487	498	487	334	323	365	356	210	201	395	390	259	254
F-statistics	27.78	29.38	13.15	.	9.451	.	11.12	.	4.014	.	13.26	.	5.933	.
R-squared overall	.	0.18	0.09	0.13	0.12	0.07	0.10	0.14	0.10	0.04	0.14	0.17	0.18	0.09
R-squared within	.	0.37	0.20	0.32	0.18	0.38	0.24	0.38	0.17	0.37	0.24	0.34	0.15	0.42
R-squared between	.	0.02	0.05	0.00	0.11	0.00	0.07	0.01	0.09	0.00	0.10	0.02	0.19	0.00
Number of countries	112	112	113	112	113	112	106	104	106	103	87	87	87	87

Source: IMF staff estimations.

Note: AE = advanced economies, EME = emerging market economies, TFP = total factor productivity, I/K = investment-to-capital ratio, OLS = ordinary least squares, and 2SLS = two-stage least squares. Robust standard errors in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$. Periods include: 1970–79, 1980–89, 1990–99, 2000–07, 2008–14.

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APPENDIX IV: PRODUCTIVITY SPILLOVERS FROM THE TECHNOLOGICAL FRONTIER[21]

This technical appendix empirically assesses the spillovers from frontier TFP growth shocks to TFP growth in other economies. The dynamics of TFP growth in key sectors over the last two decades has raised questions about the role of innovation at the frontier and spillovers, both within and across sectors. A slowdown in TFP growth at the frontier may have contributed to the general TFP slowdown in advanced economies through spillover effects. These are explored next by relying on data on (cyclically-adjusted) TFP growth rates at country-industry-level for a group of 17 advanced economies over 1970–2010.

I. EMPIRICAL STRATEGY

A. Data

TFP growth data at industry level are obtained from Furceri, Kiliç Çelik, and Schnucker (2016) and Dabla-Norris and others (2015). The data are cyclically-adjusted by econometrically correcting for time-varying unobserved utilization in capital and labor and aggregation effects. This correction is essential to properly evaluate the evolution of aggregate TFP growth during the business cycle, and in particular during periods of major expansion and recession (Basu, Fernald, and Kimball 2006; Fernald 2014a, 2014b). Similarly, controlling for aggregation effects is important to correct for sectoral heterogeneity, since the aggregate Solow residual, typically used as a proxy for TFP growth, depends on which sectors change input use the most during the business cycle (Basu and Fernald 1997, 2001; Basu and Kimball 1997; and Hall 1990).[22]

The procedure is applied for a sample of 17 advanced economies[23] over 1970–2010 using industry level data from the EU KLEMS and the WORLD KLEMS databases. These provide internationally comparable data for industry gross output and inputs of capital, labor, hours worked for 24 industries (see Appendix Table 4.1).[24] Country-industry data from EU KLEMS and the WORLD KLEMS are also employed in the analysis constructing the TFP frontier using TFP

[21] This technical appendix was prepared by Marcos Poplawski-Ribeiro.

[22] Furceri, Kiliç Çelik, and Schnucker (2016) estimate disaggregated technology changes at the industry level, following Hall (1990) and Basu and Fernald (2001). They assume cost minimization and relate output growth to the growth of the inputs and compute the utilization-adjusted TFP growth as the difference between the aggregate TFP (Solow residual) and aggregate utilization of factors.

[23] The economies considered are: Australia, Austria, Canada, Denmark, Finland, France, Germany, Greece, Japan, Ireland, Italy, Korea, the Netherlands, Portugal, Spain, the United Kingdom, and the United States. Data availability limitations preclude the analysis for years since 2010.

[24] Data on the sectors *Publishing, audiovisual and broadcasting activities* (58–60), *Telecommunications* (61), and *IT and other information services* (62–63), are not available for Australia, Canada, Denmark, Greece, Ireland, Korea, and Portugal.

(continued)

levels (see Dabla-Norris and others),[25] and for the analysis on spillover effects through the input channel, as discussed below.

Appendix Table 4.1. Industries Used in the Estimation of Total Factor Productivity Growth

Industry Description	Industry Code
Aggregated Industries	TOT
Information and Communications Technologies Goods and Services	ELECOM
Electrical and optical equipment	26–27
Publishing, audiovisual and broadcasting activities	58–60
Telecommunications	61
Information technology and other information services	62–63
Total Manufacturing, Excluding Electrical	MexElec
Food products, beverages and tobacco	10–12
Textiles, wearing apparel, leather and related prodcuts	13–15
Other manufacturing; repair and installation of machinery and equipment	31–33
Wood and paper products; printing and reproduction of recorded media	16–18
Coke and refined petroleum products	19
Chemicals and chemical products	20–21
Rubber and plastics products, and other non-metallic mineral products	22–23
Basic metals and fabricated metal products, except machinery and equipment	24–25
Machinery and equipment n.e.c.	28
Transport equipment	29–30
Agriculture, forestry and fishing	A
Mining and quarrying	B
Electricity, gas and water supply	D–E
Construction	F
Distribution	DISTR
Wholesale and retail trade and repair of motor vehicles and motorcycles	45
Wholesale trade, except of motor vehicles and motorcycles	46
Retail trade, except of motor vehicles and motorcycles	47
Transport and storage	49–52
Postal and courier activities	53
Finance and Business, Except Real Estate	FINBU
Financial and insurance activities	K
Professional, scientific, technical, administrative and support service activities	M–N
Personal Services	PERS
Accommodation and food service activities	I
Arts, entertainment and recreation	R
Other service activities	S
Activities of households as employers; undifferentiated goods- and services-producing activities of households for own use	T
Nonmarket Services	NONMAR
Real estate activities	L
Public admin, education and health	OtQ
Public administration and defence; compulsory social security	O
Education	P
Health and social work	Q

Source: EU KLEMS data.
Note: Industries classified using International Standard Industrial Classification, Revision 4.

B. Methodology

The empirical methodology follows the approach proposed by Jordà (2005) and expanded by Teulings and Zubanov (2014), by tracing out the evolution of TFP in the aftermath of TFP shocks at the frontier through the local projection method. As argued by Stock and Watson (2007) and Auerbach and Gorodnichenko (2013), among others, this approach provides a flexible alternative

[25] We are thankful to Vikram Haksar and Minsuk Kim for providing the data on TFP levels.

that does not impose dynamic restrictions embedded in vector autoregressive (autoregressive distributed lag) estimations.

Given the data availability at the country-industry level, the analysis initially focuses on shocks in U.S. industries, assuming that they constitute the TFP frontier. This assumption is relaxed later, using data on TFP levels obtained from Dabla-Norris and others (2015) to construct a time-varying TFP frontier (maximum levels of TFP) at country-industry level for a subset of 11 countries and 18 industries (see Appendix Table 4.2).

Appendix Table 4.2. Industries with Information on Total Factor Productivity Levels, 1970–2007

Industry Description	Industry Code
Accommodation and food service activities	I
Agriculture, forestry and fishing	A
Basic metals and fabricated metal products, except machinery and equipment	24–25
Chemicals and chemical products	20–21
Electrical and optical equipment	26–27
Electricity, gas and water supply	D–E
Financial and insurance activities	K
Food products, beverages and tobacco	10–12
Machinery and equipment not elsewhere classified	28
Mining and quarrying	B
Other manufacturing; repair and installation of machinery and equipment	31–33
Real estate activities	L
Rubber and plastics products, and other non-metallic mineral products	22–23
Telecommunications	61
Textiles, wearing apparel, leather and related prodcuts	13–15
Transport and storage	49–52
Transport equipment	29–30
Wood and paper products; printing and reproduction of recorded media	16–18

Source: EU KLEMS data.

Note: Industries classified using International Standard Industrial Classification, Revision 4. Data available for the following countries: Australia, Austria, Denmark, Germany, Italy, Japan, Netherlands, Spain, Sweden, the United Kingdom, and the United States.

Spillover effects can operate within each industry (through diffusion due to competition or learning) or across industries (input channel). The corresponding econometric specifications used to estimate these TFP spillovers effects are described below.

Intra-industry Spillovers from TFP Shocks in the United States

The first specification investigates the intra-industry spillover effects of U.S. industry TFP level shocks on TFP in the same industry in the other advanced economies in this study. Using the local projection method, separate regressions are estimated at different time horizons $t+k$, as follows:

$$tfp_{i,j,t+k} - tfp_{i,j,t-1} = \alpha_{i,j} + \gamma_t + \beta_k dtfp_{US,j,t} + \delta(L)dtfp_{i,j,t} + \sum_{h=1}^{k} \theta_j dtfp_{US,j,t+h} + \varphi(L)dtfp_{US,j,t} + \varepsilon_{i,t}, \quad (1)$$

where tfp is the log level of cyclically-adjusted TFP for country i and industry j; $\alpha_{i,j}$ are country-industry fixed effects; γ_t are time fixed effects; and $dtfp_{US,j,t}$ is U.S. adjusted TFP growth at the industry level. The specification includes lags of TFP growth in the United States and the other countries. Since variables affecting TFP growth are typically serially correlated, the inclusion of

lags allows for controlling for short-term factors that affect the short-term response of TFP growth in a particular country i.

Impulse response functions (IRFs) are computed directly using the estimated coefficients β_k. That coefficient measures the intra-industry (direct) spillover effect of a 1 percent change in a particular industry-level U.S. adjusted TFP level. The 90-percent confidence bands associated with the estimated IRFs are obtained using the estimated standard deviations of the coefficients β_k. Equation (1) is estimated using heteroskedasticity-robust and autocorrelation-robust standard errors.

