ARC Centre of Excellence in Population Ageing Research

Working Paper 2018/10

Demographic and Technological Change: Two Megatrends Shaping the Labour Market in Asia

Rafal Chomik and John Piggott

DEMOGRAPHIC AND TECHNOLOGICAL CHANGE: TWO MEGATRENDS SHAPING THE LABOUR MARKET IN ASIA

Rafal Chomik and John Piggott[1]

Final Draft

May 2018

[1] Rafal Chomik is Senior Research Fellow at ARC Centre of Excellence in Population Ageing Research (CEPAR); John Piggott is Centre Director at CEPAR and Scientia Professor of Economics at the University of New South Wales. This research was commissioned by the Asian Development Bank as a background paper for a workshop on the topic, to be held in Seoul in May 2018.

DEMOGRAPHIC AND TECHNOLOGICAL CHANGE: TWO MEGATRENDS SHAPING THE LABOUR MARKET IN ASIA

POPULATION AGEING AND TECHNOLOGY: TWO MEGATRENDS SHAPING THE LABOUR MARKET IN ASIA

Rafal Chomik and John Piggott

1. INTRODUCTION

Demographic and technological changes are two megatrends set to transform labour markets around the world. These shifts are already under way and are expected to accelerate, particularly in East and South East Asia, which is home to the world's oldest and fastest ageing societies and a region with an enviable pace of economic development.

The literature on the nature and impacts of each trend is vast, but the study of the interactions between them is often incidental and rarely in the Asian setting. Yet demography, technology, structural change and economic development are all related. Rapid economic development seen in many parts of Asia is the product of beneficial demographic trends as well as technological catch-up to the production productivity frontier. And technological advancements in medicine have precipitated the increasing levels of life expectancy seen around the world. In turn, while healthier life expectancies raise the prospect of working longer, technological and structural change risk leaving older cohorts behind.

As Asia continues its demographic transition, (1) will an older population result in slower rates of invention, innovation, and diffusion of new technologies and therefore impact on productivity growth; (2) how might such trends play out across workplaces, occupations, and industries; (3) how do specific technologies interact with the immediate challenges of population ageing; and (4) what policy strategies and further research are needed to ensure that labour markets perform at optimum? The purpose of this discussion paper is to map out existing evidence that attempts to address these questions and identify the types of strategies that may be needed to make the most of the dual challenge of rapid population ageing and technological advancement. Even though much of the existing literature originates in developed economies, we draw out the implications for the labour markets in East and South East Asia.[2]

2. DEMOGRAPHIC CONTEXT

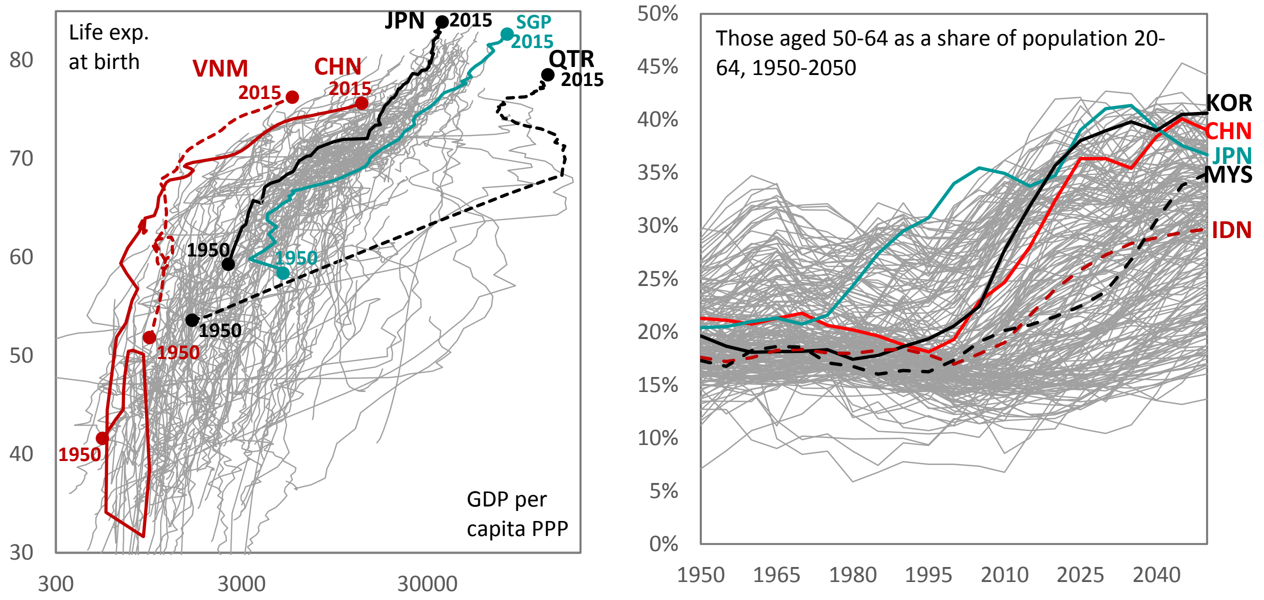
Technology advances were key in instigating the demographic transition in the first place (Preston 1975). Many Asian countries adopted medical technologies at a much lower level of development than had been achieved in the past (See Figure 1, left panel). For example, life expectancy in China increased from 45 years in 1950 to 75 years now – on of the most rapid sustained increase in life expectancy in history (Eggleston and Fuchs, 2012) and a level that is 95% of the life expectancy seen in the United States even as it has 25% of the price adjusted GDP per capita (UN, 2017; World Bank 2018).

The combination of mortality and ensuing fertility declines have resulted in what is a profound demographic transition: first an increase in the relative size of prime age workers in recent decades, followed by the ageing of the population over the next few decades. Since fertility declines have been more pronounced in East and South-East Asia – to levels well below advanced countries – so will be the rate of population ageing and workforce ageing (See Figure 1, right panel). By contrast, countries in South Asia will experience ageing at slower rate. Economies that rely heavily on migration are also expected to age more slowly than they would have in the absence of younger working-age migrants (e.g., Singapore).

Various analyses have looked at the macro-economic and fiscal impacts of population ageing. The approach is usually based on a decomposition of population, participation and productivity. That is, the population available to work, the rate at which that population is participates in work (employment rate and hours worked), and the productivity of such work (e.g., GDP per employed person or hour worked).

[2] Unless otherwise indicated, references in this paper to Asia imply East and South East Asia.

Figure 1. Demographic trends: Higher life expectancy at a given level of development and ageing workforces

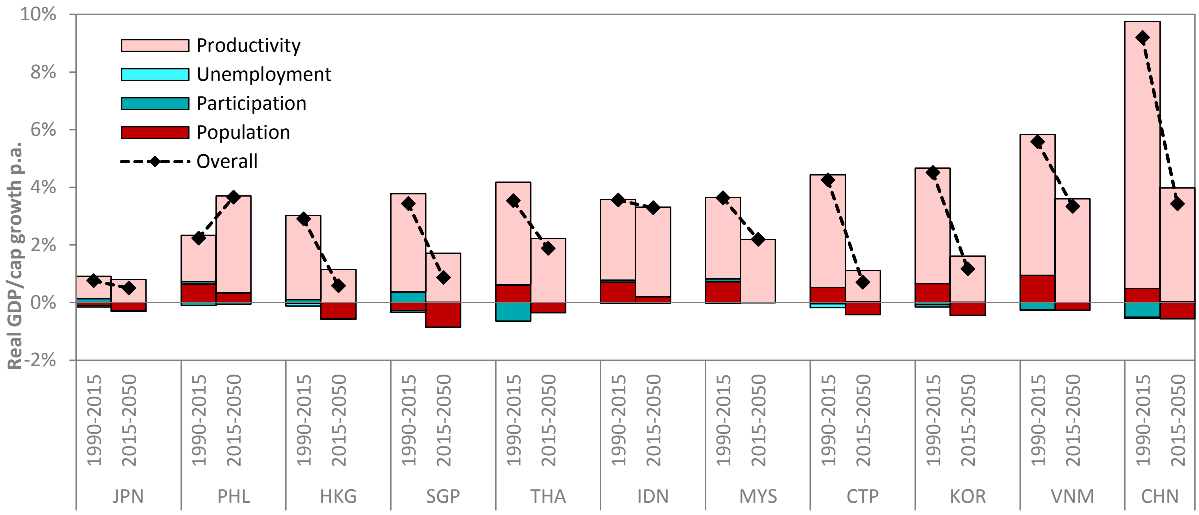


Note: Grey outlines indicate range of data across all countries. Source: Gapminder (2018); UN (2017)

So, a bulge of prime-age workers results in greater economic growth sometimes referred to as the *demographic dividend*. Its positive effect is not a given (e.g., compare growth rates in Latin America versus Asia). In Asia, the shift is estimated to explain up to one-third of the economic miracle between 1965 and 1990 (Bloom and Williamson 1998; Bloom et al. 2010).

A similar analysis is presented in Figure 2 for the period after 1990, showing both historic and projected decompositions of real GDP per capita growth in Asia. In this example, participation rates by age are held constant in the projection and labour productivity growth rates are exogenously imposed to converge to a lower rate seen among advanced economies. Over the past 25 years average (unweighted) GDP growth of the selected Asian economies was 5.2% per annum, a figure that is expected to halve to 2.2% in the next 35 years. While in the past, changes in the population age structure contributed to growth positively, they are expected to drag on it in future, turning the *demographic dividend* into a *demographic deficit*. Adding fiscal revenue and expenditure into the mix demonstrates the pressure that ageing can have on budgets, including in countries which still have lower levels of spending on older people but who have ambitions to develop their social welfare and health systems.

Figure 2. Historic and projected growth in GDP per capita by component, 1990-2050 (%)



Source: Chomik and Piggott (2017) and Chomik, Piggott and Lu (forthcoming). Note: Based on (1) medium population variant, (2) age-sex-specific participation based on no change after 2015, (3) unemployment at long term level based on ILO; and (4) convergence of productivity growth.

A common insight from such growth accounting analyses is that participation rates can offset some of the negative effects of ageing, which has been a key policy pursuit of many governments. Indeed, modelling of behavioural changes to participation rates suggests some likely automatic offsets since longer lives are likely to spur people to work longer to save for a longer retirement (Bloom et al. 2003; Fehr et al. 2008; Borsch-Supan et al. 2014).

The other insight is that as the relative size of workforces declines it is important to invest in the productivity of the remaining workers. As shown in Figure 2, even with declining productivity in Asia it is expected to be the main driver in the improvements of standards of living.[3]

So how has productivity and technology been evolving, to what extent is it linked with ageing, and what does it mean for the labour market and policy makers? We look at each of these in the following sections.

3. PRODUCTIVITY AND TECHNOLOGY CONTEXT

Productivity growth – or the increase in output for a given unit of inputs – has large effects on standards of living. As famously noted by Nobel laureate, Paul Krugman, '*productivity isn't everything, but in the long term it is almost everything. A country's ability to improve its standard of living over time depends almost entirely on its ability to raise its output per worker.'* (p13 Krugman 1994).

Productivity growth is thought to depend on three components, changes in: (1) the quality of the labour input (human capital such as health, education, training, and experience); (2) complementary inputs (infrastructure capital like transport or production capital like new factories and computers); or (3) technology (methodological improvements in the way that labour and capital are combined, e.g., via better legal, scientific, engineering, management, and organisational processes).[4]

Technological change, either as part of abstract processes of combining inputs or embodied in new equipment inputs (*better* factories or computers) is thought to be a more sustained way of increasing growth in the long term compared with increasing inputs themselves (Grossman and Helpman 1994). After all, there are a limited number of Chinese farmers that can be moved into a limited number of factories, but an innumerable number of ways in which factory workers, factory machines, and factories themselves can operate more efficiently. In each case, this increases the output for a given number of work hours.

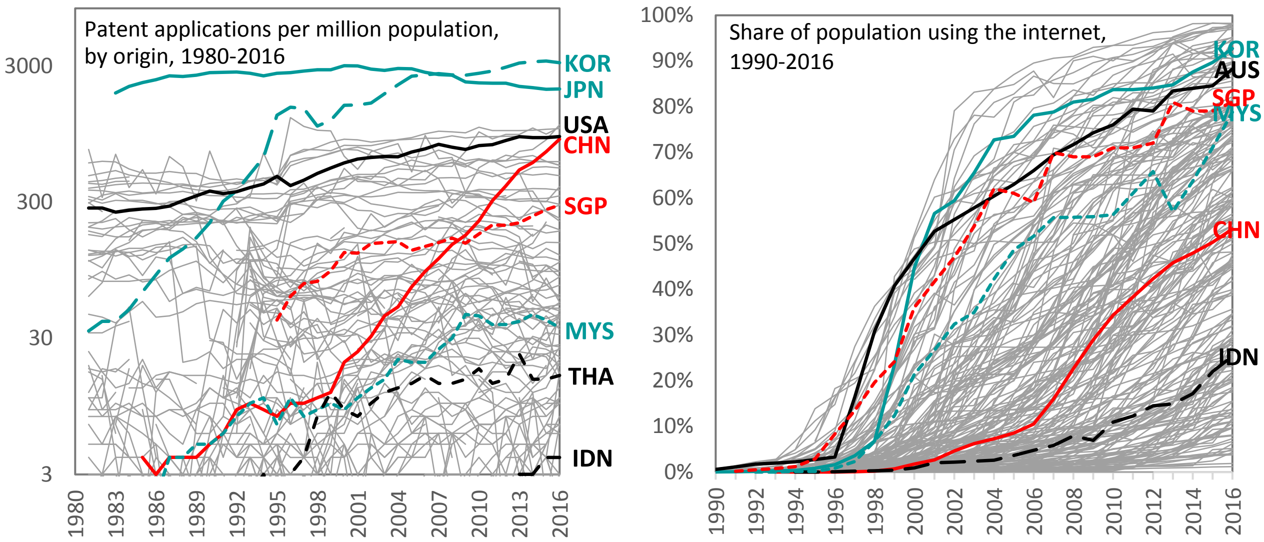
Technological progress is, in turn, thought to take place in three parts: (1) invention (when new methods are first discovered); (2) innovation (when the practical applications of new inventions are developed and standardised for use); and (3) diffusion (when, as costs reduce, and firms and people adopt new innovations across the economy).

Advanced countries, particularly the US, combine all three stages of technological progress and therefore operate close to the production possibility frontier, at least in some industries. The high level of productivity growth seen across Asia mostly relates to these countries catching up to the frontier. But some Asian countries are also at the forefront of invention and innovation. For example, patent data – an imperfect proxy for this – is presented in Figure 3 (left panel). Korea and Japan, typically apply for over 2,000 patents per million inhabitants per year. And China per capita applications are now in line with the US.

An example of diffusion of information communications technology (ICT) can be seen at the household level by data on internet penetration (Figure 3, right panel). It shows how some countries can have low levels of inventions but high rates of diffusion. For example, by these measures, Malaysia has ten times fewer inventions than Singapore but the same level of technology diffusion.

[3] Note that since labour productivity changes presented in Figure 2 are based on output per worker they will also include any changes in average hours.
[4] Unless otherwise stated, references to productivity relate to labour productivity (output per unit of labour input). This is distinct from total factor productivity which is the unexplained portion of output after labour and capital input are taken account. See Weil (2005).