Inter-industry Spillover from U.S. TFP Shocks

The second specification explores the input channel by exploiting differences across countries and industries in the extent to which inputs from the United States are used in the production process. The specification is:

$$tfp_{i,j,t+k} - tfp_{i,j,t-1} = \alpha_i + \gamma_t + \beta_k \overline{\omega} \times dtfp_{US,s,t} + \delta(L)dtfp_{i,j,t} + \sum_{h=1}^{k} \theta_j dtfp_{US,s,t+H} + \varphi(L)dtfp_{US,s,t} + \varepsilon_{i,t}, \quad (2)$$

where j is a downstream industry in advanced economies other than the United States; s is the upstream U.S. industry; and $\overline{\omega}$ is a weighting matrix denoting the use of inputs from a U.S. industry s in industry j of country i. Input utilization from the technological frontier has been typically found in the literature to be a key transmission channel for knowledge spillovers (see, for example, Coe and Helpman 1995; Coe, Helpman, and Hoffmaister 2009; Rondeau and Pommier 2012), including in the trade literature, where TFP gains from imported input variety and quality have been highlighted theoretically (such as in Grossman and Helpman 1991; Markusen 1989) and identified empirically (Kasahara and Rodrigue 2008; Topalova and Khandelwal 2011; Amiti and Konings 2013; Halpern and others 2015; Ahn and others 2016).[26]

Input-output matrices are used to construct the weights of U.S. inputs in each downstream sector of the other advanced economies. Due to data limitations, and also to minimize any endogeneity issues, fixed 2005 weights are used. Specifically, each element $\overline{\omega}_{i,j,s}$ of the weighting matrix $\overline{\omega}$ is constructed as:

$$\overline{\omega}_{i,j,s} = \frac{Input\ Industry_{i,j,s,2005}}{\sum_{j=1,i=1}^{J,N} Input\ Industry_{i,j,s,2005}}, \quad (3)$$

where ω is a weighing element for each j downstream industry in the other advanced economies and upstream industry s in the United States in a $NJ \times S$ weighing matrix $\Omega_{NJ\times S}$. $N = 16$ is the

[26] Other possibilities for country-characteristics with potential knowledge spillover effects (not investigated here) include the country's relative distance from the technology frontier—defined as the gap between the country's total factor productivity and that of the United States—and financial openness vis-à-vis the country-industry frontier.

total number of advanced economies (apart from the United States), $J = 24$ is the number of downstream industries in those countries and $S = [1,24]$ is the number of upstream industries in the United States investigated. In the analysis all upstream sectors with available data ($S = J = 24$) are investigated and, by construction, the sum of the elements of $\Omega_{NJ\times S}$ equals to 1.[27]

For each year, the weighting matrix $\Omega_{NJ\times S}$ is then multiplied by the vector of U.S. TFP growth rates for each upstream U.S. industries to obtain the vector of U.S. input shocks for each country-industry for that year:

$$\forall t: \overline{\omega} \times dtfp_{US,s,t} = \begin{bmatrix} \omega_{AUS,1,s,2005} & \cdots & \omega_{AUS,1,S,2005} \\ \vdots & \cdots & \vdots \\ \omega_{AUS,24,s,2005} & \cdots & \omega_{AUS,24,S,2005} \\ \vdots & \ddots & \vdots \\ \omega_{UK,1,s,2005} & \cdots & \omega_{UK,1,S,2005} \\ \vdots & \cdots & \vdots \\ \omega_{UK,24,s,2005} & \cdots & \omega_{UK,24,S,2005} \end{bmatrix}_{NJ\times S} \times \begin{bmatrix} dtfp_{US,s,t} \\ \vdots \\ dtfp_{US,S,t} \end{bmatrix}_{S\times 1} . \qquad (4)$$

This provides a vector $NJ \times 1$ of values of weighted averages of U.S. TFP growth rates across all sectors, for all country-industry observations in each year.

II. RESULTS

Appendix Figure 4.1 displays the main results for the two exercises discussed above. Overall, the findings indicate that, historically, a shock to U.S. TFP has had a gradual, increasing, and significant spillover effect on the TFP of the other advanced economies.

The impulse response function (IRF) corresponding to the intra-industry spillover effects are displayed in Panel A. It shows that the average TFP spillover of a particular industry in the United States on the same industry in the other advanced economies is relatively small in the short term but gradually increases over time, reaching about 0.08 percentage points for each 1 percentage point U.S. TFP level shock in the medium term—five years after the shock.[28]

The analysis on inter-industry spillovers is displayed on Panel B. The IRF indicates that a 1 percentage point rise in U.S. TFP in all industries is on average associated with an approximately

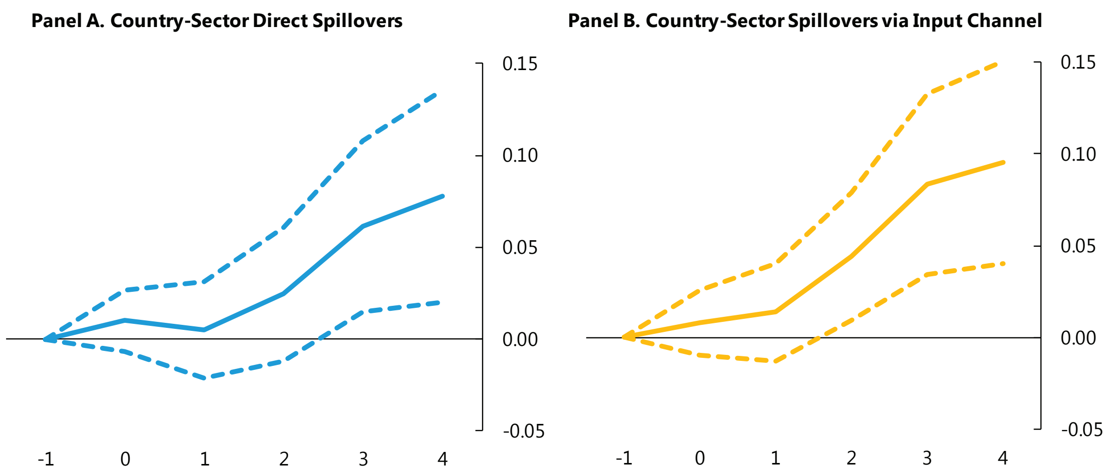
[27] Indeed, two versions of the weighing matrix $\Omega_{NJ\times S}$ are employed in the analysis. The first (baseline) eliminates inputs from an upstream industry in the United States used in a same downstream industry in the other AE. This means that the diagonals of the weighing matrix $\Omega_{NJ\times S}$ are zero, guaranteeing that the analysis is purely inter-industrial. The second version of that matrix includes non-zero values for those diagonals. The results (not shown here and available upon request) indicate very robust and similar effects using both versions of that weighting matrix.

[28] The estimations use a two-lag structure and exclude outliers at the top and bottom 5th percentile of the distribution of the TFP growth level at country-industry-year level for the advanced economies (excluding the United States).

0.1 percentage point increase in TFP in the other advanced economies in the medium term through this input channel.

Appendix Figure 4.1. Spillovers from a One Percentage Point Rise in U.S. TFP Growth to Other Advanced Economies

(Percentage points)



Sources: EU KLEMS and WORLD KLEMS data; IMF staff estimations.
Note: Years after the shock on the x-axis, t = 0 is the year of the shock. TFP = total factor productivity. Estimates of the intra-industry spillover from the United States (U.S.) TFP growth shocks to other advanced economies for different horizons obtained via local projections method. The input channel is estimated by interacting the U.S. TFP growth shocks with a weighting matrix capturing the importance of each U.S. industry as an input for a particular industry in each other advanced economies. Estimations include country-sector- and year-fixed-effects and exclude top and bottom fifth percentiles of the U.S. TFP growth sample distribution at industry level as outlier treatment. Dashed lines denote 90-percent confidence intervals. Countries considered are Australia, Austria, Canada, Denmark, Finland, France, Germany, Greece, Japan, Ireland, Italy, Korea, the Netherlands, Portugal, Spain, the United Kingdom, and the United States.

Those two results in Appendix Figure 4.1 indicate a combined (intra- and inter-industry) spillover effect of around 0.2 percentage points in the medium-term for a given 1 percentage point TFP level shock (in all industries) in the United States. This suggests that the observed slowdown in U.S. TFP growth in industries where the United States is the technological leader can partly explain the TFP growth slowdown in the other advanced economies. It should be noted that an average 0.2 percentage point effect of a 1 percentage point TFP shock at the frontier after five years implies that about 4 percent of the gap between the frontier and lagging countries is closed in a year. This is about twice as much as the typical speed of resorption of GDP per capita gaps found in the empirical growth literature (see Barro and Sala-i-Martin 2004).

III. ADDITIONAL RESULTS AND ROBUSTNESS CHECKS

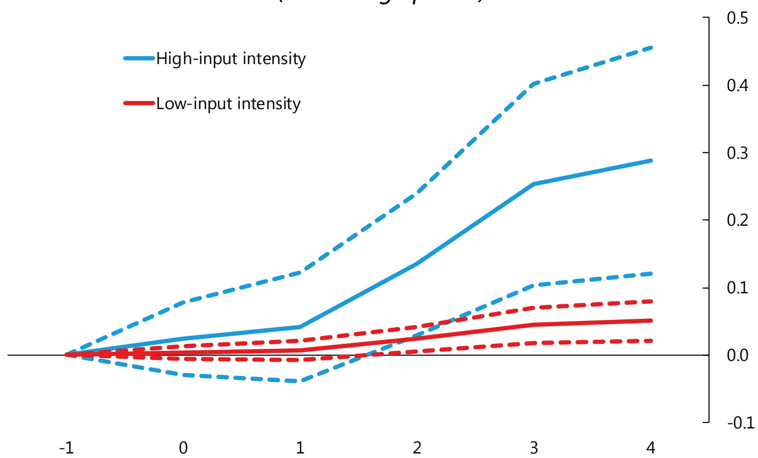
A. High and Low U.S. Input Utilization

The results presented above correspond to a country with an average use of U.S. inputs. However, the variance in U.S. input utilization is relatively high across advanced economies. A rescaling of the effect—in line with a linear specification, as in Equation (2)—for the 25th and 75th

percentiles of the input-intensity weight distribution is shown in Appendix Figure 4.2.[29] These IRFs suggest that TFP spillovers are significantly larger for countries with high U.S. inputs utilization. In particular, the increase in TFP in a country that is relatively strongly linked with the United States (at the 75th percentile) is about six times larger, at 0.23 percentage points, than in a country that has relatively low linkages (at the 25th percentile).

Appendix Figure 4.2. Inter-Industry Spillovers Through the Input Channel (High- and Low-Intensity)

(Percentage points)



Sources: Furceri, Çelik, and Schnucker (2016); EU KLEMS and WORLD KLEMS data; and IMF staff estimations.
Note: Years after the shock on the x-axis, t = 0 is the year of the shock. TFP = total factor productivity. Input channel is estimated by interacting the United States (U.S.) TFP growth shocks with a weighting matrix capturing the importance of each U.S. industry as an input for a particular industry in each other advanced economies. High- and low-intensity correspond to the 75th and 25th percentiles of the cross-country-industry distribution of the input weights in the sample. Estimations include country-sector- and year-fixed-effects and exclude top and bottom fifth percentiles of the U.S. TFP growth sample distribution at industry level as outlier treatment. Dashed lines denote 90-percent confidence intervals.

B. Average TFP Growth Changes in Advanced Economies

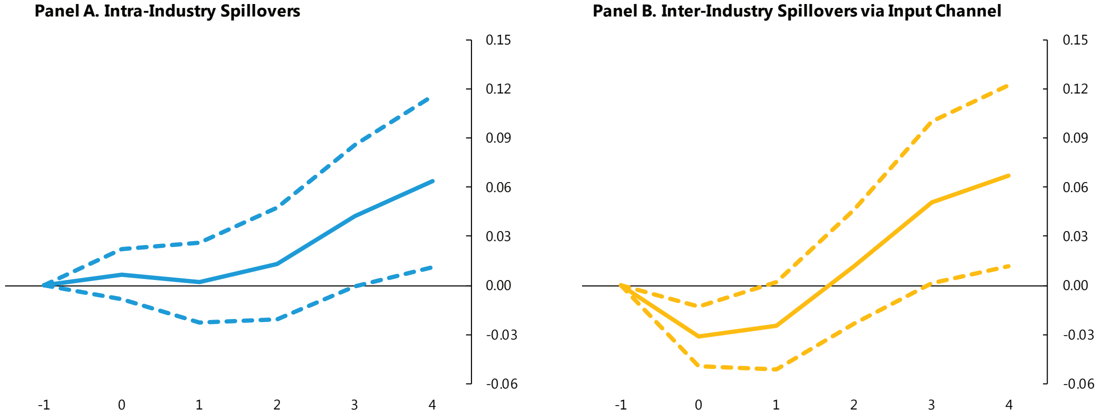
A possible concern in the estimation of Equation (1) is reverse causality and omitted variable bias. That is because changes in TFP in other countries may affect U.S. TFP, or respond to common technological shocks. Thus, a robustness check is implemented by adding the average change in TFP growth across other advanced economies following a U.S. TFP shock as an additional control in the estimation of Equation (1).

Appendix Figure 4.3 displays the corresponding IRFs, which indicate that the estimated medium-term spillover effects are robust to this robustness exercise, and only slightly smaller than the combined effect of 0.2 percentage points found in the previous analysis.

[29] More specifically, this is done by using the same coefficient β_k estimated using Equation (2), but rescaling it by the ratio between the 75th (or 25th) percentile and the average value of the of the United States input intensity across its whole country-industry-year distribution.

Appendix Figure 4.3. Spillovers from U.S. TFP Shocks, Controlling for Average TFP Changes in Other Advanced Economies

(Percentage points)



Sources: Furceri, Çelik, and Schnucker (2016); EU KLEMS and WORLD KLEMS data; and IMF staff estimations.
Note: Years after the shock on the x-axis, t = 0 is the year of the shock. TFP = total factor productivity. Estimates of the intra-industry relationship between shocks in the United States (U.S.) TFP growth and TFP growth at the country-industry level in other advanced economies for different horizons are obtained via local projection method. The input channel is estimated by interacting the U.S. TFP growth shocks with a weighting matrix capturing the importance of each U.S. industry as an input for a particular industry in each other advanced economies. Estimations include country-industry- and year-fixed-effects and exclude top and bottom fifth percentiles of the U.S. TFP growth sample distribution at industry level as outlier treatment. Dashed lines denote 90-percent confidence intervals.

C. Frontier Analysis

An additional refinement entails relaxing the assumption that the United States is the technological frontier across sectors. This is done by focus on TFP shocks from a time-varying industry frontier. While this is conceptually a clearer exercise than the baseline one presented above, it requires level (rather than growth) TFP data that are more scarce and subject to methodological limitations.[30]

The time-varying frontier is calculated by using the TFP levels from Dabla-Norris and others (2015) and finding the maximum TFP level for each available industry and year across the 11 countries (with available TFP level data). Once these frontier country-industries are identified for each year, their TFP growth rates replace $dtfp_{US,j,t}$ in the estimation of (1) and (2), while making sure that the particular country in the frontier is not included in the left-hand side of those equations and that the United States is inserted in the left-hand side when not identified as being in the frontier.

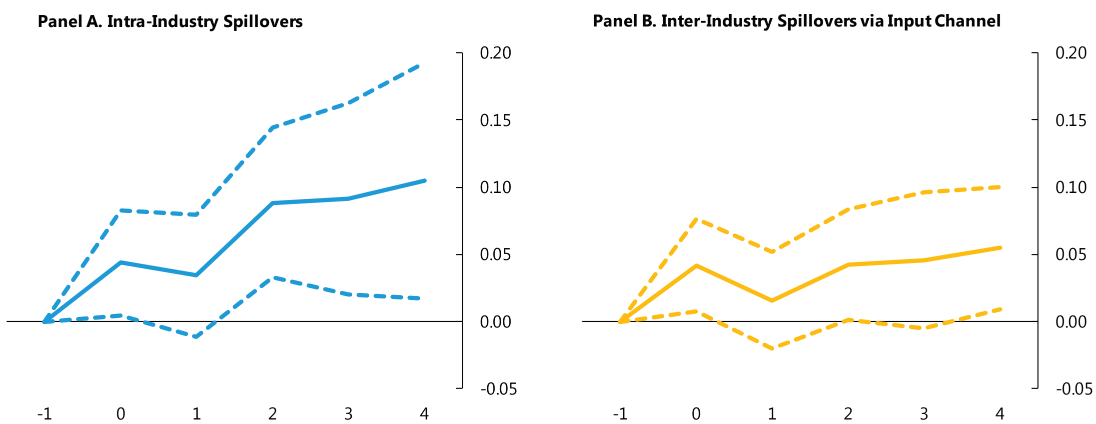
Appendix Figure 4.4 shows the estimated IRFs for both equations over the period 1985–2007. For both the intra- and inter-industry spillover analysis, the IRFs are significant in the medium term, indicating the previous findings are robust to this refinement. A one percent frontier TFP shock leads, on average, to a 0.05 percentage point increase in TFP in other Advanced economies in the

[30] EU-KLEMs provides data on TFP level only for some years (particularly 1996), which were projected forward via an inventory method using TFP growth rates more broadly available. See Appendix Table 4.2 for the list of industries containing information on TFP levels and the Technical Appendix 3 of Dabla-Norris and others (2015) for more details in the construction of this variable.

short term—1 year after the shock—and by about 0.1 percentage points in the medium term—5 years after the shock. For the inter-industry analysis via the input channel, the estimated spillover effects in this refined exercise are slightly lower than in the baseline estimation: a one percent frontier TFP shock leads, on average, to a 0.04 percentage point increase in TFP in other advanced economies in the short term—1 year after the shock—and by about 0.06 percentage points in the medium term—5 years after the shock.

Appendix Figure 4.4. Spillovers from TFP-Frontier Growth Shocks to Other Advanced Economies, 1985–2007

(Percentage points)



Sources: Furceri, Çelik, and Schnucker (2016); EU KLEMS and WORLD KLEMS data; and IMF staff estimations.
Note: Years after the shock on the x-axis, t = 0 is the year of the shock. TFP = total factor productivity. Estimates of the intra-industry relationship between shocks in the United States (U.S.) TFP growth and TFP growth at the country-industry level in other advanced economies for different horizons are obtained via local projection method. The input channel is estimated by interacting the U.S. TFP growth shocks with a weighting matrix capturing the importance of each U.S. industry as an input for a particular industry in each other advanced economies. Estimations include country-industry- and year-fixed-effects and exclude top and bottom fifth percentiles of the U.S. TFP growth sample distribution at industry level as outlier treatment. The inter-industry spillovers are estimated with one lag instead of two. Dashed lines denote 90-percent confidence intervals.

IV. CONCLUSIONS

This technical appendix estimates intra- and inter-industrial spillover effects from a slowdown of TFP growth at the frontier to TFP in the other advanced economies.

The findings indicate a combined (intra- and inter-industry) spillover effect of around 0.15–0.2 percentage points in the medium-term for a given 1 percentage point TFP shock in the frontier. This suggests that the observed slowdown in U.S. TFP growth, and at the industry-specific technological frontier more broadly, can partly explain a the TFP growth slowdown in the other advanced economies. Indeed, these are robust to calculating an alternative technological frontier using industry data on TFP levels rather than taking the United States as the frontier and to including additional variables in the analysis.