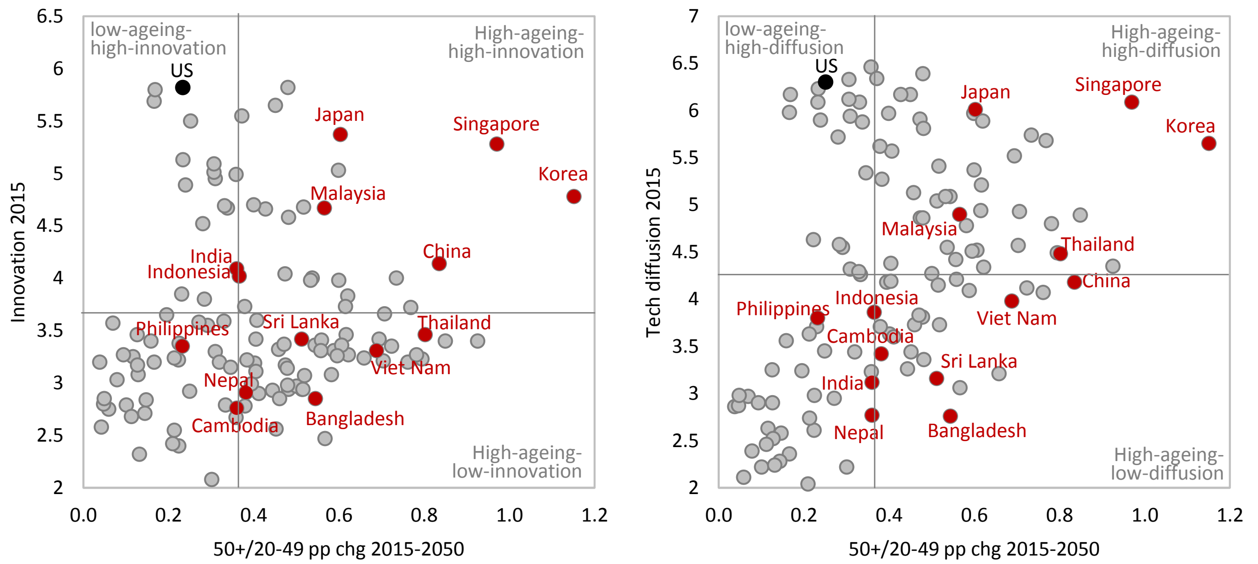
Figure 3. Recent technology trends: Invention, innovation, and diffusion



Note: Grey outlines indicate range of data across all countries. Source: WIPO (2018); World Bank (2018)

So where do different countries currently stand with respect to both the rate of population ageing and their level of technological innovation and adoption? Figure 4 presents the future expected rate of ageing against current technological development. Workforce ageing is measured here by comparing the change in the ratio of the population aged 50+ to the population aged 20-49, while technology innovation and diffusion are based on indices of various sub-measures (see note to charts)[5]. It shows that some fast ageing countries, such as Singapore, Korea, Japan, China and Malaysia are above average innovators (though behind places like the US). This should put them in better stead as populations age and a productivity offset is needed. Others, such as Thailand and Vietnam, are ageing faster by this measure than Japan but have below average levels of innovation.

Figure 4. Ageing workforce population trajectory against current technological development



Note: Innovation is an index of sub-measures such as R&D spend, quality of scientific institutions, patents, intellectual property, firm sophistication, cluster development etc. Technology diffusion relates to availability of latest technologies, absorption by firms, as well as measures of ICT use. Quadrant lines indicate unweighted average. Source: Authors' analysis of WEF (2017) and UN (2017).

An important point is that it may be enough for a country to be a fast adopter of technologies rather than inventing and innovating its own technology (Vivarelli, 2012). Technology is a public good. Its use does not always preclude others making use of it (though in some cases may depend on intellectual property restrictions). The index of diffusion (Figure 4, right panel) suggests that even though China has good innovation capacity, it is below average

[5] This is based on one of many such indices. See also, also for example, Chakravorti and Chaturvedi (2017) or World Bank (2016)

at adopting new technology across its wider economy. This is a constraint on growth. Thailand, by contrast has below average innovation but above average levels of technology diffusion. Vietnam is currently behind on both. In a developing country context, product innovation can be expected to play a minor role in overall technological upgrading. So, countries like Vietnam, will have to focus more on accessing technology via embodied technological change by investing in imported capital goods from advanced countries, including via foreign direct investment, as well as ensuring its firms and workers have the capacity and skills to apply new technology.

For the more advanced Asian economies the transition to become innovators and endogenizing technological change is a great opportunity to offset ageing. Innovators tend to also lead in income per capita because they can take advantage of the externalities of innovation. For middle-income countries like China and Thailand this switch will require cautiously paring back subsidies and increasing competition (Acemoglu et al. 2006).

But will population ageing itself hinder productivity growth and technological progress? This is addressed next.

4. THE EFFECT OF POPULATION AGEING ON PRODUCTIVITY

Comprehensive surveys of the productivity and technology literature (e.g., Oberdabernig 2015) have surprisingly little to say about demography. A recent report looking at ageing and productivity in Asia focused mostly on the employment of older people rather than the effect on measures of productivity (Phang 2011a). This relationship is only beginning to be debated (e.g., Prskawetz et al 2008; Bloom and Sousa-Poza 2013).

A non-exhaustive list of channels through which ageing may affect productivity are mapped out in Table 1. These are grouped into the different components affecting productivity described above: human capital, physical capital, and technology. Some can be expected to have positive effects on productivity, some negative, but the direction or magnitude of these or the net effect is unclear. Each will also have a different policy response which either mitigates the negatives or encourages the positives.

Of these three components, the most commonly identified channel relates to physical capital accumulation. Since savings increase until a late age, more people surviving to later ages and retiring later is likely to increase the stock of physical capital, raising productivity of labour and ushering in a second demographic dividend (Mason and Lee 2007; Mason et al 2010). These studies tender evidence that the second demographic dividend is taking effect in parts of Asia such as Korea, Chinese Taipei, and Japan. But despite evidently high savings rates, the macro-economic impacts are yet to be fully analysed in other parts of Asia, including China. Some of this may depend on retirement income design, such as prefunding. And simulations that include increased taxes required to balance government budgets suggest that any capital deepening will be subdued (De Nardi et al. 1999; Fehr 2000) or even that capital shallowing will result (Kotlikoff et al. 2007; Fehr et al. 2008). Even in settings with high savings rates, poor financial intermediation may result in wasted investments. For example, many parts of Asia suffer from inadequate investment in infrastructure. Recent estimates of the infrastructure investment gap are equal to about 2.4% of GDP (ADB 2017). There are other, less studied effects of ageing on physical capital accumulation. For example, to what extent will budget pressures and macroeconomic outcomes of ageing affect the attractiveness of older countries to attract foreign investment or their ability to respond to economic shocks? Indeed, we don't know if merely ageing or also declining populations and workforces will discourage investors and the extent to which this can be mitigated.[6]

In Asia, human capital rather than physical could be a greater driver in productivity growth differentials given its change over time and between cohorts. On the one hand, since older cohorts are less educated, a greater share of older people in the workforce could reduce the human capital of the average worker. On the other hand, there are offsetting behavioural effects (Bloom et al. 2011; Lisenkova et al. 2013). Since people expect to live longer, they need more savings to finance a longer retirement. They may also be forced to work longer due to later pension ages (Gruber and Wise 1998). These dynamics in turn result in workers having greater incentives to invest in their own health and education (Vogel et al. 2017; Prettner et al 2013; Borsch-Supan et al 2014). Firms may also find it more cost effective to invest in their employees at later ages. But such incentives will differ across the skills

[6] Chomik et al 2017, show how seven of APEC's 21 economies can expect declines in absolute size of workforces and note that.is migration declined in the region, 11 economies would see declines.

distribution and have implications on productivity and inequality. Higher educated workers, who have longer life expectancies and who are less reliant on public pensions may want to work and save more to be independent. The low-educated may respond less since they rely heavily on government programs and mind less about their savings. Yet they could be more responsive to changes in pension age.

Table 1. Plausible channels through which population ageing could affect productivity

	Component affected	Nature of transmission	Effect	Key policy response
1.	Human capital	**Human capital declines with age:** Education, health, physical/cognitive capacity lower avg. quality of labour	Negative	Invest in life-long education and training, reskilling, and public health
2.		**Human capital peak dynamics**: Demography moves into most productive peak e.g., around age 40	Positive	Enable middle-age workers, address skill gaps for both young and old
3.		**Greater experience** of older people and more *learning-by-doing* may increase quality of the labour input	Positive	Workforce strategies that invest in retention and mentoring
4.		**Investment in own human capital** (health and ed.) because need to work and save for longer period	Positive	Delaying pension ages and retirement; access to education
5.		**Investment in next generations' human capital:** more spending on old, but evidence spending *per* child is up	Positive	Ensure quality and not necessarily quantity of education
6.		**Healthy life expectancy** and increases alongside longer life expectancy; ageing retarded in successive cohorts	Positive	Public health investment over lifecycle; management of chronic illness
7.	Physical capital	**Life-cycle saving** profile means more savings/investment in capital accumulation (2nd demographic dividend)	Positive	Efficient financial intermediation; pre-funded pensions
8.		**Labour to capital ratio**: Fewer workers per unit of existing capital implies higher productivity per worker	Positive	Broad strategies to maintain capital stock against depreciation
9.		**Foreign Direct Investment:** Ageing countries with shrinking workforces may be less attractive for FDI	Negative	Broad strategies that target efficiency and competitiveness of economy
10.		**Higher taxes** may discourage investment (i.e., due to fiscal pressure of ageing and smaller fiscal buffers)	Negative	Implement responsible fiscal policies
11.	Technology (innovation)	**Creativity**: Lower levels of invention and innovation if creative outcomes are negatively correlated with age	Negative	Import technology from younger more innovative countries
12.		**Second careers:** More innovation if 2nd careers of older people mean more entrepreneurs with access to credit	Positive	Encourage incubators tailored to older entrepreneurs
13.		**Risk preferences:** Less venture capital investments if older people have lower risk preferences	Negative	Target funds to research and development and raise access to credit
14.	Technology (diffusion)	**Adoption of tech:** Lower levels of diffusion if older people have lower adoption rates of new technologies	Negative	Invest in life-long education and training; lower costs of adoption
15.	Various	**Inducement:** Smaller high-wage workforce may induce investment, innovation, and diffusion by sheer need	Positive	Reduce barriers to and costs of new technology investments
16.		**Consumption composition** may see growth in low-productivity industries (e.g., personal services, but offset by high tech medicine)	Unclear	Focus on productivity improvements across services sector
17.		**Migration:** Ageing may drive workers/innovators to high growth areas or attract them if wages rise in labour-scare countries; may inhibit average mobility	Unclear	Develop skilled migration and entrepreneur visa programs
18.		**Factor endowment:** If older people are less skilled, the skill-intensity of country's production may decline	Negative	Education and workforce skills strategies
19.		**Age-diversity** in workplace may be synergistic or polarising and reduce cohesion	Unclear	HR policies and company culture could help
20.		**Fewer new workers** may reduce innovation and diffusion	Negative	Encourage other cross-pollination

The effect of ageing on technological change and thus productivity has had less attention still. There is some scant research linking the demography with elements of technological invention, innovation, and diffusion. For example, Weinberg (2004) developed a model in which the adoption of technologies may increase with age when a specific technology complements existing experience. Chinn and Fairlie (2006) found that internet diffusion is affected by demography. Fryer (2008) found that average age of patent applicants tends to be stable at 48 years, based on two decades of US data. And Vandenbussche et al (2005) concluded that since innovation is intensive in the most up to date skills, it will be driven by the share of the younger population. The ageing and mobility of labour channel was considered by Schubert and Andersson (2015) who used firm level data to find that age affects firm innovation negatively but that even in an ageing workforce this can be partially offset by greater mobility and turnover.

The empirical research literature that links ageing to productivity – not always explicitly via these channels – can be grouped into those that consider data at the individual, team, firm, and macro level.

Productivity by age at the individual level

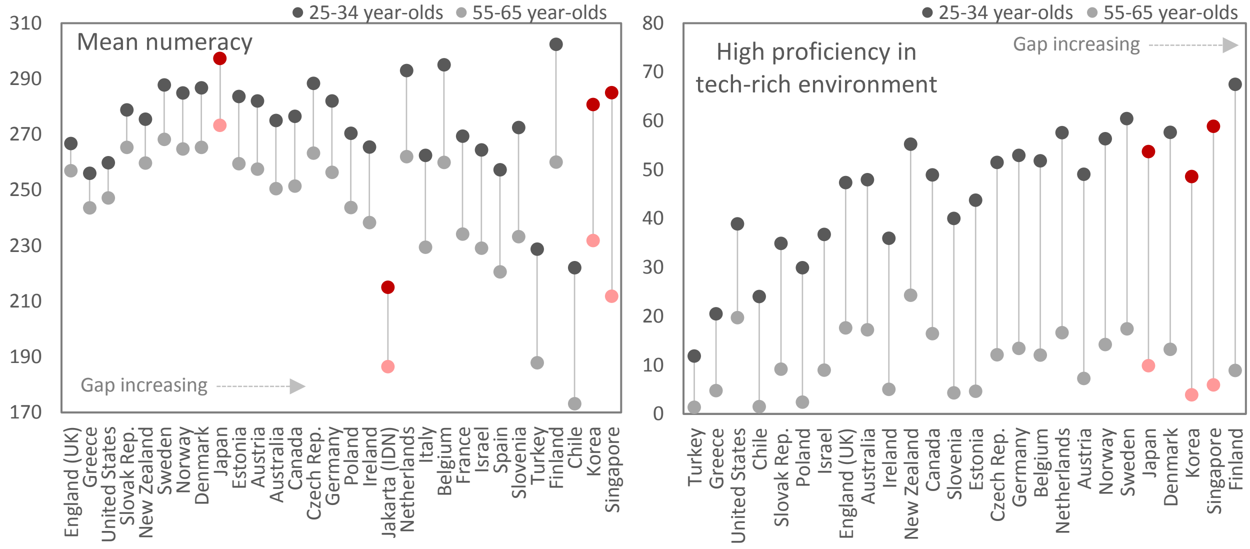
Characteristics of workers of different ages that can affect productivity outcomes differ widely. Age serves as a proxy for a range of other characteristics, including education, skill, and experience. It's not always apparent that age itself is a factor.

This line of research can be grouped into studies that look at: (1) wages by age (2) achievements by age (e.g., in sport or age at which Nobel winners gained their insights); (3) psychometric testing (e.g., cognitive intelligence, literacy, numeracy, and problem solving); (4) subjective ratings (e.g., by peers or supervisors); and (5) objective measures of output (e.g., sales, errors, task completion, production volumes etc.). Let's look at a selection of these.

In theory, wages reflect the productive output so a wage profile by age should be close to productivity by age. Ideally estimated using longitudinal data, with adjustments for those people who drop out of the labour force, the pattern reveals a hump-shaped age-profile of wages, but declines at later ages are small (Heckman et al. 2003). The shape is similar across different categories of worker (e.g., by gender, skill, or education). A lack of decline may suggest that productivity does not drop or it could relate to market frictions (e.g., seniority wages) or delayed compensation (for high productivity and loyalty in early years).