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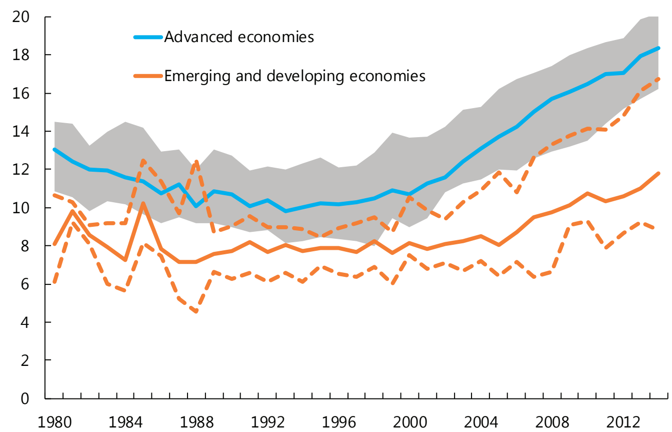
APPENDIX V. LABOR FORCE AGING AND PRODUCTIVITY GROWTH[31]

I. INTRODUCTION

Over the last two decades, many advanced economies and emerging market economies have witnessed the effects of demographic transition on their workforces, as population aging has led to significant increases in the share of most senior workers, particularly in advanced economies (Appendix Figure 5.1).

Appendix Figure 5.1. Share of Elderly (Ages 55–64) to Total Labor Force Participation

(Percent)



Sources: International Labour Organization Labour Statistics; IMF staff estimations.
Note: Solid lines display the median of the distribution of the share of old labor force participation. Shaded area and dashed lines represent the interquartile range.

This secular trend may have direct implications for productivity growth. As stressed in the literature, a worker's productivity varies over her working life, for reasons such as the accumulation of experience over time, depreciation of knowledge, and age-related trends in physical and mental capabilities. On one hand, a mature labor force will have higher average levels of work experience, with positive effects on productivity (Disney 1996). On the other hand, the workforce's stock of skills is likely to become increasingly dated as the average age of workers rises, leading to a decline of innovation and productivity (Dixon 2003; Feyrer 2008; Aksoy and others 2015; Jones 2010). Moreover, if job requirements evolve as a result of structural changes in the economy, older workers may find it more difficult to adapt (OECD 1998), especially with increased penetration of information technologies (Dixon 2003).

However, empirical work on this issue remains scarce and the evidence is somewhat mixed. For example, Feyrer (2008) shows that in the United States, the median age of innovators has been

[31] This technical appendix was prepared by Marcos Poplawski-Ribeiro.

stable at about age 48 over 1975–95, whereas the median age of managers who adopt new ideas is lower at around age 40. Aksoy and others (2015) also show that demographic structure affects innovation, with older workers (in particular the 50–59 age group) having a strong negative impact on the number of patent applications. Consistent with this, Jones (2010) finds that innovation increases with the presence of young and middle-aged cohorts and is reduced by the presence of older cohorts. Other recent papers, based on sector or firm-specific data, yield mixed results. Acemoglu, Akcigitz, and Celik (2014) show that younger managers lead firms to have more innovation as they are more open to product destruction. Göbel and Zwick (2012) find no significant differences in age-productivity profiles between manufacturing and services sectors in Germany, whereas Börsch-Supan and Weiss (2016) find that the productivity of workers in a large car manufacturer in Germany declines at around age 60. Taken together, these results might suggest that aggregate effects could be larger than sector or firm-level effects when externalities linked to workforce aging are taken into account (Feyrer 2007). More recently, Maestas and others (2016) study the relationship between aging and GDP per capita across U.S. states, finding a negative association between them. Acemoglu and Restrepo (2017), on the other hand, explore the issue and conclude that the link between aging and economic growth is not significant, which they explain by the greater incentives to adopt labor-saving innovations in rapidly aging societies. Their findings suggest that the effects of aging have been, at least recently, offset by the adoption of automation technologies.[32]

This technical appendix reassesses the relationship between changes in the share of older workers in the labor force (age 55–64) and total factor productivity (TFP) growth at the country level.

The econometric evidence indicates that aging has played a meaningful role in slowing down TFP growth both for advanced economies and emerging market economies over the last two decades. In particular, the observed increase in the share of older workers may have contributed to the TFP slowdown, on average, by as much as 0.2–0.5 percentage points a year in advanced economies and 0.1 percentage points a year in emerging market economies during the 2000s.

II. Empirical Strategy

The empirical strategy builds on Feyrer (2007) and Aiyar, Ebeke and Shao (2016).[33] Taking Feyrer's specification as a benchmark, this appendix (i) extends the sample coverage to 2014, by using updated data on labor force participation from the International Labour Organization (ILO);

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[32] Methodologically, we differ from Acemoglu and Restrepo (2017) in that we (i) focus on TFP rather than GDP per capita; (ii) use a more restrictive definition of aging based on the share of employed workers, (iii) allow for dynamic effects on this relationship by using five-year panel—instead of cross-section—data and techniques (time fixed-effects); and (iv) instrument the latter using past demographic characteristics of the population, as explained in more detail below.

[33] See also related work by Jaimovich and Siu (2009), and Wong (2007).

(continued)

(ii) adds a new identification strategy to instrument labor force aging and estimate its effect on TFP growth; and (iii) refines the approach by focusing on the age structure of employed workers (as opposed to the age structure of the labor force).[34]

A. Data

The analysis focuses on a panel data set composed of at least 31 and at most 60 Advanced economies and emerging market economies over the period 1985–2014.[35]

Drawing on the recent cross-country empirical literature (Feyrer, 2007; Cuaresma, Loichinger, and Gallina, 2016), workforce aging is measured in two alternative ways: (i) the ratio of older workers (aged 55–64) to the total labor force; and (ii) the ratio of older employed workers (ages 55–64) to the total number of employed workers. Data on labor force participation by age group is obtained from a newly updated data set from the ILO, focusing on a selected group of 68 countries (see details in Appendix Table 5.1). Data on employment by age group for a smaller set of 35 advanced economies and emerging market economies is obtained from the OECD Labor Statistics (Appendix Table 5.1).

Appendix Table 5.1. Sample of Economies Included in the Analytical Exercises

Group 1/	Economies 2/	Exercise 3/ I	II	III	IV
A	Australia,* Austria,* Belgium,* Canada,* Chile, Czech Republic,* Denmark,* Estonia,* Germany,* Finland,* France,* Hungary, Ireland,* Israel,* Italy,* Japan,* Korea,* Netherlands,* New Zealand,* Norway,* Portugal,* Slovak Republic,* Spain,* Sweden,* Switzerland,* Turkey, United Kingdom,* United States*	X	X	X	X
B	Brazil, Slovenia,* South Africa	X	X	X	
C	Mexico	X		X	X
D	Argentina, Bulgaria, Chile, Costa Rica, Croatia, Dominican Republic, Egypt, Guatemala, Hong Kong SAR,* Honduras, Iceland,* Indonesia, Jamaica, Malta,* Mauritius, Mongolia, Morocco, Panama, Paraguay, Philippines, Poland, Romania, Senegal, Singapore,* Thailand, Tunisia, Ukraine,	X	X		
F	Greece,* Russia			X	X
G	Barbados, Benin, Burundi, Burkina Faso, Cyprus,* Lesotho, Moldova, Peru, Sri Lanka, Uruguay	X			
H	Colombia			X	

Source: IMF staff compilation.
1/ Group of countries according to their use in different analytical exercises.
2/ Asterisk (*) denotes advanced economies as classified by IMF, *World Economic Outlook*.
3/ Analytical exercises performed: I = fixed effects (FE) and ordinary least squares (OLS) estimation with International Labour Organization (ILO) data; II = FE and two-stage least squares (2SLS) estimation with ILO data; III = FE-OLS estimation with Organisation for Economic Co-operation and Development (OECD) data; IV = FE-2SLS estimation with OECD data.

[34] Compared to Aiyar, Ebeke and Shao (2016), this appendix (i) analyzes the effects of changes in (instead of the level of) older worker labor force participation on productivity growth; and (ii) extends their analysis to emerging market economies.
[35] The raw dataset initially covers 202 countries over the period of 1960 to 2014. See Appendix Table 5.1 for the list of all countries actually covered in the analysis once data availability constraints are taken into account.

TFP growth at country level is obtained from the Penn World Table (PWT, 9.0). Finally, population data (total and by age group) and dependency ratios are retrieved from the UN Population Statistics.

B. Methodology

As in Feyrer (2007), the analysis tests whether the TFP level $(TFP)_{i,t}$ in country i at time t is affected by the share older labor force participants in the total labor force, or alternatively, the share of employed older workers (aged 55–64) in total employment. The econometric specification is:

$$log(TFP)_{i,t} = \alpha_i + \gamma_t + \beta w55_{i,t} + \delta yadr_{i,t} + \varphi oadr_{i,t} + \varepsilon_{i,t}, \quad (1)$$

where α_i is a time-invariant country fixed effect; γ_t is a time fixed effect common to all countries; $oadr_{i,t}$ $(yadr_{i,t})$ is the old- (young-) age dependency ratio. Both ratios are additional controls for the effect of aging on TFP levels.[36]

Given that aging is a slow-moving process that is likely to affect TFP only gradually, all variables in Equation (1) are measured as non-overlapping at five-year averages. Moreover, to deal with the fact that log(TFP) is I(1), the estimation of (1) is done in first-differences (Δ):

$$\Delta log(TFP)_{i,t} = \alpha_i + \gamma_t + \beta \Delta w55_{i,t-1} + \delta \Delta yadr_{i,t} + \varphi \Delta oadr_{i,t} + \varepsilon_{i,t}, \quad (2)$$

where standard errors are clustered by country to correct for serial correlation in the error term, which is further attenuated by the use of 5-year averages.

Equation (2) is initially estimated using panel fixed-effects ordinary least squares (FE-OLS). However, a potential issue is the endogeneity of the share of older workers (or that of older labor force participants) to TFP. Experienced individuals may supply more labor in response to wage-augmenting technological innovations. At the same time, higher income arising from faster aggregate productivity growth may induce older workers to leave the labor force. Hence, the direction of the possible endogeneity bias is unclear. As in Aiyar, Ebeke and Shao (2016), the share of older workers is instrumented—as one of the alternative specifications for equation (2)—by the 10- to 14-year lagged share of the population aged 45–54 years. Such variable should be highly correlated to the share of workers aged 55–64 a decade later, but orthogonal to future technological innovations. The instrumental variable specification is estimated via panel fixed-effect two-stage least squares (FE-2SLS).

[36] Those dependency ratios are obtained here by dividing the share of young (0–14 years-old) and old (65+ years-old) population to the active population. They aim to capture several other channels through which a higher dependency ratio (that is, fewer workers in a fixed population) could affect productivity, such as lower aggregate savings (life cycle theory) and thereby lower investment rates, pressures on public finances via age-related spending increases, greater aggregate volatility (Jaimovich and Siu, 2009), and structural transformation (Siliverstovs and others 2011). See Aiyar, Ebeke and Shao (2016) for a detailed discussion.

III. Results

Appendix Table 5.2 reports the estimated relationship between our demographic variable of interest and TFP growth over 1985–2014. The results are reported for both the FE-OLS and FE-2SLS (instrumental variable) estimators. Moreover, different data sets are used to check the robustness of the findings.

The results show that aging can meaningfully slowdown TFP growth in advanced economies and emerging market economies. For example, the significant coefficient of older labor force participation in the OLS regression in Column (1) indicates that a 1 percentage point increase in the share of 55–64 years-old age group leads to a statistically significant cumulative decrease in TFP of about 0.7 percentage points over five years (that is, about 0.15 per year).

This negative OLS coefficient remains statistically significant when OECD data are used for older labor force participation as shown in column (3). The coefficient in that column is higher as the country sample includes only Advanced economies and EMs, possibly because these economies have been more affected by the population aging than low-income countries (see Appendix Figure 5.1). For older employed workers—a variable that should be more directly connected to the efficiency of the production process *a priori*—the coefficient using OLS is not significant as shown in column (4). This indicates issues with the endogeneity of that variable and challenges in estimating such relationship using OLS.

The robustness of the results increases by using the FE-2SLS estimator. All coefficients become statistically significant and are quantitatively larger in this case, indicating a downward bias of the (OLS) estimates when not dealing with the endogeneity. In particular, when using the OECD data set and country sample—Appendix Table 5.2, Column (8)—the estimation suggests that a 1 percentage point increase in the share of older workers in the labor force leads to a statistically significant cumulative decrease in TFP growth of about 1.8 percentage points over five years (that is, about 0.35 percentage points per year).

To illustrate the economic significance of those results, Appendix Figure 5.2 depicts the estimated contribution of aging to average annual TFP growth in the 2000s, under the alternative estimations.[37] In all cases, the estimates point to economically sizable adverse effects of aging, of some 0.2–0.5 percentage points in advanced economies and about 0.1 percentage points in emerging market economies.

[37] The solid dots are constructed by using the estimates from columns (4) and (8) of Appendix Table 5.1 and taking the difference in the average share of older labor force in the 1990s (13.8 percent of the total labor force) minus the average share of older labor force in the 2000s (10.6 percent of the total labor force).

Appendix Table 5.2. Effects of an Increasingly Elderly Labor Force on Productivity (TFP) Growth, 1985–2014

Panel estimation method	Fixed Effects -OLS				Fixed Effects - Instrumental Variable			
Labor variables database	ILO[a]	ILO[a,b]	OECD[c]	OECD[c]	ILO[a]	ILO[a,b]	OECD[c]	OECD[c]
Independent Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Δ share of old labor force	-0.864**	-0.873**			-2.166**	-2.449**		
	(0.390)	(0.405)			(1.074)	(1.175)		
Δ share of old labor force $_{t-1}$			-0.909**				-1.702*	
			(0.355)				(0.960)	
Δ share of old employed workers $_{t-1}$				-0.641				-1.774*
				(0.404)				(0.956)
Δ old dependency ratio	-0.019***	-0.020***	-0.008*	-0.009	-0.029***	-0.033***	-0.006	-0.006
	(0.006)	(0.006)	(0.005)	(0.006)	(0.009)	(0.010)	(0.004)	(0.004)
Δ young dependency ratio	-0.006*	-0.008***	-0.003	-0.001	-0.004	-0.007**	-0.007*	-0.008*
	(0.003)	(0.003)	(0.004)	(0.003)	(0.003)	(0.003)	(0.004)	(0.004)
Adjusted R-squared[d]	0.21	0.24	0.45	0.44	0.16	0.15	0.26	0.23
Regression F-statistic	9.80	9.35	15.96	15.66	6.93	6.54	11.70	11.64
Anderson correlations (underidentification) LR statistic					19.90	17.19	19.44	16.14
Anderson correlations LR test p-value					0.00	0.00	0.00	0.00
Cragg-Donald chi-square (weak identification) statistic					20.91	17.99	21.18	17.32
Cragg-Donald chi-square test p-value					0.00	0.00	0.00	0.00
Country-fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Time-fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Number of countries	73	68	36	36	63	57	32	32
Number of observations	274	257	151	151	264	246	147	147

Source: IMF staff estimates.

Notes: Significance at *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$; time- and country fixed-effects not reported in the table. Instrumental variable is here the 10 to 14 years lagged share of population at age 44–54 years-old to total population. All overidentification tests reject the null hypothesis. List of countries included in the analyses reported in Table 1.

[a] Sample includes all IMF *World Economic Outlook* economies with data available excluding Greece, Latvia, Lithuania, Luxembourg, Serbia, and Zimbabwe, and excludes top and percentile of the TFP growth rates distribution as outlier treatments.

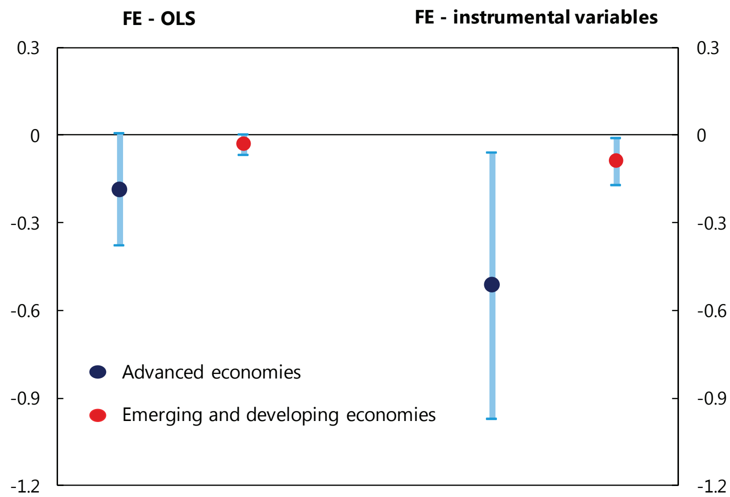
[b] Sample further excludes countries with less than 1 million people in 2014.

[c] Sample includes all OECD economies with data available excluding Latvia and countries with less than 1 million people in 2014.

[d] For estimations with instrumental variables, the centered R-squared is reported.

Appendix Figure 5.2. Estimated Effect on TFP Growth of Change in Share of Elderly Labor Force (Aged 55–64) Between the 1990s and the 2000s

(Annual average, percent)



Sources: International Labour Organization Labour Statistics; IMF staff estimations.
Note: TFP = total factor productivity, FE= fixed effects, and OLS = ordinary least squares. Vertical lines indicate the 90-percent confidence bands. Average effects for each income group are based on observed changes in the share of old employed workers, and the estimated effects on TFP growth.

IV. CONCLUSIONS

This technical appendix has explored the relationship between labor force aging and TFP growth in a panel setting composed of advanced economies and emerging market economies over 1985–2014. The evidence indicates that aging can meaningfully slowdown TFP growth in advanced economies and emerging market economies. The observed increase in the share of older workers in the labor force may have contributed to the TFP slowdown, on average, by as much as 0.2–0.5 percentage points a year in advanced economies and 0.1 percentage points a year in emerging market economies during the 2000s. Given the projected demographic trends, the findings indicate that population aging will remain a drag on productivity growth in the years to come.

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APPENDIX VI. TRADE AND PRODUCTIVITY GROWTH[38]

Anemic global productivity growth in recent years has been accompanied by a slowdown in global trade. While the trade slowdown is first and foremost the result of weak economic activity, waning trade liberalization efforts and the maturation of global supply chains have also been a driving factor (IMF 2016). Irrespective of its sources, however, the trade slowdown itself can have potentially important implications for productivity, through two main channels:

- Import penetration. With stronger foreign competition increasing pressure on domestic firms to produce more efficiently or to innovate; and imported inputs expanding the variety of and enhancing the quality of the intermediate goods to which firms have access;

- Exports, which can improve firm-level productivity through exposure to competition or improved access to foreign markets.

These channels can operate both at the firm level—by inducing firms to adapt more efficient production processes, improve product quality, or undertake specific investments—and at the sectoral level, by inducing a reallocation of resources toward more productive firms within a sector. The relevance of these effects on productivity growth are explored in this technical appendix.