Insights from psychology reveal that while some cognitive capacities decline with age, many do not, and some improve (Cattell, 1963; Chomik et al. 2018). Fluid intelligence, like problem-solving and pattern recognition – the raw processing power and speed – usually decreases with age after peaking in the late-twenties. Crystallised intelligence, which relates to accumulated knowledge, strategic skills, empathy, big-picture perspective, shows limited decline. Vocabulary, for instance, is shown to continue increasing into very old age. These patterns are broadly consistent across cultures, including in Asia (Park et al 1999), but interact with education when it comes to work related productivity. People with higher educational attainment not only score higher across cognitive tests at all ages but are also able to better preserve cognition until later ages.

Figure 5. Comparison of generational gap in numeracy and technology tests, 2012-2015



Note: Asian countries are highlighted in red. High proficiency relates to share scoring level 2 or 3. Source: OECD (2016)

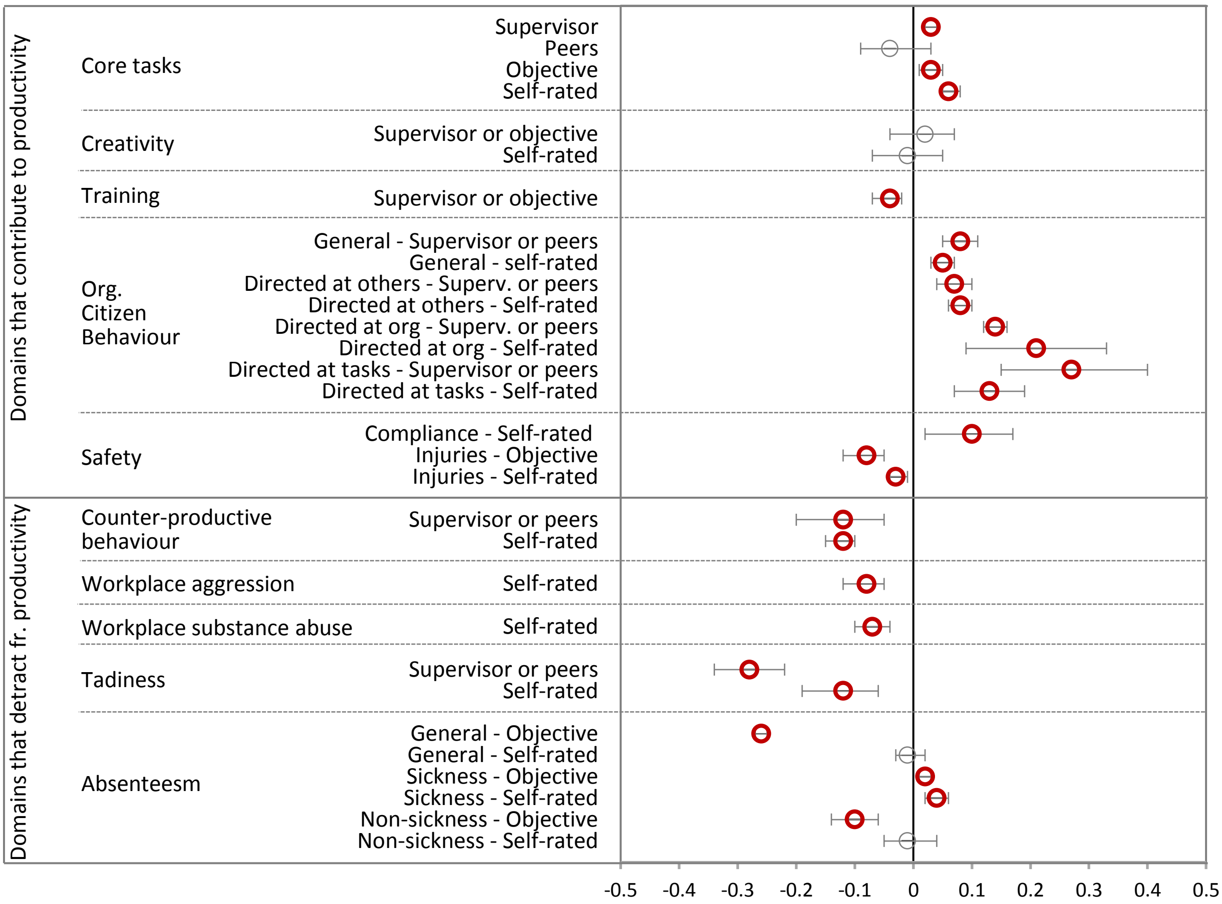
Figure 5 shows how this plays out in the score differences between younger and older adults when tested on numeracy and problem solving in technology-rich environments. Korea and Singapore, which have seen a very rapid expansion in education see their young adults scoring particularly well, but at the same time they reveal the largest gaps with older people. In fact, Singaporean numeracy and literacy scores peak earlier than in OECD countries and decline faster with age. Much of this age gap is estimated to be explained by education. It suggests that fast developing countries need to be mindful about not leaving older people behind as pace of change increases. This digital divide is reflected in the use of IT at work by age. In the OECD, about 27% of workers aged 55-64 use email or the Internet at work daily, compared to 49% among those aged 35-44 (OECD 2016).

Rating- and objective-based analysis of performance by age is also revealing. Figure 6 presents the findings of a meta-analysis of performance related to work environments for people aged 17 to 59. It is based on over 400 empirical studies from across different countries, including from several emerging and developed Asian countries.

It shows that age tends to be positively correlated with domains that contribute to productivity and negatively correlated with those that hinder it. For example, objective, supervisor and self-rated performance in core tasks is found to be slightly higher for older workers than younger workers. And good organisational behaviour, particularly behaviour targeted at the organisation and at tasks tends to be higher among older workers. By contrast, creativity appears to have no relationship with age, and lateness and absenteeism tend to decrease with age, even though sick leave is slightly higher.

One issue with such analyses, however, is selection bias. Older people who had worse outcomes may have dropped out of the labour market so that those remaining are not necessarily representative of the purported age gradient in performance. There may also be subjective bias from peers or supervisors because of differing levels of loyalty.

Figure 6. Meta-analysis of correlation between age and performance at work

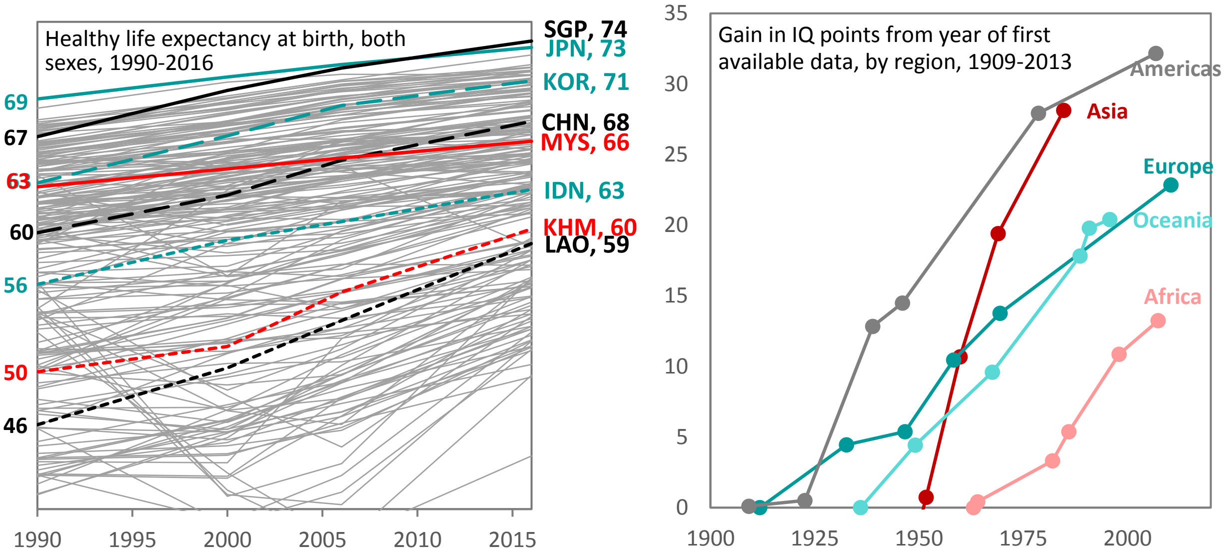


Note: The range indicated by error-bars is the 95% confidence interval. Source: Adapted from Ng and Feldman (2008)

Another important issue when considering individual level productivity is that older workers today are not the same as older workers of tomorrow. Ageing is a dynamic process that includes both age and cohort effects. Not only does continued education have a strong effect on each new cohort's level of human capital but health itself has been improving alongside life expectancies. Indeed, healthy life expectancies, which measure the average disability free years of life, have increased dramatically in recent decades, including in Asia (left panel of Figure 7). For example, since 1990, healthy life expectancy at birth has increased by between 3 years in Japan and Malaysia to 13 years in Laos. Singaporeans currently live an average of 74 years without significant health problems, the highest in the world. We've known for some time that healthier workers are more productive, so extended healthy life expectancies are likely to increase productivity at any given age and lead to a revision of what age constitutes an 'older worker' (Strauss and Thomas 1998, Arora 2001, Bloom and Canning 2005, Weil 2013).

These dynamics also affect cognitive capacity. Each new cohort benefits from what's known as the *Flynn* effect – the finding that people across all ages in many countries are seeing a substantial and continuous increase in their fluid and crystallised intelligence scores, likely driven by education. Evidence of this is presented in Figure 7, right panel, and shows particularly high increases in Asia. To test how the compositional effects of ageing interact with the Flynn effect, Skirbekk et al. (2013) modelled the projected average UK citizen's word recall and verbal fluency with and without trend improvements. They found that if current rates of cognitive improvement continue then so will average intelligence despite population ageing. This is positive, since there is evidence that cognitive skills at the aggregate level are a driver of innovation and diffusion (Messinis and Ahmed 2013).

Figure 7. Changes in average healthy life expectancy and cognitive ability over time



Note: Grey outlines indicate range of data across all countries. Source: GBD (2016); Nagdy and Roser (2017)

Productivity by age at the team, plant, and firm level

Work often takes place in teams and among networks of people rather than through the isolated effort of individuals. So a variation in team members' physical ability, fluid and crystallised intelligence, and technical skills may result in synergies. On the other hand, these may drag down output, especially if technological change is added. That is, technology may increase the rate of skill obsolescence and since investment in skills or ability to retrain declines with age then so might the team or firm's productivity (Behaghel and Greenan 2010). In this vein, an important strand of literature uses employer-employee matched data at the level of the firm to study the relationship between demographics and output (Skirbekk 2008). These tend to be based on data from Europe or North America – no studies were found across Asian countries, likely because of data limitations.

The results are mixed. For example, research by Borsch-Supan and Weiss (2016), using data on work teams in a manufacturing plant reveals that while errors increase with age the severity of errors declines with age. They conclude that overall productivity does not decline until at least age 60.

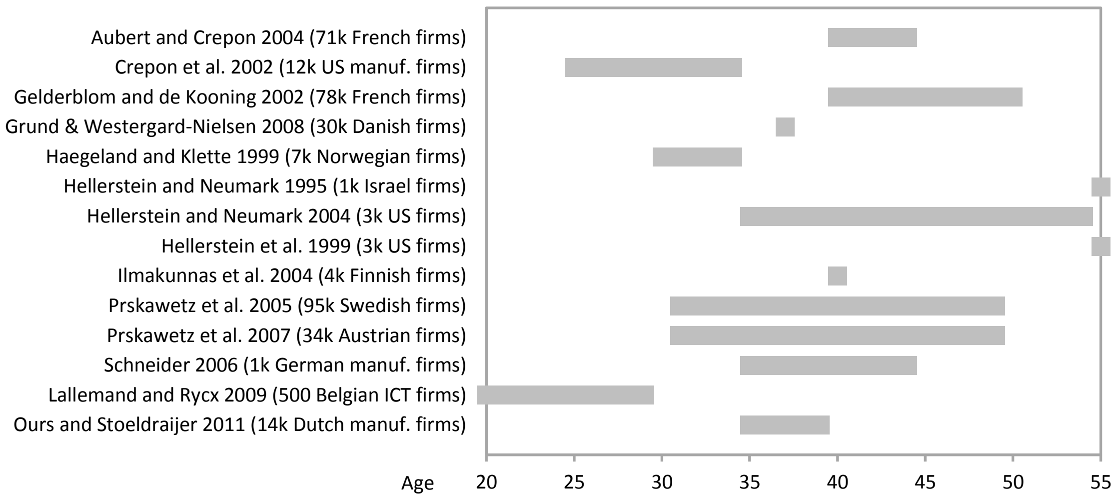
The ages at which productivity is estimated to peak in a selection of these studies is summarised in Figure 8. Generally peak productivity is estimated to be between about age 30 and 45, with declines after age 50. The modal peak based on Figure 8, appears to be 40. But some studies find peaks at higher ages and others at younger ages. Adding gender into the mix may further confuse the issue: Vandenberghe (2013) find that older women are less productive than older men. Results should be interpreted cautiously; they depend on the age brackets used and may be subject to data selection issues as well as reverse causality – well performing firms may also be the ones hiring younger workers, whereas older workers tend to work in older firms, with older machines. Some studies try to control and correct for such bias.

One reason for differences may relate to the industries under investigation. Some studies find differing effects of demography depending on industry and region, which in turn may relate to differences in intra-industry specialisation (Mahlberg et al 2013). For example, based on data for Dutch manufacturing firms, Ours and Stoeldraijer (2011) concluded that peak productivity is between age 35-39. By contrast, Lallmand and Rycx (2009), based on data for Belgian ICT firms, estimated that productivity peaks earlier, at ages 19-29.

Testing productivity effects of demography by ICT intensity of firms is another way of testing this. Bertschek and Meyer (2009) looked at German firms in manufacturing and services industries and found that productivity rises with age, flattens after age 30 and does not decline, that older workers using computers were significantly more productive than older workers not using computers, and that ICT enabled productivity was not hindered by employment shares of older people.

Similarly, Daveri and Maliranta (2006) separated Finnish industries by technological sophistication and compared productivity with remuneration. Productivity improvements by age appeared to peak sooner than wages in high-tech firms and industries, but that this effect is mediated by education. That is, more senior, highly-educated workers are less likely to drag down productivity in high-tech firms. Such findings are instructive for countries seeing rapid technological change as Finland experienced in the 1990s with the very rapid growth of high-tech industries. With technological progress both education and wage flexibility become more important. Rigidity in wage contracts may constrain growth while education can help offset potential productivity declines by age where these do occur.

Figure 8. Peak in productivity by age in firm-level studies, by study, 1999-2011



Note: Peak productivity age as found in studies is shaded in grey. Authors' compilation and Skirbekk (2008)

What about cross-country analysis for a given industry? Ilmakunnas and Miyakoshi (2013) use cross-country manufacturing data between 1970 and 2005 to regress productivity on labour that differs by skill and age and on capital that differs by ICT intensity. They find that investment in ICT capital in isolation increases productivity; and that ageing in isolation increases productivity when it takes place among high-skilled workers. But, when interacted, investment in ICT *reduces* productivity in the presence of ageing high-skill workers and *increases* in the presence of low skilled older workers. They conclude that the negative productivity effects of ageing have been offset by different countries in different ways. Korea's population ageing has so far been offset by increases in skills among the young while the US and Finland benefited more from investment in ICT capital. It's unclear if the negative interaction between high-skills, age, and ICT exists outside of manufacturing and if it changes at different levels and rates of technological development. The implication is that at a time of rapid change, policies need to be directed at all skill categories.