A. Empirical Strategy

The empirical strategy entails using the opening of China to international trade over the last two decades as an exogenous shock to identify the effects of greater trade integration on productivity, using country-sector level data on trade and productivity.

In order to identify the respective effects of export and import—both vis-a-vis China—on productivity at the country-sector level, the following empirical specification is considered:

$$\ln TFP_{ist} = \beta_1 IMP^{CHN}_{is,t-l} + \beta_2 EXP^{CHN}_{is,t-l} + FE_{is} + FE_{it} + \varepsilon_{ist}, \qquad (2)$$

where subscripts i, s, t denote country, sector, and year, respectively. The dependent variable $\ln TFP_{ist}$ denotes log total factor productivity (TFP) in country i and sector s in year t, while $IMP^{CHN}_{is,t-l}$and $EXP^{CHN}_{is,t-l}$ are the corresponding country-sector-level imports from China (as a ratio to total domestic output) and exports to China (as a ratio to total domestic output), both lagged l years. The specification also includes country-sector (FE_{is}) and country-year fixed effects (FE_{it}).

[38] This technical appendix was prepared by Jaebin Ahn, and is based on Ahn and Duval (forthcoming).

The latter control for any variation that is common to all sectors of a country's economy, including for instance exchange rate shocks, aggregate output growth or reforms in other areas. The country-industry fixed effects allow us to control for industry-specific factors, including, for instance, cross-country differences in the growth of certain sectors that could arise for instance from differences in comparative advantage. This specification with fixed effects is tantamount to asking how changes in trade with China in a given sector and country are associated with changes in productivity levels in that country-sector.

To address potential endogeneity bias in the simple OLS estimates, we follow Autor, Dorn, and Hanson (2013) by instrumenting imports from China in a given country-sector with average imports from China in the same sector but other countries of the sample. Likewise, we propose the average exports to China in other countries as an instrumental variable for exports to China in any given country-sector. In so doing, we aim to exploit exogenous portions of imports from China (supply-driven) and exports to China (demand-driven) in 2SLS procedures.

B. Data

We combine the country-sector-year-level TFP data from the EU KLEMS and World KLEMS databases with the corresponding trade data from the World Input Output Database (WIOD). This data set provides annual information on sectoral input, output, TFP as well as export (by destination countries) and import (by source countries) over 1995–2011, covering 18 manufacturing and non-manufacturing sectors across 18 advanced economies.[39]

C. Estimation Results

Appendix Table 6.1 presents the baseline regression results from both simple OLS (columns 1–3) and 2SLS (columns 4–6), showing the impact of imports from China and exports to China on TFP.

39 The sample of includes: Australia, Austria, Canada, Czech Republic, Finland, France, Germany, Hungary, Ireland, Italy, Japan, Korea, Netherlands, Slovenia, Spain, Sweden, United Kingdom, and the United States of America.

Appendix Table 6.1. Estimates of Effect of Trade on Total Factor Productivity

	OLS			2SLS		
Dependent variable: [ln (TFP)ist]	(1)	(2)	(3)	(4)	(5)	(6)
(Imports from China/Total ouput)*100ist-1	0.006 **		0.005 *	0.017 ***		0.009 ***
	(0.003)		(0.003)	(0.006)		(0.003)
(Exports to China/Total outputs)*100ist-1		0.051 ***	0.048 ***		0.129 ***	0.112 ***
		(0.012)	(0.011)		(0.040)	(0.037)
First stage F-stats				62.4	36.9	32.9; 22.4
First stage p-value				0.00	0.00	0.00; 0.00
Obs	3,543	3,543	3,543	3,543	3,543	3,543

Source: IMF staff estimates.

Note: OLS = ordinary least squares, 2SLS = two-stage least squares. The dependent variable is log total factor productivity (TFP) in country *i* and sector *s* in year *t*. Independent variables are corresponding country-sector-level imports from China (as a ratio to total domestic output) and total exports to China (as a ratio to total domestic output), both lagged one year. The average value of imports from China relative to domestic output in all other countries and the average value of exports to China relative to domestic output in all other countries, both lagged one year, are used as instrumental variables for corresponding variables in columns (4)-(6). Country-sector as well as country-year fixed effects are included in all columns. Robust standard errors clustered at country-sector level are provided in parentheses.

D. Contributions to TFP Growth

The median country-sector in the sample experienced cumulative TFP growth of 14.7 percent between 1995 and 2007. During the same period, a median increase in the ratio of imports from China to total domestic output was 0.84 percentage points, whereas the increase in the ratio of exports to China to total domestic output was 0.3 percentage points. Following the methodology employed in Autor, Dorn, and Hanson (2013), we quantify that an exogenous portion of an increase in the ratio of imports from China to domestic output was 70 percent, while that in the ratio of exports to China was 30 percent.[40] Taking the benchmark semi-elasticity of 0.9 and 11.2 from imports and exports, respectively (column (6) in Appendix Table 6.1), we conclude that the exogenous variation in trade with China could explain up to 10 percent of the total increase in TFP growth (or 1.5 percent growth in level) in median country-sector.[41]

[40] For details, see Appendix B.A in Autor, Dorn, and Hanson (2013).

[41] (0.84*0.7)*0.9+(0.3*0.3)*11.2=1.5

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APPENDIX VII. IMPACT OF MIGRATION ON PRODUCTIVITY IN RECEIVING COUNTRIES[42]

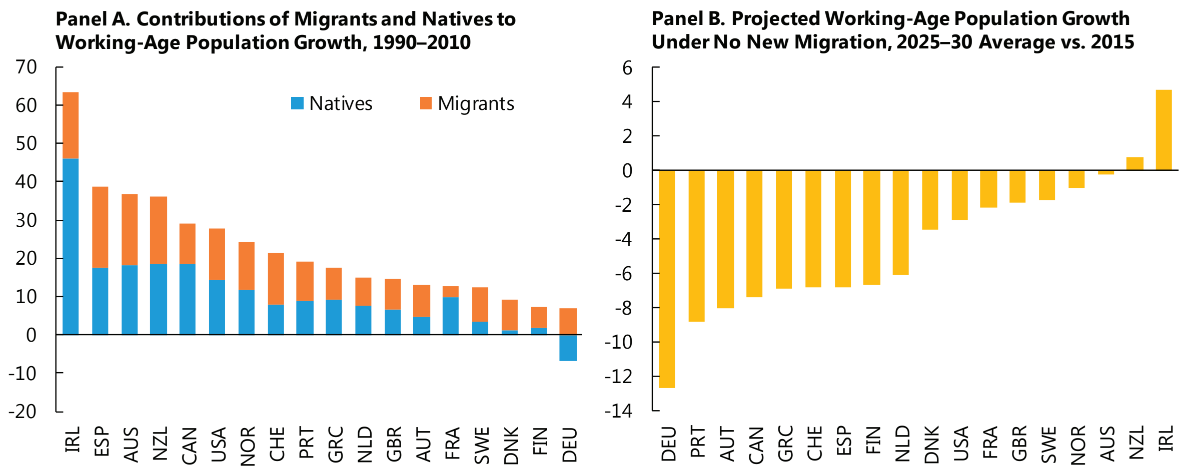
This appendix studies the impact of immigration on labor productivity and its components, with a focus on advanced economies. It builds on the recent work by Jaumotte, Koloskova and Saxena (2016). In line with previous literature, the analysis finds that migration can lead to economically meaningful long-term productivity gains.[43] These findings indicate that migration policies can be important not only in addressing adverse demographic challenges (population aging) but also in boosting aggregate productivity.

A. Migrants and Working-Age Population

Migration has already played an important role in mitigating the shrinking labor force in some advanced economies. Between 1990 and 2015, immigrants contributed about ½ of the growth in working-age population in many of these economies (Appendix Figure 7.1—Panel A), boosting the ratio of working age-to-total population.

Appendix Figure 7.1. Migration and Working-Age Population in Advanced Economies

(Percent)



Source: Jaumotte, Koloskova, and Saxena (2016).
Note: Data labels in the figure use International Organization for Standardization (ISO) country codes. Working-age population refers to age group 15–64. Sample of countries includes Australia, Austria, Canada, Denmark, Finland, France, Germany, Greece, Ireland, the Netherlands, New Zealand, Norway, Portugal, Spain, Sweden, Switzerland, the United Kingdom, and the United States.

[42] This technical appendix was prepared by Ksenia Koloskova, building on Jaumotte, Koloskova, and Saxena (2016).

[43] Ortega and Peri (2014) study the long-run impact of immigration share on incomes per capita in a large cross-section of countries and find that the effect mainly operates through total factor productivity. Alesina, Harnoss, and Rapoport (2016) focus on the birthplace diversity aspect of migration, and find positive effects of skilled immigrants diversity on total factor productivity.

With adverse demographics projections for most advanced economies, the role of immigration in maintaining a favorable demographic structure is likely to become even more important in the coming years. In the absence of further migration, the United Nations projects that working-age population will decline by as much as 5–10 percent in a large group of advanced economies—including large systemic economies such as Germany, Australia, Canada—over the next 10–15 years (Appendix Figure 7.1—Panel B).

In addition to mitigating population aging, immigration can arguably play a role in boosting aggregate productivity, in part because migrants are typically younger than the natives, but also through other channels such as innovation and complementarity of skills with natives. This is the focus of the following section, which assesses empirically the effect of immigration on labor productivity.