Another aspect is the *distribution* of ages in the workplace: is there an even spread or polarisation; and how does this affect productivity? The age-diversity literature finds both positive effects of age diversity, based on the idea that there are knowledge and skill complementarities (Horwitz and Horwitz 2007; Kunze et al 2011), and negative or diminishing effects, which could relate to social and value differences that reduce cohesion and cooperation of teams (Grund and Westergaard-Nielsen 2008). Apparently, both effects can exist but differ by firm size and institutional settings (Harrison and Klein 2007; De Meulenaere et al. 2016). An even spread of people of different ages indeed increases productivity whereas a polarised distribution can decrease it. But these effects are greater in bigger firms and positives are more pronounced when job security in the firm is high. The field is ripe for further analysis of the relationships between age, productivity, human resource policies and how workplace settings affect how younger and older people interact.

Productivity by age at the aggregate level

Firm level data may suffer from selection bias and misses interactions that take place in the labour market and among firms, industries, regions and countries. So, it's worth asking if older people harm the productivity of whole economies.

At the aggregate level, productivity growth has slowed across Asia and the world despite dramatic advances in technology. This is known as the Solow paradox, after the economist quipped that "you can see the computer age everywhere except in the productivity statistics". Some have suggested that this is because we understate the quality improvements of products (Hatzius et al. 2016) but others are sceptical (Syverson 2017). Other factors include the increase in the size of the services sector, which tends to have lower levels of productivity. Plausibly, ageing plays a role.

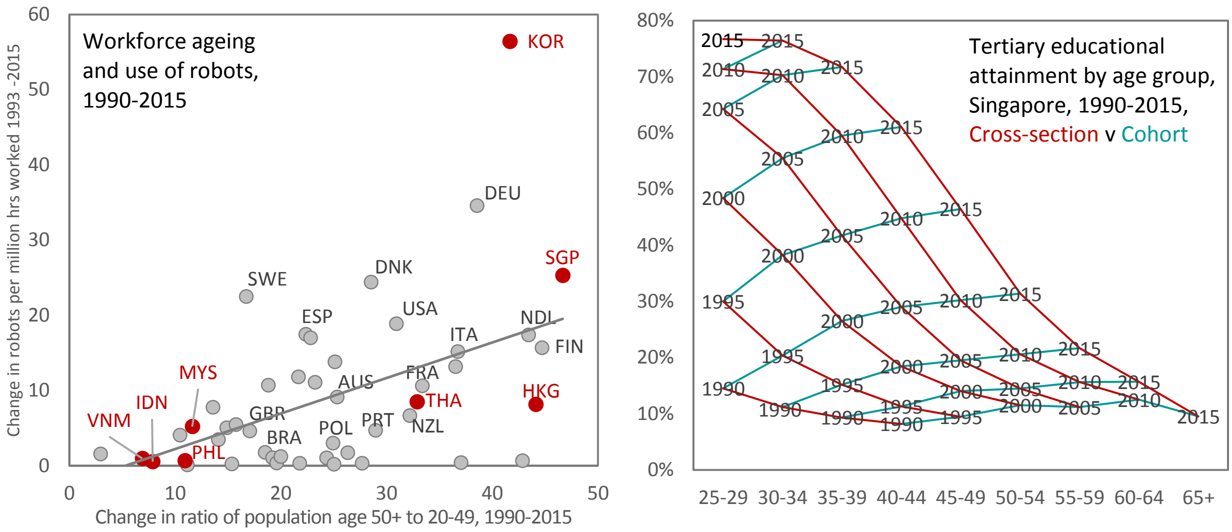
An early study by Lindh and Malmerg (1999), used OECD data between 1950 and 1990 to show that labour productivity (per worker) was positively related to share of the 50-64 age group while shares in younger age groups had no effect. Most other macro studies investigate total factor productivity, which is productivity unaccounted for by labour and capital inputs. Using a wider panel of 87 developing and developed countries between 1960 and 1990, Feyrer (2007, 2008) found that the 40-49 age group drove differences in total factor productivity growth. But the estimates seem implausible – they suggest that a one percent increase in that age group has ten times more impact on productivity growth than a one percent increase in the 30-39 age group. Using a similar set up, Liu and Westelius (2016) replicate the Freyer's model using data from Japanese prefectures between 1990 and 2007 (Maestas et al 2016 do so for US states). They too find that total factor productivity is driven by the 40-49 age group and use these findings to project that ageing will drag on productivity in the future.[7] As is the case with most such macro analyses the channels for the relationships are unexplored and structural changes are overlooked.

In summary, the empirical literature doesn't always agree about the direction, magnitude or channels in which ageing affects productivity. Even as total factor productivity becomes elusive, ageing can be potentially offset by investments in physical and human capital. A notable study by Acemoglu and Restrepo (2017), using data from 169 countries between 1990 and 2015, finds a strong positive relationship between ageing and GDP per capita (thus combining the supposedly negative effects of productivity and factor inputs). The implication is that scarcity of younger and middle-age labour can induce capital investment and automation that increases output per person. As shown in Figure 9 (left panel), countries with increasing shares of older workers are associated with increases in the use of automation, as proxied by number of robots per million hours worked. Asia already has about 1 million industrial robots – about 57% of the stock worldwide. The International Federation of Robotics estimates that by 2020 this will almost double to 1.9 million, or about 64% of all industrial robots. The public sector can encourage such developments. Indeed, public spending on research and development has been shown to reduce potentially negative effects of ageing on productivity (Aiyar et al. 2016).

Similarly, investment in human capital (both health and education) can transform the productivity of cohorts as they combine with new technology. In fact, a deeper understanding of the patterns described in this paper can come from appreciating the difference between a cross-sectional and a cohort-based analysis of age. The right panel of Figure 9 shows this for tertiary educational attainment by age in Singapore. A cross-sectional view suggests a simple pattern of education declining with age. A cohort view demonstrates again how older people of tomorrow are not the same as older people today.

[7] Some studies then use such insights (e.g., salary or consumption profiles, or coefficients) in projections (e.g., Mason and Lee (2011) and Guest (2011).

Figure 9. Solutions and explanations: Technological inducement and human capital by cohort



Note: Labels in right panel indicate year of data points. Source: Acemoglu and Restrepo (2017); Authors' analysis of Statistics Singapore data

5. TECHNOLOGICAL CHANGE AND MATURE-AGE EMPLOYMENT

Ever since the industrial revolution technological change has been associated with a process of creative destruction in which some jobs are destroyed while new ones are created. On the one hand, technology displaces labour (e.g., via automation of routine tasks); on the other, it complements it and allows firms to expand production, lower costs, generate more income, and create new employment opportunities.

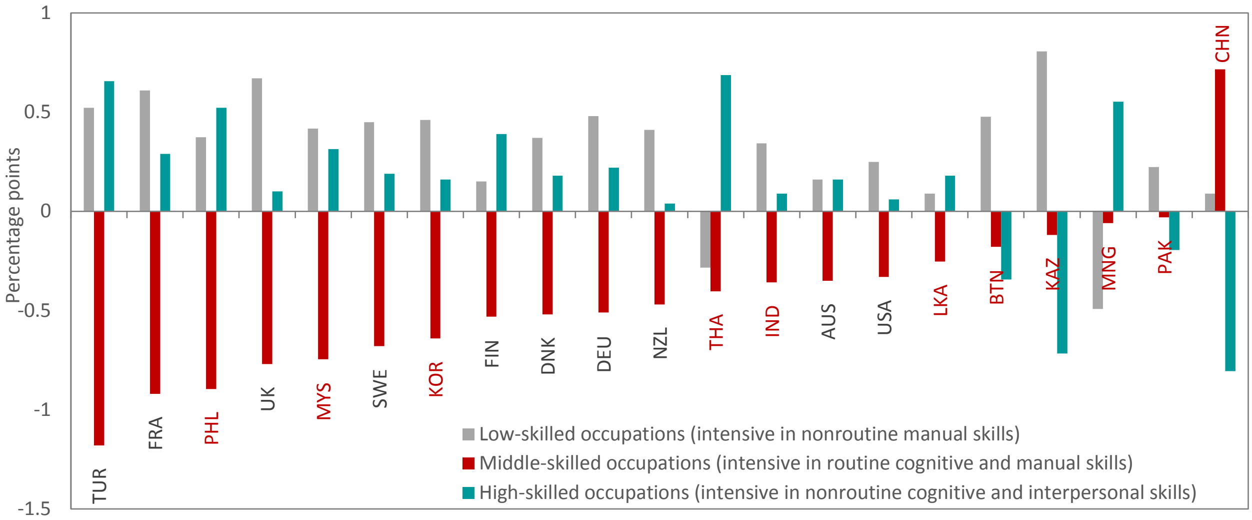
Vivarelli (2014) provides a survey of the theory and empirical literature of the impacts of technological change on labour markets. But as with other surveys, the demographic dimension hardly gets a look in. The employment effects are variously studied at the firm, industry, and economy-wide levels. Some look at the effects on employment in terms of *quantity* – whether technology substitutes or complements jobs – while others focus on the *quality* of jobs – whether changes are skill-biased.

Employment effects of technological change at the firm and industry level

Most of the research is at the firm level. Those studies that look at quantity tend to find that the technology effect on employment in countries ranging from Italy (Hall et al. 2007) to India (Mitra and Jha 2015) is positive, or at worst neutral (Biagi and Falk 2017) But greater disaggregation suggests that while product innovations are positive, process innovations can reduce employment, and that these effects can be larger if, for example, the firms are foreign owned (Brouwer et al., 1993; Dachs and Peters 2014).

Many studies looking at the effect of technology on the quality of employment suggest that even if technological change has no effects on the number of jobs, the job mix and wages share changes to favour skilled workers. The effect can differ on stage of development, type of industry, or local factor endowments. Technology changes have so far mainly been detrimental to middle-skilled workers who are substituted while technology complements low- and high-skill workers and drives up the wage share of the latter. The skill bias impact changes over time. For example, there is evidence in developed countries of the skill-bias diminishing over time, perhaps as low- or middle-skilled workers adapt or as skills needed at different stages of adoption change (O'Mahoney et al 2008; Conte and Vivarelli 2007; Chun 2003; Michaels et al 2014). Some studies suggest that the effects also differ by level of development (Caselli and Colman 2006). But the hollowing out of middle skill occupations is a widely observed phenomenon across developed and emerging countries. This is shown in terms of changes in shares of occupations by skill level in Figure 10. Notably, based on this analysis, China is one of the only countries in the world, where middle-skill occupations have seen gains at the expense of high-skill occupations.

Figure 10. Annual average change in employment share, by occupation skill, selected Asian and OECD countries, 1990-2012



Source: Adapted from World Bank (2016)

Age-biased technological change at the firm and industry level

A small subset of the literature has sought to break down these dynamics by testing for the presence of *age-biased* technological change. As discussed previously, since skills depreciate more with technological change and incentives to invest in or ability to update skills are lower among older workers, this group may be disproportionately affected by technological shocks. In theory, it becomes a race between skill investment and skill depreciation (Aubert et al 2006) and the effects appear in either wages or employment or both. As the population ages this may affect more workers who, instead of retraining may retire or be made redundant, especially if wages don't track their productivity.

In this vein, Peng et al (2017), used industry-level data across nine European countries between 1970 and 2007 to test the impact of skill-biased technological change across the age distribution of workers. They find that technological change is related to high-skill workers gaining wage share across all age groups. Low-skill older workers gain in terms of employment. It suggests that technology complements low-skilled jobs such as those in hospitality, nursing, primary teaching and community care, or is unable to replace them. Various labour market institutions can play into this. For example, they find that minimum wages and union density benefit skilled older workers while collective, centralised wage bargaining can ease the skill-biased technological change impacts on older workers. Training can also dampen the age-bias of technological change (Behaghel et al 2014). Such studies sometimes find structural breaks in the data, which suggests that the impacts can lessen as new generations of less skilled workers are able to better adapt to ICT technology.

Hujer and Radic (2005) tested for age-bias in mid-90s German data. He also found that low-skilled older workers were affected positively, but contrary to the above, older high-skill workers were affected negatively. The difference may again be indicative of the stage and timing of the technology shock – higher skilled older workers in 1990s Germany may have not adapted as well as more recent older workers that have a greater knowledge of ICT.

What about different types of technological change? Beckmann (2007) used similar data to test for the overall *quantity* effect. He split technology improvements into changes in technology intensity and change in organisational processes. He found that both increase the net demand for younger workers and reduce it for older workers.

The dynamics of employment changes play out in hiring, firing and retirement flows. For example, Aubert et al (2006) find that wage share of older workers in innovative French firms is lower than younger workers and that this is because older workers are less likely to be hired and more likely to leave such firms. Ahituv and Zeira (2011) suggest that while some retire for others the higher wage that result from technology means they delay retirement.

We know from the literature on formalisation that there is limited switching between informal and formal sectors but rather that formalisation takes place as formal firms expand, displace small, inefficient, informal firms, and hire new younger workers (La Porta and Schleifer 2008). This dynamic has been little explored with respect to technology and ageing.

Generalising employment effects at the macro level

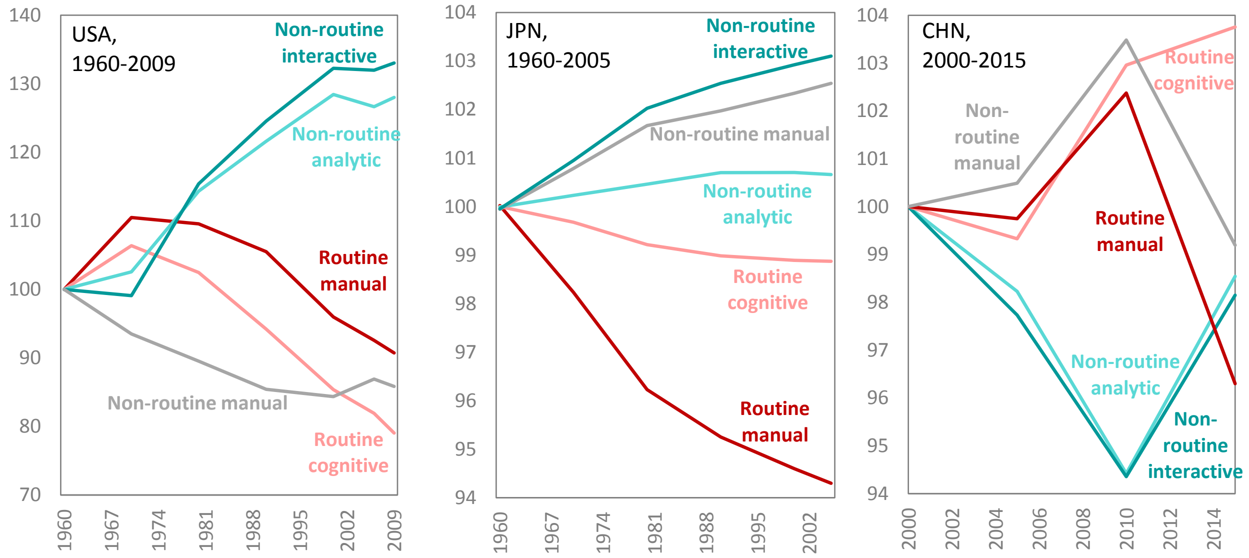
While firm level studies are instructive, it's difficult to generalise about the total impacts since some people are not employed. Goaied and Sassi (2017), using large panel macro-level data of developed and developing countries 1990-2015, find that ICT adoption is labour saving in the short term and long term, resulting in structural unemployment. The displacement, they note is "real, persistent, and universal". It suggests that much more policy work needs to be done to help the labour market transition from old to new jobs. The analysis does not, however, identify older workers separately.

Task based analysis at the macro level

A recent approach, pioneered by Autor et al (2003) and further summarised in Autor (2013), has been to analyse changes in the quality of work by breaking down job tasks at the detailed occupational level into *routine/non-routine* and *manual/cognitive* categories. Non-routine cognitive tasks are also split into *interactive*, which require communication, negotiation, and management; and *analytic*, which require unstructured, abstract problem solving.

Tasks in each occupation can then be weighed by the number of employees in each occupation to the level of industries and economies to understand how technology is changing the modern workplace and shifting the demand for different types of skills[8]. For example, evidence compiled in Figure 11, from the US and Japan, shows that in developed economies, occupations dominated by non-routine cognitive tasks (both interactive and analytical; e.g., teachers or physiotherapists) have increased in demand. At the same time, occupations and tasks that are substitutable by technology, such as those intensive in routine cognitive (e.g., middle-skill categories such as clerks) and routine manual (e.g., factory workers) have declined in both countries. Finally, occupations intensive in non-routine manual tasks (e.g., truck drivers, personal care assistants, and waiters) first declined in the US, but have seen a recent increase and have increased slightly in Japan.[9] The trends are consistent with the polarisation of the labour markets in most countries. By contrast, China has seen the opposite trend in the early 2000s, with some reversals more recently.

Figure 11. Changes in tasks performed across the economy



Note: Employment shares of tasks normalised to 100 in 1960. Note that charts have different scales and over different periods. Source: Adapted from Levy and Murnane (2013), Ikenaga (2013), and Park (2017).

---

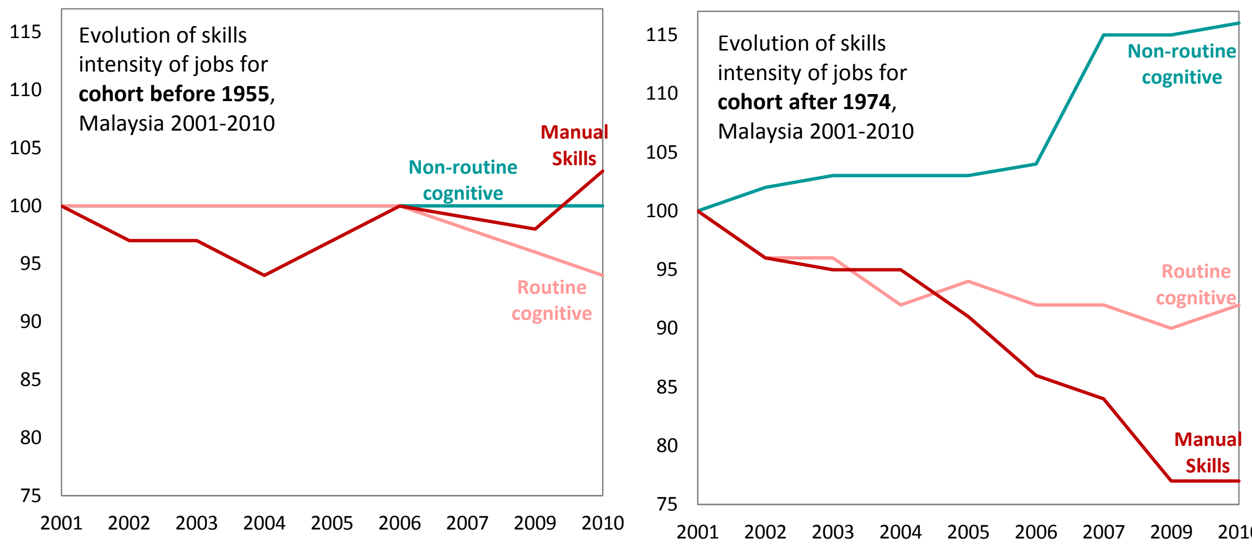
[8] Research usually uses US-based occupational definitions, but extensions allow more accurate estimates in emerging economies (Hardy et al 2017).
[9] However, some research suggests that cognitive work in the US has not grown as fast as the share of educated workers, which has reduced the average cognitive intensity of tasks done by workers with tertiary degrees (Beaudry et al 2013).

Explanations for the differing trends relate to automation (which can increasingly displace routine and some non-routine tasks such as driving; de la Rica and Gortazar 2016) as well as trade patterns (i.e., the China effect; see Goos et al 2014). This is why another task categorisation was proposed by Blinder (2009), the '*offshorability*' of a task. It's likely that demographics plays a role not only in terms of factor endowments but also in the composition of consumption of an older population. For example, it may explain the increases in Japan of demand for non-routine manual skills.

Task based analysis at the macro level, by age

So, what is the likely impact of fewer routine-manual and routine-cognitive occupations on workers across the age distribution? This will depend on their ability to move up, toward high-skill, nonroutine jobs or down, toward low-skill, nonroutine jobs. Autor and Dorne (2009) in the US and Lewandowski et al (2017) in Europe broke down the trends by age. They find that occupations requiring mostly routine tasks aged faster than occupations with fewer routine tasks. That is, older people seem to stay within occupations and industries that are more subject to automation. They find that only the youngest workers appear to both move upward and downward in the skill distribution. Some of these patterns can be demonstrated by looking at Malaysian data, for example, in Figure 12 (however note that routine and non-routine manual skills are grouped here). The figure shows little change in skill intensity of older cohorts' work, even as the labour market changes around them. By contrast, younger cohorts are increasingly less likely to be in jobs that require routine cognitive and manual skills. Instead, they find jobs that require non-routine cognitive skills, which are least automatable and most remunerative. According to the research, education mediates the extent to which older people find themselves stuck in obsolete occupations.

Figure 12. Changes in task intensity by cohort: Younger cohorts are driving the increases in non-routine cognitive jobs

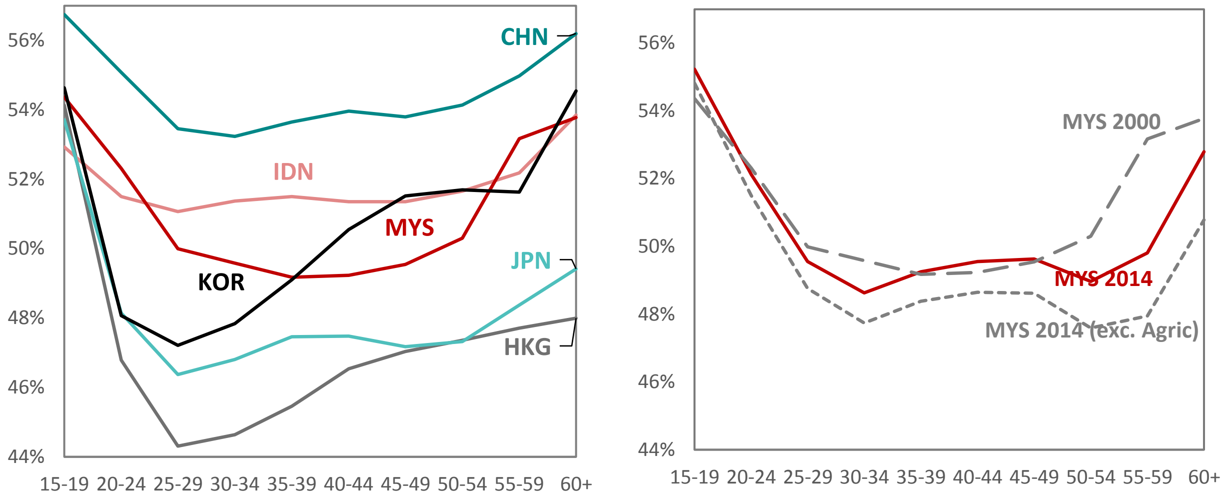


Note: The y-axis represents the percentile of skill distribution for jobs held by each cohort in any given year, with respect to corresponding median skills intensity of jobs held by that cohort in initial year, scaled to index of 100. An increase means that jobs increased in intensity in that skill. Source: Adapted from World Bank (2016)

It's worth finally asking about the potential scale of automation and, if fully realised, its impact on employment. Estimates for developed countries suggest that anything between 9% and 47% of jobs are automatable with existing technology (Arntz et al. 2016; Frey and Osbourne 2017). Manyika et al (2017) attempt estimates of automation potential across the world by applying automatable task intensities in US industries to the employment structure seen in other countries. They suggest, for example, that about half of China's full-time-equivalent jobs are automatable with current technologies. But how does this play out by age?

To examine this effect by age, we apply Manyika et al's index of automation for each industry to the observed level of employment by age in selected Asian economies. Essentially, we weigh each industry's existing employment share of an age group with the automation potential in that industry to estimate the overall automation potential of current employment by age. The results, shown in Figure 13, suggest that both younger and older workers in these countries tend to be in industries which have greater potential of automation. At earlier ages this is driven by more young people working in accommodation and food services and retail trade and wholesale trade. The pattern at older ages relates to older people's concentration in agriculture (except in Hong Kong, where this is mostly to do with administrative support and transport & storage). Compared to high-income economies, the pace of actual automation in middle-income economies is likely to be slower and incremental given lower levels of diffusion of technology. And regulation may also act as a barrier (e.g., automating transport). But a comparison of Malaysian data fourteen years apart (right panel) shows that automatable industries are ageing out of the workforce.

Figure. 13 Ageing and automation: Share of employment subject to potential automation, by age, 2016 or latest



Note: Data for China from 2010, China-HKG-SAR from 2011, Indonesia from 2010, Japan from 2010, Malaysia from 2010 or as indicated, Korea from 2016. Source: Authors' calculations based on Manyika et al (2017), UN (2018), and national statistics office data.

In summary, the relationship between technology and employment is complex. The overall adverse effect of technology on employment is overstated (Autor 2015). But technology is often found to affect the employment and wages of middle- and lower-skilled workers. To the extent that older people overlap with workers whose skills fall out of demand and are less likely to invest in updating their skills as technology requires it, or are less able and willing to switch occupations, then skill-biased technological change will also be age-biased. A greater population share of older people may mean that ageing countries will find it more difficult to match their skills to new technologies and could suffer lower economic growth as a result. The size of these effects may differ by technology type, stage of development, and factor endowments.

The best response is not to stifle the development of technology but to ensure institutions are in place that address technical unemployment, early retirement, and any skill mis-matching or obsolescence across skill categories and by age. Findings from literature on tasks suggests that as machines become more advanced education will need to focus on skills that require abstract, unstructured, and flexible analytical thinking. These institutions need to be nimble to adapt to future technological shocks, whatever they may be. At the same time, governments can encourage firms to adopt age-friendly practices, flexible wage contracts that reduce effect of seniority wages, age-specific job design, training programs targeted at life-long learning, and continuous mixed age-group interactions. They can also harness and encourage specific technologies that complement an ageing population. We look at some of these next.

6. SPECIFIC EMERGING TECHNOLOGIES IN AN AGEING WORLD

Technologies, ranging from robotics and AI, to biotech and materials technology, and ubiquitous computing and connectivity, have their applications in specific domains. In this section, we touch on technological innovation in three very specific domains that relate to ageing – long term care (LTC), health services, and digital identification for the delivery of social pensions. Each links with demographic change and the labour market in different ways.

In the care industry, which is driven by increasing demand and where labour intensity is high, the application of new technologies – and especially digital and robot technologies – has implications for the care burden on families, labour force participation, and the projected size of the care workforce. As noted at the outset, health and ageing are strongly related – new health technologies prolong life, directly generate an aging population, and keep people healthier longer, making them able to work for longer. Digital identification technologies which build state capacity in the implementation and delivery of social pension systems have wider applications in the economy at large and have the potential to enhance labour productivity by making formalisation more rewarding and less expensive. As ageing generates greater demand for health, care, and public services, it could induce invention, innovation, and diffusion across these sectors and increase productivity and change the composition of the labour market.

Long term care

Long term care is often seen as the new frontier of social policy. It can also stimulate the development and deployment of technologies that will allow two generations to continue to be economically productive: the older generation will be able to retain independence for longer, while the younger generation will be able to remain in the labour force for longer, reducing tensions between work and care.

In this context, technological innovation has the potential to free up members of the mature working age population – growing ever more numerous as demographic transition sets in – to engage in productive market-based work, thus improving the labour force participation rate.

Most care for older people is done by family (up to 90%), particularly women (about two-thirds of informal care; OECD 2011). But the reliance on families will be challenged by population ageing and the growing demand for care. In Asia, the expansion in demand for care services is at its most stark. By 2050, Asia will be home to more than twice as many people aged 80 and over as in the rest of the world (Chomik 2017). Yet in Asia, and especially among emerging economies, LTC policy has barely begun to be formulated (Chomik and Piggott 2015). China is currently experimenting with delivery models on a pilot basis (Lu et al 2017).

Technical innovations in the sector can broadly be divided into three categories: assistive technologies (AT); information and communication technology (ICT); and Robot technology (RT). In all cases, the successful application of these technologies depends upon their acceptance by older cohorts who may be suspicious of or insecure in using them. Their impact depends as much on psychology as technology per se.

Blaschke et al (2009) provide a comprehensive review of assistive and ICT technologies as they apply to ageing and care. These assist with monitoring behaviours, performance of tasks, and connectivity with other sources of support. For example, smart home and monitoring devices actively identify abnormal behaviour (e.g., falls) and alert care-givers of potential dangers. Telehealth, on the other hand, allow older people to access health services easily and cheaply. These often also incorporate monitoring systems and can exchange diagnosis data (e.g., blood pressure), raising care quality and health decision making regardless of setting. While the evidence base concerning the efficacy and cost effectiveness of deploying these technologies is incomplete, the potential advantages suggest that accessibility to ATs and ICTs should be encouraged.

A rather different category of supportive technology for those requiring assistance in old age is the robot. Asian countries have already invested heavily in robotics (see Section 4). Broekens et al (2009) review the use of this technology in the context of elderly care. Assistive social robots have aspects that are *functional* (as a form of user interface) and *affective* (raising quality of life – e.g., through companionship). Studies show positive effects of either the robot or its placebo version, such as a non-functional robot or a pet toy, and an openness to this kind of technology. Flandorfer (2012) finds that the sociodemographic characteristics such as age, gender, and education matter for user acceptance, concluding that assistive devices should be tailored to individual needs. In some cases, robots may be used to deal with routine manual tasks, such as laundry or transport services, freeing up staff to attend to non-routine caring tasks.