B. Methodology

Following Jaumotte, Koloskova, and Saxena (2016), the effect of migration on the variables of interest (output per worker, TFP, and so on) is estimated using the following specification:

$$\ln y_{dt} = \beta_0 + \beta_M MSH_{dt} + \beta_S \ln S_{dt} + \beta_C Controls_{dt} + \mu_d + \theta_t + \varepsilon_{dt} \qquad (1)$$

where y is the variable of interest, d is the destination country, t is time; MSH_{dt} is the migration share of defined as the number of foreign born adults relative to the destination country's adult population. Throughout the analysis, migration is defined according to the country of birth rather than citizenship, as the latter can change with naturalization and legislation regulating the acquisition of citizenship typically varies among countries and time. Throughout the analysis, both migrants and population refer to individuals aged 25 and older. S_{dt} is the total population of the destination country (which allows to control for country size); $Controls_{dt}$ is a vector of other control variables such as the share of population with high and medium skills, trade openness, young dependency ratio and age structure of the working-age population (lagged by 5 years to mitigate endogeneity problems); μ_d denotes the destination country fixed effects; θ_t is the common time fixed effect, and ε_{dt} is the error term.

Estimation of Equation (1) with an Ordinary Least Squares (OLS) estimator could lead to several potential biases, related to reverse causality, omitted variable, and measurement error. Thus, we estimate it using a Two-stage Least Squares (2SLS) procedure, where the share of migrants is instrumented using the predicted migration shares from an estimated pseudo-gravity model.[44] In addition, total population—one important control in Equation (1)—is instrumented using native

[44] The model predicts bilateral migration shares based on origin countries' push factors, such as economic, political and social factors, and based on bilateral geographic and cultural migration costs (and their interactions). It does not include pull factors specific to the destination country, as they could be correlated with destination country's productivity. Predicted bilateral migration shares from the model are aggregated across origin countries to obtain an instrument for total migration share at destination.

population to clean out the contribution of migration. See Jaumotte, Koloskova, and Saxena (2016) for details.

C. Data

Data on migration comes from the Institute for Employment Research, which reports the immigrant (foreign-born) population for ages 25 years and older, by gender, country of origin, and educational level. The sample covers 18 OECD countries over 1980–2010, with data reported at five-year-intervals.[45] The sample used for the estimation of Equation (1) is based on 1990–2010 data, as the observations in 1980–1985 are used in the gravity model to construct the series for the instrumented migration share starting from 1990.

Data on the shares of population 25 years and older (with high education and secondary school) come from the Barro-Lee data set. Series of young dependency ratio (share of population 0–25 years old in total population) and the age structure of the population of ages 25 and older are constructed using UN population data.

National accounts data, such as labor productivity (GDP per worker), the capital-to-labor ratio, the human capital measure, and TFP are from the Penn World Tables version 9.0.

D. Results

Appendix Figure 7.2 presents the key findings, summarizing the estimated effects of immigration on labor productivity (output per worker) and its components (capital-to-labor ratio, human capital, and TFP). Appendix Table 7.1 reports the second stage results both for the baseline specification—columns (1), (3), (5), and (7)—and for results correcting the standard errors for the possible presence of weak instruments—columns (2), (4), (6), and (8).[46] Results of the gravity model—used to construct the instrument of migration—and further details are reported in Jaumotte, Koloskova and Saxena (2016).

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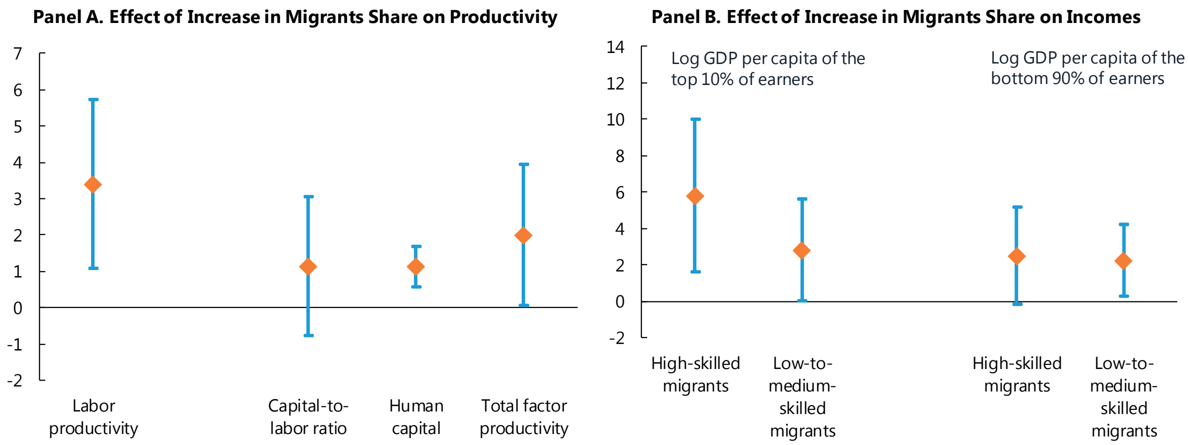
[45] The sample includes Australia, Austria, Canada, Denmark, Finland, France, Germany, Greece, Ireland, the Netherlands, New Zealand, Norway, Portugal, Spain, Sweden, Switzerland, the United Kingdom, and the United States.

[46] One concern about the estimates relates to the possible weakness of the instruments (as indicated by the Kleinbergen-Paap statistic in comparison to the Stock and Yogo threshold), and the possible violation of the assumption of independently identically distributed (iid) error terms. To address these concerns, we construct standard errors consistent with weak instruments. Results are presented in columns (2), (4), (6), (8) and are similar in magnitude and significance to those of the baseline estimation.

Appendix Figure 7.2. Impact of Migration on Productivity and Incomes

(Percent change per 1 percentage point increase in migrants share)



Sources: Jaumotte, Koloskova, and Saxena (2016); IMF staff calculations.
Note: The estimation is based on a two-stage least squares approach, where the migration share is instrumented using a gravity-type model of bilateral migration flows. For details, see Jaumotte, Koloskova, and Saxena (2016). The estimation of the effect on labor productivity, capital-to-labor ratio, human capital and total factor productivity controls for the total population size, the share of population with tertiary and secondary education, young age dependency ratio, and the age structure of the working-age population (defined as 25+ years old). The estimation of the effect on inequality controls for the total population size, the share of population with tertiary and secondary education, trade openness, and share of information and communications technologies in total capital stock.

Contribution of Migrants to Labor Productivity

The results suggest that migrants can contribute directly to labor productivity through channels not related to the age structure. In the long term, a higher share of immigrants leads to higher labor productivity, even after controlling for the young dependency ratio and the age structure of the working-age population. The effect comes mainly through higher human capital and TFP—with a 1 percentage point increase in the share of migrants leading to a 1 percent increase in the level of human capital and a 2 percent increase in level of TFP in the long term. Meanwhile, the increase in the capital-to-labor ratio is not statistically significant—indicating that physical capital adjusts to the increased labor force in the long term.

Previous work has found that increased human capital and productivity come partly from the addition of high-skilled migrants—who bring diverse skills and different technology to their new home countries—but also from the effect of a larger stock of low-skilled immigrants. As extensively documented in previous work (see Peri 2016 for a survey), low-skilled migrants can contribute to aggregate human capital and productivity by: (i) filling in labor shortages, for example in non-tradable services, and thus helping to exploit complementarities with natives' skills; (ii) taking more manual and routine tasks, thus allowing natives to take occupations which require more complex (abstract and communication) skills, in which they may have comparative advantage (see, for example, D'Amuri and Peri 2014); (iii) by increasing the supply of household and childcare services, which help boost labor supply of high-skilled females (for example, see Cortes and Tessada 2011).

Distribution of Gains from Migration

Beyond the aggregate effects, a key concern about immigration—especially of low-skilled workers—has been the impact it may carry on low income natives (and income distribution more generally). As shown in Jaumotte, Koloskova and Saxena (2016), immigration increases average per capita income for both the top 10 and bottom 90 percent of earners—although high-skilled immigration tends to benefit high income earners more, possibly due to stronger synergies between high-skilled migrants and high-skilled natives. Moreover, there is no evidence that inequality within the bottom 90 percent—captured by the Gini coefficient—increases with immigration. While this does not exclude that natives in some occupations might be affected by immigration, especially in the short term, it suggests that such effects are not significant at the macro level over a longer horizon.

Appendix Table 7.1. Effect of Immigration on Labor Productivity and Its Component

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Log labor productivity	Log labor productivity	Log capital-to-labor ratio	Log capital-to-labor ratio	Human capital	Human capital	TFP	TFP
	Baseline IV	Weak IV consistent CI	Baseline IV	Weak IV consistent CI	Baseline IV	Weak IV consistent CI	Baseline IV	Weak IV consistent CI
Migration share	3.41***	4.35***	1.13	1.15	1.12***	1.05**	2.00**	2.94**
	(2.870)	(2.611)	(1.155)	(0.852)	(3.901)	(2.548)	(2.017)	(2.227)
Ln pop (Ln nat pop in (2), (4), (6), (8))	0.93	0.90	0.02	0.02	-0.07	-0.07	0.93*	0.90**
	(1.448)	(1.489)	(0.047)	(0.047)	(-0.487)	(-0.482)	(1.915)	(1.978)
Share of population high skilled	0.15	0.13	0.20	0.20	0.13	0.14	0.03	0.01
	(0.422)	(0.405)	(0.765)	(0.765)	(1.281)	(1.277)	(0.112)	(0.067)
Share of population medium skilled	0.37*	0.36**	0.10	0.10	0.15***	0.15***	0.31*	0.30*
	(1.957)	(2.018)	(0.694)	(0.718)	(2.898)	(3.007)	(1.866)	(1.881)
Trade openness and age structure	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Number of observations	90	90	90	90	90	90	90	90
R-squared	0.763	0.775	0.893	0.893	0.826	0.824	0.557	0.577
Number of destinations	18	18	18	18	18	18	18	18
Excluded instruments	MSH Ln nat pop	MSH	MSH Ln nat pop	MSH	MSH Ln nat pop	MSH	MSH Ln nat pop	MSH
Underidentification test *P*-val	0.00721	0.00574	0.00721	0.00574	0.00721	0.00574	0.00721	0.00574
Kleibergen-Paap rk Wald *F*-stat	3.891	8.651	3.891	8.651	3.891	8.651	3.891	8.651
Stock-Yogo 10% max IV size	7.03	16.38	7.03	7.03	7.03	16.38	7.03	16.38
Stock-Yogo 15% max IV size	4.58	8.96	4.58	4.58	4.58	8.96	4.58	8.96
Weak IV 95% AR-based confidence set		[2.04126, ...]		[-1.14731, ...]		[.413427, ...]		[.9005, ...]