There are two likely impacts on the labour market. First, ICTs, ATs, and robot technology will mutually reinforce to relieve informal carers of some of their burden, making mature carers more amenable to formal labour force participation. Second, the possibility of substitution arises. Do robots have the capacity to replace formal carers in an institutional, or home or community, setting? If this is the case, then the international movement of care workers may be reduced; and any predicted shortage of aged care workers in developed countries may be mitigated.

Also, some technology development induced by demands of care may be transferable to the wider economy and result in greater innovation and productivity bonuses. For example, assistive devices such as those that addresses hearing and vision problems have been shown to have a positive effect on the productivity of teams with older workers (Gobel and Zwick 2013).

Health care

Technological innovation in health care has been dramatic over the last century. But health technology brings with it not only longer life, but longer healthy and active life (see Section 4). The available workforce can be substantially increased because of these technical innovations. It is important to recognise that these increases are not adequately captured in ratios such as the mature labour force participation rate, because the technology increases the population, not just the workforce. But the increase in the potential mature age workforce is important because it offsets in some degree that reduction in younger workers consequent upon fertility decline.

To realise this productive benefit, however, requires adjustment of social institutions (such as retirement age) and individual and family expectations about length of work life. It vividly illustrates the importance of policy design and intervention in generating increases in overall productivity, not by "picking winners", but by encouraging sensible use of human resources.

Health costs are widely seen as one of the fiscal challenges of population ageing. Many technological innovations in this space are expensive to implement and deliver. Innovation in health care is geared to mature cohorts, because they are becoming more numerous and wealthier, and because they have disproportionate political influence. But technological innovation may also be a conduit for remote delivery of services and monitoring that has the potential to drive down costs. Chronic disease, predominantly the preserve of elderly cohorts, is the largest of absorber of medical resources in developed economies, and the possibility of reducing the costs of treating chronic disease through remote monitoring is real (see Box 1).

Box 1: Deploying telehealth to reduce the costs of chronic disease

Much of the cost of health care is related to chronic non-communicable disease (NCDs). In future, NCDs will become more important in Asia, but already, 62% of deaths in South-East Asia are attributable to these (WHO 2018). The incidence of chronic disease increases with age, so population ageing will mean increasing health costs attributable to NCDs. One innovation is the introduction of telehealth for chronic disease management. This is more than just video-conferencing. In its complete form, it involves home monitoring equipment which can track vital signs without inconveniencing the patient with trips to a doctor or hospital. Early signs of an acute episode can be detected, and early intervention means less hospitalization.

Telehealth trials have been taking place for over a decade. The UK Department of Health reports that among the impacts of its *Whole System Demonstrator Programme*, is a 15% reduction in emergency visits, a 20% reduction in emergency admissions, a 14% reduction in bed days, and a 45% reduction in mortality rates (DH 2011).

This technology has yet to be introduced universally in any country. But the US Department of Veterans Affairs reported that about 700,000 US veterans received care in 2014 via telehealth. So, the technology not only works, but is scalable. An analysis of more than 17,000 *Care Coordination Home Telehealth* patients reveals a 25% reduction in the number of bed-days of care, and a 19% reduction in numbers of hospital admissions; and at much lower cost (Comstock 2014). In Australia, Celler et al (2016) published preliminary results from a telehealth trial involving several hundred people with chronic conditions across 5 states and territories. The $6 million trial over 18 months focused on chronic disease management. The findings were striking, and broadly consistent with international evidence. He says that over one year, the group receiving telehealth delivery experienced a 53% reduction in hospital admissions, a 68% reduction in hospital stays, and an over 40% reduction in mortality. Over one year the rate of medical and hospital expenditure was reduced by more than 63%, and pharmaceutical costs declined by more than 25%.

Digital Identification Technology

Digital identification technology (DIT) has been sporadically deployed in developing countries to improve the implementation and delivery of social programs, especially those directed toward older cohorts. Both retirement transfers and health services have been delivered using DIT, sometimes linked with smartcards (see Box 2).

Population aging has motivated the development of these applications in emerging economies, enhancing state capacity. The development of widespread DIT in an emerging economy can also have major positive impacts on development and productivity, benefiting both the economy and retention of older cohorts in the workforce. It is an example of how new technologies initially developed to meet the needs of older cohorts can bring macroeconomic benefits when more widely applied.

Identification and authentication systems can be thought of as a form of public infrastructure. But such systems can be expensive to set up and maintain. Low- and middle-income nations have not done this optimally. Poor people within these nations often find themselves without the means to prove who they are. The issue is more urgent as regional migration reduces the reach of physical identification. This urgency is exacerbated by calls for social services to be more uniformly available.

This *identity gap* may be a symptom of underdevelopment, but it also inhibits development, particularly for the less well-off (Gelb and Clark 2013). In developing countries, people at the top of the income distribution were highly likely to registered births, compared to those in the bottom (World Bank, 2007). A lack of documentation can result in difficulties in accessing education, affecting skills and work prospects, which can in turn create an intergenerational cycle of exclusion. A second application which will directly impact productivity growth relates to financial services. Reliable identification is a pre-requisite for raising capital, and other financial transactions conducive to increased productivity growth. These examples illustrate that lack of identification collateral impedes growth and is consistent with the perspective that identification support is a public service which a jurisdiction can provide to its citizenry.

Box 2.: Digital Technology and Social Programs for older cohorts

Various studies examine the efficacy of digital technology in delivering social programs in developing countries. Some of these involve identification and information, others involve payment mechanisms.

An ambitious program, using biometric smartcards to deliver payments under the beneficiaries of employment (NREGS) and pension (SSP) programs has been implemented in Andhra Pradesh, India (Muralidharan et al 2016). About 19 million people were involved. The new system delivered a faster, more predictable, and less corrupt NREGS payments process without adversely affecting program access" (p.1), while enhancing state capacity for public transfer programs.

If identification technology can be universally established and act as a game-changer in the trend toward development and formalisation of the workforce. Although the initial applications are age-related, the more widespread benefits of the universal application of this kind of technology will widen the scope for development and formalisation to take place, and the resulting increased productivity (especially labour productivity) will help to meet the fiscal challenges posed by an ageing demographic. Indeed, the process of formalisation is generally viewed as enhancing productivity (La Porta and Shleifer 2014; Khamis 2014). While the formalisation costs for individuals and firms can outweigh benefits, simpler procedures can tip the equation toward formalisation.

Gelb and Clark (2013) identify and survey 160 cases where biometric identification technology was implemented in developing nations. In many cases, in Africa in particular, the number of people impacted are quite small. But 27 of their cases are located in South Asia, and these cover more than 400 million people. And a further 13 are based in East Asia and the Pacific. Growth in the biometrics market is very high; in the Asia Pacific compound growth over the next 7 years is forecast to be 20%. This suggests that systematic government efforts to marshal DIT as a public resource may be feasible and have major socioeconomic payoffs.

7. WHAT POLICIES WILL BE NEEDED?

The following is an incomplete list of the types of policies that will be needed to respond to the dual effect of population ageing and technological change. These should be read along with policy interventions listed earlier, in Table 1.

Human resource policies

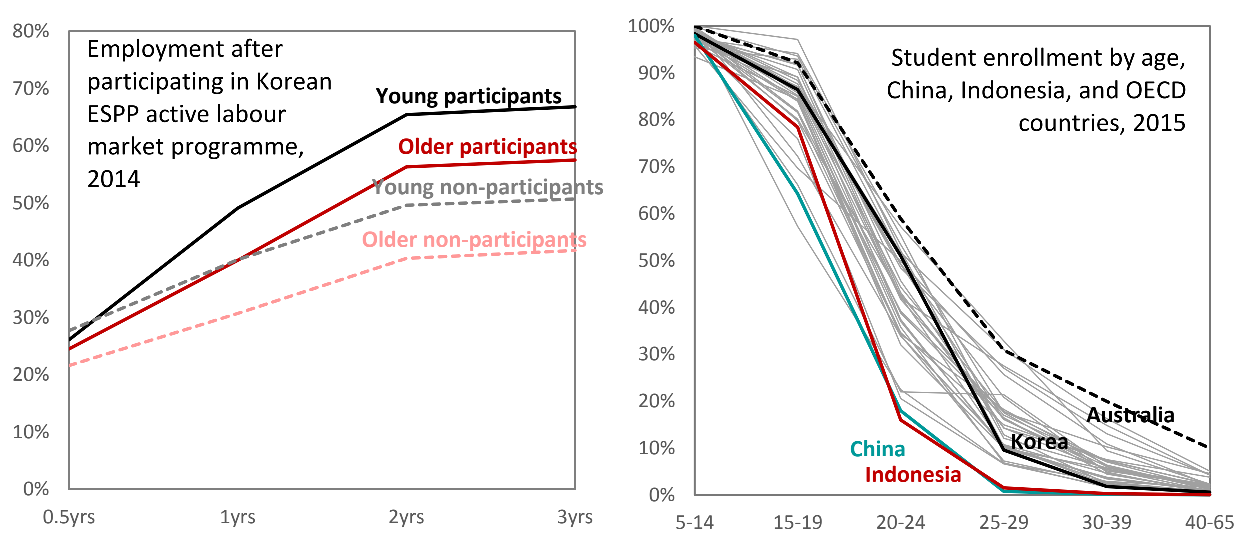
Education and training strategy

Family life and early education experiences are vital in developing fundamental skills and establishing the readiness to learn in later life, as 'skills beget skills' (Cunha et al 2010). Longer careers and changing skill requirements careers will mean lifelong learning becomes increasingly important. So far, formal adult learning, reskilling, and training to cope with the development of new technologies is nascent and where such programs exist, they are often fragmented, under-resourced, and rarely directed to those most in need of re-skilling.

The policy area requires a clear strategy involving governments, educators, employers and individuals themselves. This starts with mapping of industries and skill demand and how these match with existing education options, and the extent to which training bottlenecks exist across industries and sectors. Policy thinking in this area is among the most advanced in Nordic countries. But Korea and Singapore stand as two benchmark examples. Both have linked economic forecasting, prioritising, and planning with workforce programmes such as vocational and technical education. They have also developed skills monitoring and forecasting systems that keep track of changing skill demand (Jagannathan and Geronimo 2013).

On some measures, Asian countries lag the OECD in mature age education and training. Korean mature age training programs, where job training subsidies are available for those covered under the occupational skills development scheme, have had low take-up (Phang 2011b). More recent schemes build adult training into active labour market policies, which must become a bedrock of matching existing skills to existing jobs as well as incentivising the updating of skills as jobs change. Korea's ESPP activation programme, which provides targeted, case-managed job-search support as well as training and allowances that incentivise participation in training, has had some positive outcomes but, so far, they advantage younger workers (Figure 14, left panel). The overall rate of learning at older ages remains low in Asia (Figure 14, right panel). While Singapore has a continuous education and training infrastructure it still spends far less than what is observed in other developed countries (Thang 2011). This has recently been remedied with the introduction of the SkillsFuture for Digital Workplace programme, which entitles Singaporeans over age 25 to a credit that can be spent on a number of approved courses.

Figure 14. Active labour market policies and lifelong learning



Source: OECD (2018a); OECD (2017)

According to the European Commission (EC 2001) the essential elements of a lifelong learning strategy comprise: (1) developing partnerships across all stakeholders (public at all levels, employers, service providers, and civil society); (2) identifying skill needs; (3) identifying public and private resources and investment models; (4) increasing access (e.g., geographically, across industries, and targeting disadvantaged minorities); (5) creating a learning culture (e.g., motivational campaigns, reducing barriers); and (6) establishing evaluation and quality control mechanisms.

The list provides a policy agenda for countries keen to leverage the labour potential of older workers. Some action items require no more than establishing an ecosystem in which institutions can cooperate. In other cases, specific actions, information collection will be necessary. In still others, establishment of mature age scholarships, or subsidising the establishment of learning centres, will be required. In practice, there is some debate about the successes of these policies in different European countries and the applicability of lessons for Asia Osborne and Borkowska (2017).

Tech-ready education

Technological advancement means that basic IT skills are becoming important in both advanced and emerging Asia and in both services and manufacturing, even in traditionally unskilled occupations. For example, in 2011, over a quarter of intermediate inputs in Philippine manufacturing was related to computer, electronic, and optical equipment; and in Vietnam in 2015, about 90 percent of firms used websites or email to communicate with clients or suppliers (OECD 2018b). Asian countries ignore these trends at their peril. UNESCO (2018) data shows that over 70% of Chinese *innovation-active* manufacturing firms reported that a lack of qualified personnel was hampering their development – the highest rate across surveyed countries. Many economies have the potential to capitalise on technology trends but need to start with getting the basics right, including in schools, universities, vocational training, and lifelong learning programs. Essentially, these will need to establish *learning* as a skill in itself, in preparation for later life.

Indonesia, for example, lags some of its neighbours in gross tertiary enrolment rates, which means that it's future workforce may lack the skills to take advantage of the opportunities that a digital economy offers. Technical and vocational education and training (TVET) can also foster skills for the new economy. For example, in 2015, Malaysia, launched the eUsahawan programme to integrate IT learning into its TVET institutions (OECD 2018). Singapore is a good example where lifelong learning is being taken seriously. The government subsidised program includes courses ranging from e-payments and e-commerce platforms to data analytics and automation. An estimated 100,000 people will benefit from this programme over the next three years (OECD 2018b).

Targeting education and training

In developed economies, formal lifelong learning programs, such as continuing education programs organised by universities, tend to have richer people as their clients. The cost of training is easier to bear by those with greater incomes and time and perhaps more likely to be taken up by those in the know, who are more educated. So, it is necessary to target subsidies and interventions as well as information campaigns to engage those who may be in most need of such programs – people whose working lives revolve around routine tasks, but whose employers are seeking workers able to take on more non-routine responsibilities. Employers themselves are unlikely to voluntarily offer such training, because non-firm specific training, such as basic ICT competencies, are readily marketable to other organisations. For these individuals, training will have to be made available through some external educational or training facility. Financial and time costs are likely to operate as barriers to participation in such training, and explicit measures will need to be enacted to encourage engagement. Similar considerations will apply to other groups where adult training may yield high returns, such as migrants. Nordic countries, for example, have been more successful in ensuring broader access to lifelong learning due to union involvement in these programs, greater access to information technology generally, and strong active labour market policies with appropriate *sticks* and *carrots* (Martin 2017). In Germany, for example, unions have negotiated with some industries to establish a 'demography fund' to support older workers and their training needs (Berg et al 2017).

Participation of older adults in these programs is sometimes seen as less valuable than for younger participants and employers offer them less support in on-the-job training (Maurer et al 2003). But payoffs over longer careers are increasing. For migrants, for example, such training can have intergenerational payoffs (Rege et al. 2011; Oreopoulos et al. 2005). Employers wanting to hold on to their older workers, training can serve as a good human resource management tool. One reason why some training programs have lower outcomes for older workers is that these do not take account of differences in motivations and older workers preference for informal and practical skills (Zwick 2015). When training is tailored to older workers, it has been shown to have positive effects, such as later retirement, but evidence relating training content to outcomes is limited (Berg et al 2017).

That popular view that older employees prefer informal, on-the-job training rather than formal, class-room or course-based, learning is consistent with findings from educational neuroscience whish suggest that adults, and especially older adults, have different ways of learning (Howard-Jones and Meadows 2012). Such research reports that early education is critical, but that new skills can be developed later in life (and indeed that new neurons are created) in response to need and stimuli but that different learning strategies are employed. While younger people learn things passively, adults rely on focusing attention, suggesting that teaching needs to be in small chunks. Also, the preference for practical skills helps build on older people's established, or *crystalised*, knowledge. Strategies will need to be developed with employers to be relevant. These need to include a series of shorter modules, and respect for past learning. It is indeed where many Massive Open Online Courses (MOOCs), provided online by universities and other providers, have been moving. Greater completion rates have been shown to relate to breaking down degrees into modules, modules into courses, and courses into smaller and shorter units; alternatively, the courses can act as *nanodegrees* in themselves with a patchwork of credentials (The Economist 2017).

Migration Policies

A rather different human resource policy relates to migration. The benefits, in terms of improved productivity and efficiency gains, of free labour mobility between countries have been demonstrated repeatedly (e.g., Hamilton and Whalley 1985; Chomik et al 2017).

Skills-based migration has the potential to relax points of tension in an expanding economy facing skill shortages as it adopts new technology. For example, countries such as Australia operate very successful skills-based migration programs. Immigrants often spread know-how to domestic workers, which is crucial to growth and development. As well, to the extent that skill shortages are linked to demographic structure, technical expertise possessed by younger workers may lead to changing the age structure of the destination country.

A second important incentive to liberalise migration flows relates to low skill workers, such as carers. Interestingly, Taiwan, Singapore and Hong Kong host about 230,000, 240,000 and 340,00 foreign domestic/nursing workers, respectively. Yet Japan with a particularly old population has just 2,627 foreign nurses and care workers.[10]

It points to the fact that migration policies are often controversial, not only because of the misconceived notion that migration reduces domestic opportunity, but also for cultural reasons. For many nations, it is not straightforward to adopt more open immigration policies. But migration should at least be on the menu of policy initiatives that are available to address the impact of simultaneous technical innovation and ageing.

Production and infrastructure

Strong capital investment and supporting infrastructure policies are an essential part of any economy embracing technological advance, and an ageing workforce and population reinforce this. As noted earlier, recent estimates of the infrastructure investment gap in Asia are large (ADB 2017).

Again, the links between ageing, technology, and capital and infrastructure development run in many directions. New technology embodied in capital investment may enable workers to work for longer. New technology also has the potential to improve returns to private capital, encouraging further private investment, and raise retirement

[10] These statistics are taken from Ogawa et al (2017), who also provide useful commentary on the international migration of care workers, especially in the Asian region.

incomes. An ageing population requires adaptive infrastructure, ranging from ramps in public buildings to residential *smart* dwellings and aged care facilities. Policies directed towards support for the ever-growing population of retired workers can be designed to generate sources of capital suitable for long term investment.

Sources of Capital for Investment

The major sources of capital for investment are domestic saving, foreign investment and taxation. To encourage domestic saving, tax distortions should be minimised and property rights well understood and credible (with strong governance). As populations age, saving for when earnings capacity is exhausted potentially provides a powerful source of investment funds. As noted previously, this is the *second demographic dividend* – in emerging economies, it comes predominantly from workers and households operating in the formal sector.

Even within this group, however, policy settings, especially around retirement provision, are critical. National under-saving in the developed world has often been linked to the provision of unfunded social security. An organised public program which mandates saving can generate a large pool of funds which can be used as a source of capital for investment and deliver benefits that correspond to those in an equivalent-cost unfunded program. Mandating overcomes the under-saving often observed in voluntary retirement saving projections. Examples of this system include Chile, Australia, the Netherlands, and Switzerland. To draw on just the Australian example, which was introduced in 1987, and fully phased in only in 2002: It currently has generated more than AUD 2.5 trillion (USD1.9 trillion) in funds under management, the fifth largest pool of funds of any nation, even though Australia has a population of only 25 million. Mitchell and Piggott (2016) provide a recent review of workplace pensions, emphasising these kinds of arrangements.

In some Asian countries prefunding has been implemented via provident funds, including in Malaysia, Singapore, and the Philippines, although on a far less systematic basis. Some countries, such as China and Korea, with substantial unfunded schemes have also built in some prefunding, often on a voluntary basis.

Appropriately managed, and with adequate financial intermediation, the long timeframes involved in retirement saving can make this pool of funds especially amenable to well-chosen infrastructure investment.

International investment can be encouraged through various means, including tax breaks, subsidies, and competitive leases on land. But trade and skill exchange programs can also be of help. The agreement can involve manufacturing in an emerging economy, using developed-economy capital and know-how, and domestic labour. Output can gain some preferential treatment in the developed country's domestic market. In this way, new capital can be attracted to the emerging economy, and training, either formal or informal, is provided to the domestic workforce. This can be an important vehicle not only for growth, but for the dissemination of technical skills.

Public Infrastructure

The idea that public infrastructure is required for development is not new. The intuition is that for reasons related to market conditions and coordination requirements, centralised provision of certain kinds of infrastructure is either required or is more efficient. A good example is a fast broadband network. Many attempts have been made by economists to measure the impact of public infrastructure on total factor productivity and on the return to private investment (for example, Otto and Voss 1994, 1996 1998). A recent survey of the literature by Pereira and Andraz (2013) reports the effects of public infrastructure investment are smaller than past estimates but almost always positive, and higher for less developed countries.

This suggests that there is indeed a return to emerging economies in particular identifying opportunities for infrastructure investment that may support an ageing demographic, either in the workforce or later life, and using funds from taxation or private saving to implement them.

In section 6 above, we identify digital identification technology as an example of the ways in which emerging technologies have interacted with an ageing demographic. In section 8 below, we suggest investigating a research project to assess whether widespread development of this technology for identification purposes in emerging economies might facilitate the formalisation of labour markets. If research indicates that there would be a major return to the wider application of digital identification technology, this would be a potential public infrastructure investment with connections to technical innovation, the labour market, productivity, and ageing.

Associated with public infrastructure, although distinct from it, is establishing coordination policies which standardise new technologies. Standardising bandwidths in a broadband network is one example. Standardisation also allows for people of different skill levels and abilities to make use of new technology.

Addressing inequality

Reducing inequality is a universal policy objective. Its link to the technology-aging nexus is twofold. First, ageing and inequality appear to be related, and technological change may be one conduit for this relationship. Second, technological advances may provide the state with increased capacity to implement more effective policies to reduce inequality.

Inequality tends to increase within a cohort as it ages and differences accumulate (Burtless 2012, Crystal et al 2016). It follows that population ageing will be associated with increasing inequality, because older cohorts generally display greater inequality in consumption/income than younger counterparts, at least in the absence of strong social protection (Deaton and Paxson 1998). This link has received some attention in the Asian context, (Deaton and Paxson 2000, Ohtake and Saito 1998), but broad investigation of the interaction between population ageing and inequality, especially in the context of emerging economies, is sparse. As discussed earlier, new technologies that bias skilled workers exacerbate this pattern and may require greater levels of redistribution, particularly within the retirement income system.

Three major sets of policy initiatives can help tackle inequality. First, policy formulation should be based on the life course. Targeted investment in human capital, from early childhood and at key life stages, supporting health and education, can generate the best chance of reducing inequality in the long term. Digital technologies have the potential to be deployed to deliver these services, reducing cost and increasing coverage. Lifelong learning may be the best way of helping workers to develop the capacity to respond flexibly to technical change, and to utilise that capacity throughout working life.

Second, workers, and especially older workers, who are displaced by the adoption of new technologies should be targeted in support programs. This is analogous to displacement through trade policy. In the US, for example, a large Trade Adjustment Assistance program provides displaced workers with relocation assistance, subsidised health insurance and extended unemployment benefits in addition to basic social safety net protections. Perhaps a corresponding program for labour markets impacted by technological change could a t*echnology adjustment assistance*. The US program has many shortcomings, often providing too little assistance too late (Muro and Parilla 2017). Such programs need to do more than provide financial support – they need to assist displaced workers to re-engage with society and expand their capacities to explore new opportunity.

Third, the current uneven development of social protection in Asia needs urgent attention (Chomik and Piggott 2015). It suggests that a push for a dynamic and flexible labour market and comprehensive active labour market policies need to be matched by strong social protection policies. Denmark is a successful example of combining these policies in its *flexicurity* model. Social pensions, directed at people whose earning capacity has been compromised are a particularly important policy instrument (Lu et al 2014). Technologies which have the potential to give the state this capacity have been piloted in India and Mexico with some success (see Section 6).

8. RESEARCH NEEDS

Data and modelling capability

There is an urgent need for better, and more tractable data so that we have a basis for improving our understanding of the complex relationship between technology, education, workforce, and aging. While there is increasing access to "big" data, as a by-product of social media or commercial transactions, this can rapidly become intractable, and provide limited reliable insight into relevant phenomena. The assembly of quality data on the issues raised in this paper is vitally important for understanding what possibilities there are for improving wellbeing. For example, linked employee-employer data is sparse in Asia.

Information about the relationship between age-related changes in functioning and job performance is needed, especially where job performance requires use of new technology. Equally, longitudinal data to enable us to better understand health trajectories for different populations as they age are vital in gaining an appreciation of the opportunities and limitations of policies designed to retain older workers in the labour force. Evaluating empirically the effects of Singapore's lifelong learning program is an obvious example. At another level, data on the potential of technological infrastructure to contribute to development is not readily available.

Systematic initiatives to collect and generate data to provide an information base across these domains will allow much better responses to the policy challenges generated by the interaction of technical change and ageing. Extending the OECD's adult skills surveys to other Asian countries would help, for example.

Associated with better data is the potential for improved modelling. There is a dearth of sophisticated economic modelling to shed light on the interactions between technical progress, ageing, and policy interventions. As a result, we have a limited sense of the extent to which a given policy intervention will impact inequality, allocation of resources, efficiency, and growth. Both overlapping generations type macro models, which are the cutting-edge economic models focused on demographic change, and micro-simulation models, which detail policy-induced changes in inequality, are needed. These models need to be adapted to capture the impact of technical innovation.

Workplace and job design

An important knowledge gap in this area relates to workplace and job design interventions. That is, how does job design (e.g., task design, work flexibility, remote working, age-inclusive culture) affect the productivity and motivation of mature workers?

We need to better understand how work factors, including technological change, in combination with individual differences, promote or inhibit successful ageing. For example, work designs need to incorporate change occurring within work in general (e.g., move toward cognitive non-routine tasks) at the same time as developmental and physical changes that characterise older employees (e.g., fluid intelligence declines with age, whereas crystallised intelligence and accumulated job-based knowledge increase). Good work designs have the potential to preserve and maintain cognitive, social, and psychological functioning (Zacher 2015). While psychologists have been looking at this area for a while, economists have rarely engaged with such changes in human capital.

The idea that work can be designed to facilitate such outcomes is part of an emerging, innovative perspective that mental and psychological capital can be enhanced across the lifespan. It allows for the possibility not only for greater mature labour force participation and less technology-induced labour obsolescence, but a framework within which working longer is seen as a positive by both worker and employer and can inhibit cognitive decline (and promote healthy ageing (Rodin 1986). How long people work will also depend on opportunities for training, retraining, and continuing education.

Part of effective work design could include developing and deploying technologies, including person-based biomedical advances as well as workplace devices, that can help improve the health and capacity of individuals with various types of disabilities to perform job-related functions, help with career and employment transitions, or deliver effective adult education interventions. This will depend on understanding the technological adaptations that are effective, workers prefer, and employers are willing to provide.

Channels through which population ageing could affect productivity

We have listed previously, in table 1, the likely channels through which demography and technology interact and how these may affect productivity. Many of these channels remain under-researched. For example, to what extent will demographically-driven changes in the composition of consumption affect the growth in low-productivity industries (e.g., personal services) or be offset by growth in high tech industries (e.g., medical equipment). How will the macro-economy and trade be affected by changes in labour factor endowments – will older countries have lower labour- and skill-intensity in production, and therefore lower productivity and income? And will greater age-diversity in workplace be synergistic or polarising and reduce social and workplace cohesion? The study of these channels requires new models and new attempts to isolate their effect.

Cost and benefit analyses of specific technologies

There are numerous areas of technical innovation in infrastructure that impact the ability of older cohorts to engage in the labour market (e.g., transport, communications, workplace access). But a concerted effort to identify those that would be most cost-effective would help. One highlight, for example is Digital Identification Technologies. We reported in section 6 on the role of DIT in building state capacity to deliver various public programs to older individuals and argued that this kind of infrastructure can complement development. Yet research on its impact on formalisation, productivity, or indirect effects on public health, is absent.

9. CONCLUSION

As described in this paper, demographic and technological changes are already transforming labour markets across Asia. Yet there is limited literature on the interactions between these trends and rarely in the Asian setting.

In this paper we have mapped out (1) the interactions between technology, ageing and productivity; (2) the impacts of these on employment, occupations, and industries; (3) how specific technologies interact with the immediate challenges of population ageing; and (4) what policy strategies and further research are needed.

The findings suggest that the empirical literature doesn't agree about the direction, magnitude or channels in which ageing affects productivity. We have identified numerous channels, each of which requires further investigation. The research suggests that an older population does not necessarily need to result in slower rates of productivity growth, particularly if it induces greater investments in automation and since future older cohorts are likely to be healthier, more educated, and able to adapt to technology than older people are now.

The relationship between technology and employment is also complex. The adverse effects of technology and automation on employment, as often portrayed in the media, are overstated. But technology is found to affect the employment and wages of middle- and lower-skilled workers – many of whom are older. And since older people are less likely to update their skills it suggests that technological change is indeed age-biased. The evidence suggests that such effects are also present in Asia.

The best policy response is not to stifle the development of technology but to ensure institutions are in place that address technical unemployment, early retirement, and any skill mis-matching or obsolescence across skill categories and by age. All Asian countries need comprehensive lifelong learning strategies, tailored to their specific requirements, that respond adequately to digitalisation and target programs at those in most need. These need to be built into active labour market policies and educational programs to ensure appropriate matching of skills in the short term, retraining in the medium term, and a pipeline of adaptable skills in the long term. At the same time, technological advancement can be encouraged by appropriate funding mechanisms and human capital and physical infrastructure. Population ageing can, in turn, be managed by appealing to a number of technologies, particularly in health, care, and those that enable the public sector to play a part in raising technological capacity of its citizens (e.g., digital IDs).

Finally, the findings suggest that an ambitious research agenda is needed. One that includes investment in new data and modelling; looks at how technology and job designs help or hinder older people in the workplace; investigates the myriad channels in which the relationships between ageing, technology and the labour market play out; and investigates the cost-effectiveness of public sector investments in specific technologies.