Source: IMF staff estimates.

Note: Robust t-statistics are reported in parentheses. *** denotes significance at the one percent level, ** at the 5 percent level, and * at the 10 percent level. MSH denotes the gravity-predicted migration share from Jaumotte, Koloskova, and Saxena (2016). All regressions include country and time fixed effects. Trade openness is defined as the sum of exports and imports relative to GDP, controlling for total population (lagged by five years to avoid endogeneity). Age structure includes young dependency ratio and the shares of population ages 25-24, 35-44, 45-54 and 55-64 in the population older than 25, all lagged by five years to avoid endogeneity.

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APPENDIX VIII. THE IMPACT OF STRUCTURAL REFORMS ON PRODUCTIVITY[47]

There are several ways in which deregulation can have an impact on productivity (see Nicoletti and Scarpetta 2005 for a review of theoretical literature): (i) by reducing slack in the use of resources; (ii) by facilitating technology diffusion and adoption; (iii) by increasing incentives to innovate. Previous industry-level studies have empirically documented that product and labor market structural reforms tend to increase output and productivity (Bouis, Duval and Eugster 2016; Nicoletti and Scarpetta 2005; Bassanini, Nunziata, and Venn 2009). This note studies the impact of labor and product market reforms on total factor productivity and other key macroeconomic variables at the macro level. The analysis is based on a new narrative-approach data set on *major* structural reforms by Duval and others (Forthcoming)—as opposed to OECD indicators typically used in earlier studies. Moreover, following IMF 2016, the analysis uses a dynamic approach to capture the fact that the positive impact of reforms can build up gradually over time.

A. Methodology

Given their likely lagged effects, the impact of reforms on macroeconomic outcomes is estimated at different time horizons, $k = [0,4]$, using the local projections method (Jorda 2005). Specifically, the following specification is estimates for each horizon *k*:

$$y_{t+k,i} - y_{t-1,i} = \alpha_i + \gamma_t + \beta_k R_{i,t} + \theta_k X_{i,t} + \varepsilon_{i,t} \qquad (1)$$

where $y_{t+k,i} - y_{t-1,i}$ denotes the change of the variable of interest (for example, TFP) in levels between *t-1* and *t+k*; α_i and γ_t are country- and time-fixed effects; $R_{i,t}$ is a dummy variable that captures the implementation of a structural reform at time *t*. The latter can be a product market or an employment protection legislation reform. Control variables $X_{i,t}$ include two lags of GDP growth, contemporaneous and past crisis dummies (defined as annual growth below -3 percent), three lags of the relevant reform variable, and leads of the reform variable from period t until period $t + k - 1$ to correct a possible bias that arises from using the local projection method, as suggested by Teulings and Zubanov (2014). The methodology is applied to construct impulse responses of TFP, output, employment, and labor productivity.

The employment protection legislation reform dummy takes values {1; 0; -1}, denoting a deregulating reform, absence of a reform, or a reversal of a reform.

For product market reform, the analysis focuses on major deregulation in seven network industries: gas, electricity, telecom, post services, rail, airlines, and road transportation. The

[47] This technical appendix was prepared by Ksenia Koloskova.

product market reform dummy takes value of 1 if there were at least two reforms over three years in one or more of the seven network industries, and zero otherwise.

B. Data

The TFP measure is obtained from Penn World Tables version 9.0. Structural reforms data are from Duval and others (Forthcoming). The sample covers 1970–2013 and data are an unbalanced panel. The analysis includes 26 advanced economies for which the structural reforms data are available: Australia, Austria, Belgium, Canada, Czech Republic, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Italy, Japan, Korea, Luxembourg, the Netherlands, New Zealand, Norway, Portugal, Slovak Republic, Spain, Sweden, Switzerland, the United Kingdom, and the United States.

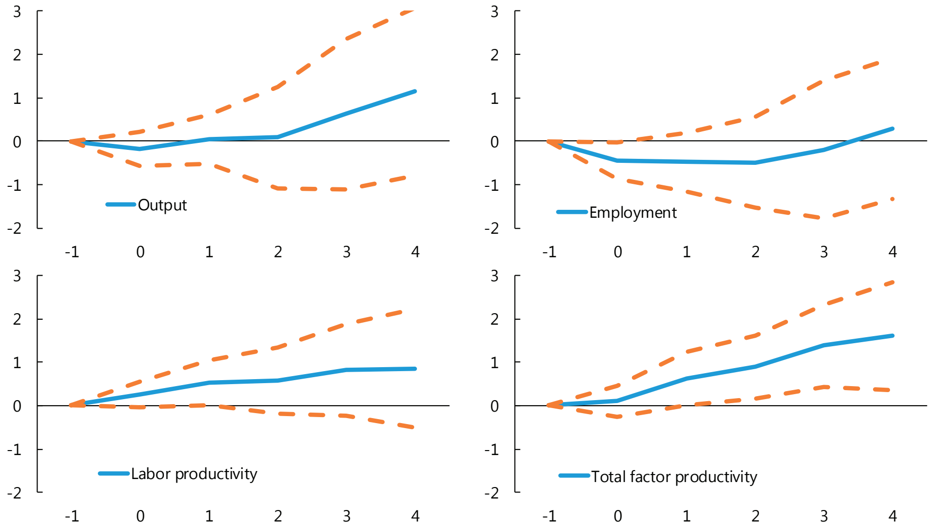
C. Results

Employment Protection Legislation Reforms (Regular Contracts)

The results of the analysis using equation (1) for output and some of its components are reported in Appendix Figure 8.1. Employment protection legislation reforms do not show a significant near-term impact on output nor employment, although this reflects the role of initial conditions. Indeed, the effects of reforms differ substantially under strong and weak economic conditions (see IMF 2016). Both variables show a significant decline if the reforms are undertaken under weak economic conditions, and a significant increase otherwise. Overall, this implies a muted impact on labor productivity. Capital deepening declines in the medium term as the relaxation of employment regulation induces substitution toward labor. At the same time, employment protection legislation reforms have unambiguously positive effects on TFP. Lifting strict employment protection legislation facilitates hiring and firing process, improving labor allocation and increasing total factor productivity.

Appendix Figure 8.1. Effect of Employment Protection Legislation Reforms

(Percent)



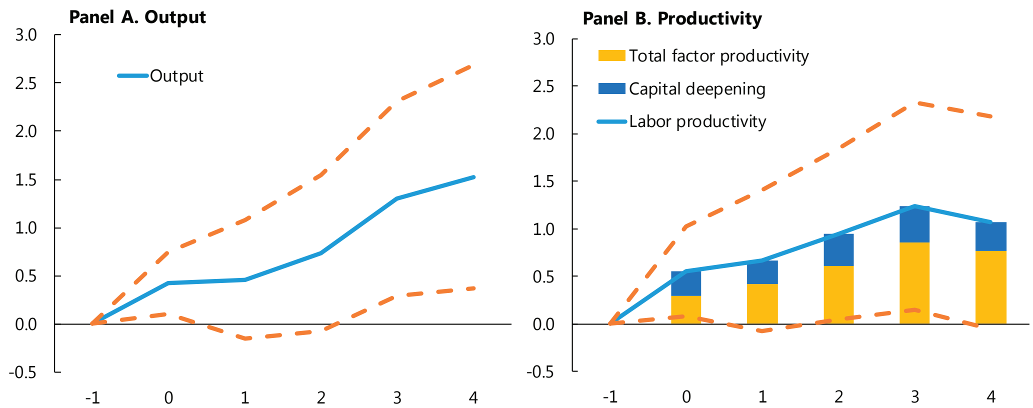
Sources: Penn World Table 9.0; Duval and others (forthcoming); and IMF staff calculations.
Note: Years after the shock on the x-axis, t = 0 is the year of the shock. Dashed lines denote 90-percent confidence bands. The effects are estimated using local projections method (Jordà 2005), controlling for lagged growth, past reforms, crisis dummies and using a bias correction suggested by Teulings and Zubanov (2014).

Product Market Reforms

In line with the findings in IMF (2016), product market reforms can significantly increase output in the medium term, and raise labor productivity (Appendix Figure 8.2). This effect reflects both increased capital deepening and TFP, with TFP explaining about two-thirds of the total increase in labor productivity. Statistical significance decreases, however, once the labor productivity is divided between these two components. These findings are consistent with those from sector- and firm-level analysis in IMF (2016). As shown in the latter, product market reforms can facilitate new firms' entry, and result in higher employment and investment by incumbent firms. These reforms also have significant output spillovers to upstream and downstream sectors.

Appendix Figure 8.2. Effect of Product Market Reforms

(Percent)



Sources: Penn World Table 9.0; Duval and others (forthcoming); and IMF staff calculations.
Note: Years after the shock on the x-axis, t = 0 is the year of the shock. Dashed lines denote 90-percent confidence bands. The effects are estimated using local projections method (Jordà 2005), controlling for lagged growth, past reforms, crisis dummies and using a bias correction suggested by Teulings and Zubanov (2014).

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