10. REFERENCES

Acemoglu, D. and P. Restrepo (2017) 'Secular stagnation? The effect of aging on economic growth in the age of automation', American Economic Review, 107, 174-79

Acemoglu, D., P. Aghion, and F. Zilibotti (2006) 'Distance to frontier, selection, and economic growth', Journal of the European Economic association, 4, 37-74

ADB [Asian Development Bank] (2017) 'Meeting Asia's Infrastructure Needs', Manila

Ahituv, A. and J. Zeira (2011) 'Technical progress and early retirement,' The Economic Journal, 121(551), 171-193

Aiyar, S., C. Ebeke, and X. Shao (2016) 'The impact of workforce aging on European productivity', International Monetary Fund Working Paper. No. 16/238

Arntz, M., T. Gregory and U. Zierahn (2016) 'The risk of automation for jobs in OECD countries: A comparative analysis', OECD Social, Employment and Migration Working Papers, No. 189, OECD Publishing, Paris

Arora. S., (2001) 'Health, human productivity, and long-term economic growth', The Journal of Economic History 61(3), 699–749

Aubert, P., E. Caroli, M. Roger (2006) 'New technologies, organisation and age: firm-level evidence,' The Economic Journal, 116(509), F73-F93

Autor, D. (2013) 'The "Task Approach" to Labor Markets: An Overview', Journal for Labour Market Research, 46(3), 185–199

Autor, D., (2015) 'Why are there still so many jobs? The history and future of workplace automation', Journal of Economic Perspectives, 29, 3-30

Autor, D., D. Dorn (2009) 'This job is "getting old": Measuring changes in job opportunities using occupational age structure', American Economic Review: Papers & Proceedings 2009, 99(2), 45–51

Autor, D., F. Levy, and R. Murnane (2003) 'The skill content of recent technological change: An empirical exploration', The Quarterly Journal of Economics, 118(4), 1279–1333

Beaudry, P., D., Green, and B. Sand (2016) 'The great reversal in the demand for skill and cognitive tasks', Journal of Labor Economics, 34, S199-S247

Beckmann, M., (2007) 'Age-biased technological and organizational change: Firm-level evidence and management implications', WWZ Discussion Paper, no. 05/07

Behaghel, L., and N. Greenan (2010) 'Training and age-biased technical change', Annals of Economics and Statistics, 317-342

Behaghel, L., E. Caroli and M. Roger (2014) 'Age-biased technical and organizational change, training and employment prospects of older workers', Economica, 81(322), 368-389

Berg, P., M. Hamman, M. Piszczek, and C. Ruhm (2017) 'The relationship between employer-provided training and the retention of older workers: Evidence from Germany. International Labour Review', 156, 495-523

Bertschek, I. and J. Meyer (2009) 'Do older workers lower IT-enabled productivity?', Jahrbucher fur Nationalokonomie und Statistik, 229, 327-342

Biagi, F., and M. Falk (2017) 'The impact of ICT and e-commerce on employment in Europe', Journal of Policy Modeling, 39(1), 1-8

Blaschke, C., P. Freddolino, and M. Mullen, (2009) 'Ageing and technology: A review of the research literature', British Journal of Social Work, 39, 641-656

Blinder, A., (2009) 'How many US jobs might be offshorable?', World Economics, 10, 41

Bloom, D. and A. Sousa-Poza (2013) 'Ageing and productivity: Introduction', IZA Discussion Paper No. 7205

Bloom, D., and D. Canning (2005) 'Health and economic growth: Reconciling the micro and macro evidence', Mimeograph, Harvard School of Public Health

Bloom, D., and J. Williamson (1998) 'Demographic transitions and economic miracles in emerging Asia', The World Bank Economic Review, 12(3), 419–455

Bloom, D., D. Canning, and B. Graham (2003) 'Longevity and life-cycle savings', Scandinavian Journal of Economics, 105, 319–38

Bloom, D., D. Canning, G. Fink (2011) 'Implications of population aging for economic growth', Oxford Review of Economic Policy 26 (4) 583–612

Bloom, D., D. Canning, J. Finlay (2010) 'Population aging and economic growth in Asia' in T. Ito and A. Rose (eds) 'The economic consequences of demographic change in east Asia', University of Chicago Press

Borsch-Supan, A., and M. Weiss (2016) 'Productivity and age: Evidence from work teams at the assembly line', The Journal of the Economics of Ageing, 7, 30-42

Borsch-Supan, A., K. Härtl, and A. Ludwig (2014) 'Aging in Europe: Reforms, international diversification, and behavioral reactions' American Economic Review, 104 (5), 224-29

Broekens, J., M. Heerink, and H. Rosendal (2009) 'Assistive social robots in elderly care: a review', Gerontechnology, 8, 94-103

Brouwer, E., A. Kleinknecht, and J. Reijnen (1993) 'Employment growth and innovation at the firm level', Journal of Evolutionary Economics, 3(2), 153-159

Burtless, G., (2012) 'Life expectancy and rising income inequality: Why the connection matters for fixing entitlements', The Brookings Institution, Op-Ed www.brookings.edu/opinions/life-expectancy-and-rising-income-inequality-why-the-connection-matters-for-fixing-entitlements

Caselli, F., and W Coleman (2006) 'The world technology frontier', The American Economic Review, (June), 499-522

Cattell, R., (1963) 'Theory of fluid and crystallized intelligence: A critical experiment' Journal of Educational Psychology, 54(1), 1-22

Celler, B., M. Varnfield, R. Sparks, J. Li, S. Nepal, J. Jang-Jaccard, S. McBride, and R. Jayasena (2016) 'Home monitoring of chronic disease for aged care', Australian e-Health Research Centre (AEHRC) CSIRO

Chakravorti, B., and R. Chaturvedi (2017) 'Digital planet 2017: How competitiveness and trust in digital economies vary across the world', The Fletcher School, Tufts University

Chinn, M., and R. Fairlie (2007) 'The determinants of the global digital divide: A cross-country analysis of computer and internet penetration', Oxford Economic Papers, 59, 16-44

Chomik, R. and J. Piggott (2015) 'Population aging and social security in Asia', Asian Economic Policy Review, 10(2), 199-222

Chomik, R., (2017) 'The constellations of demography fact sheet', CEPAR

Chomik, R., J. Piggott, and P. McDonald (2017) 'The Impact of demographic change on labour supply and economic growth: Can APEC meet the challenges ahead?', CEPAR working paper

Chomik, R., S. Graham, R. Gawthorp, K. Anstey (2018) 'Cognitive ageing and decline: Insights from recent research', CEPAR Research Brief

Chun, H., (2003) Information technology and the demand for educated workers: Disentangling the impacts of adoption versus use, The Review of Economics and Statistics, 85(1), 1-8

Comstock, J., (2014) 'Telehealth served 12 percent of VA-covered veterans in 2014', Mobihealthnews, October 2014

Conte, A., and M., Vivarelli (2007) 'Globalization and employment: Imported skill biased technological change in developing countries', IZA, Discussion paper no. 2797

Crystal, S., D. Shea, and A. Reyes (2016) 'Cumulative advantage, cumulative disadvantage, and evolving patterns of late-life inequality', The Gerontologist

Cunha, F., J. Heckman, and S. Schennach (2010) 'Estimating the technology of cognitive and noncognitive skill formation', Econometrica, 78(3), 883–931

Dachs, B,, and B. Peters (2014) 'Innovation, employment growth, and foreign ownership of firms: A European perspective', vol. 43(1) 214-232

Daveri, F. and M. Maliranta (2006) 'Age, technology and labour costs', Keskusteluaiheita – Discussion papers No. 1010

De La Rica, S., and L. Gortazar (2016) 'Differences in job de-routinization in OECD countries: Evidence from PIAAC', IZA DP No. 9736

De Meulenaere, K., C. Boone, and T. Buyl (2016) 'Unraveling the impact of workforce age diversity on labor productivity: The moderating role of firm size and job security', Journal of Organizational Behavior, 37, 193-212

Deaton, A., and C. Paxson (1998) 'Aging and inequality in income and health', The American Economic Review, 88(2) 248-253

Deaton, A., and C. Paxson (2000) 'Growth, demographic structure, and national saving in Taiwan', Population and Development Review, 26, 141-173

DH [UK Department of Health] (2011) 'Whole system demonstrator programme: Headline findings', Department of Health, HM Government, United Kingdom

EC [European Commission] (2001) 'Communication from the commission of 21 November 2001 on making a European area of lifelong learning a reality', EC, Brussels

Economist, The (2017) 'Special Report: Lifelong Education'

Eggleston, K., and V. Fuchs (2012) 'The new demographic transition: Most gains in life expectancy now realized late in life', Stanford University, Walter H. Shorenstein Asia-Pacific Research Center, Asia Health Policy Program working paper 29 Ethier, W., (1999) 'Multilateral roads to regionalism', in Piggott, J. and Woodland, A., International Trade Policy and the Pacific Rim, IEA Inaugural Australian Roundtable Conference Proceedings, Sydney, July 1996; Macmillan, London

Fehr, H., C. Habermann and F. Kindermann (2008) 'Social security reform with rational and hyperbolic consumers', Review of Economic Dynamics 11, 884-903

Feyrer, J., (2007) 'Demographics and productivity', The Review of Economics and Statistics, 89, 100-109

Feyrer, J., (2008) 'Aggregate evidence on the link between age structure and productivity', Population and Development Review, 34, 78-99

Flandorfer, P., (2012) 'Population ageing and socially assistive robots for elderly persons: The importance of sociodemographic factors for user acceptance', International Journal of Population Research Volume 2012, Article ID 829835

Frey, C. and M. Osborne (2017) 'The future of employment: How susceptible are jobs to computerisation?', Technological Forecasting and Social Change, 114, 254-280

Gapminder (2018) data accessed online at www.gapminder.org

GBD [Global Burden of Disease Study] (2016) 'Disability-adjusted life years and healthy life expectancy 1990-2016', Seattle, United States: Institute for Health Metrics and Evaluation (IHME) 2017

Gelb, A., and J. Clark (2013) 'Identification for development: The biometrics revolution' CGD Working Paper 315, Washington, DC: Center for Global Development

Goaied, M., and S. Sassi (2017) 'The effect of ICT adoption on labour demand: A cross-region comparison', Papers in Regional Science

Gobel, C., and T. Zwick (2013) 'Are personnel measures effective in increasing productivity of old workers?', Labour Economics, 22, 80-93

Goos, M., A. Manning, and A. Salomons (2014) 'Explaining job polarization: Routine-biased technological change and offshoring', American Economic Review, 104, 2509-26

Grossman, G., and E. Helpman (1994) 'Endogenous Innovation in the Theory of Growth'. The Journal of Economic Perspectives,8(1) 23-44
Gruber, J., and D. Wise (1998) 'Social security and retirement: An international comparison', The American Economic Review, 8 8, 158-163
Grund, C., and N. Westergaard-Nielsen (2008) 'Age structure of the workforce and firm performance', International Journal of Manpower, 29, 410–422
Guest, R. (2011) 'Population ageing, capital intensity and labour productivity', Pacific Economic Review, 16, 371-388
Hall, B., L. Lotti, J. Mairesse (2007) 'Employment, innovation, and productivity: Evidence from Italian microdata', National Bureau of Economic Research, Working Paper No. 13296
Hamilton, B., and J. Whalley (1985) 'Geographically discriminatory trade arrangements', Review of Economics and Statistics 67 (3), 446-55
Hardy, W., P. Lewandowski, and A. Park (2017) 'The global distribution of routine and non-routine work: Findings from PIAAC, STEP and CULS', IBS working paper 06/2017
Harrison, D., and K. Klein (2007) 'What's the difference? Diversity constructs as separation, variety, or disparity in organizations', Academy of Management Review, 32, 1199–1228
Hatzius et al. (2016) 'Productivity paradox v2.0 revisited', Goldman Sachs Economic Research, 2 September 2016
Heckman, J., L. Lochner, and P. Todd (2003) 'Fifty years of mincer earnings regressions', National Bureau of Economic Research, NBER Working Paper No. 9732
Horwitz, S., and I. Horwitz (2007) 'The effects of team diversity on team outcomes: A meta-analytic review of team demography', Journal of Management, 33, 987–1015
Howard-Jones, P., E. Washbrook, and S. Meadows (2012) 'The timing of educational investment: A neuroscientific perspective', Developmental Cognitive Neuroscience, 2, 18-29
Hujer, R., and D. Radic (2005) 'Age and skill biased technological change: A multiple treatment approach using a linked employer employee dataset', Ageing Horizons, 2, 4-12
Ikenaga, T., (2013) 'Increase in Nonroutine Tasks in the Japanese Labor Market - Background and Policy Implications', ESRI International Conference, Tokyo, July 2013
Ilmakunnas, P. and T. Miyakoshi (2013) 'What are the drivers of TFP in the aging economy? Aging labor and ICT capital', Journal of Comparative Economics, 41, 201-211
Jagannathan, S. and D. Geronimo (2013) 'Skills for competitiveness, jobs, and employability in developing Asia-Pacific', ADB Brief No. 18, Asian Development Bank, Manilla
Khamis, M., (2014) 'Formalization of jobs and firms in emerging market economies through registration reform', IZA World of Labor 2014: 67
Kotlikoff, L., K. Smetters, and J. Walliser (2007) 'Mitigating America's demographic dilemma by pre-funding social security', Journal of Monetary Economics 54, 247–266
Krugman, P. (1994) 'The age of diminishing expectations', Cambridge MIT Press
Kunze, F., S. Boehm, and H. Bruch (2011) 'Age diversity, age discrimination climate and performance consequences: A cross organizational study', Journal of Organizational Behavior, 32, 264–290
La Porta, R., and A. Shleifer (2008) 'The unofficial economy and economic development', Brookings Papers on Economic Activity Fall: 275-352
La Porta, R., and A. Shleifer, (2014) 'Informality and development', Journal of Economic Perspectives, Vol 28, No. 3, 109-126
Lallemand, T., and F. Rycx (2009) 'Are older workers harmful for firm productivity?', De Economist, 157(3), 273–292
Levy, F., and R. Murnane (2013) 'Dancing with robots: Human skills for computerized work', Third Way NEXT, Washington, DC
Lewandowski, P., R. Keister, W. Hardy, and S. Gorka (2017) 'Routine and ageing? The intergenerational divide in the deroutinisation of Jobs in Europe, IZA Discussion Paper No. 10732
Lindh, T. and B. Malmberg (1999) 'Age structure effects and growth in the OECD, 1950—1990', Journal of population Economics, 12, 431-449
Lisenkova, K., M. Merette, and R. Wright (2013) 'Population ageing and the labour market: Modelling size and age-specific effects', Econ. Model., 35 (2013), pp. 981-989
Lisenkova, K., M. Merette, and R. Wright (2013) 'Population ageing and the labour market: Modelling size and age-specific effects', Econ. Model., 35, 981-989
Liu, Y. and N. Westelius (2017) 'The impact of demographics on productivity and inflation in Japan', Journal of International Commerce, Economics and Policy, 8, 1750008
Lu, B., He, W. and Piggott, J. (2014) 'Should China introduce a social pension?', The Journal of the Economics of Ageing, 6, 76-87
Lu, B., J. Piggott, Y. Zhu, and H. Mi (2017) 'A sustainable long-term health care system for aging china: A case study of regional practice', Health Systems & Reform, 3(3):1–9
Maestas, N., K. Mullen, D. Powell (2016) 'The effect of population aging on economic growth, the labor force and productivity', NBER Working Paper 22452
Mahlberg, B., I. Freund, J. Cuaresma, and A. Prskawetz (2013) 'The age-productivity pattern: Do location and sector affiliation matter?', The Journal of the Economics of Ageing, 1, 72-82

Manyika, J., M. Chui, M. Miremadi, J. Bughin, K. George, P. Willmott, and M. Dewhurst (2017) 'Harnessing automation for a future that works', McKinsey Global Institute
Martin, J., (2017) 'Policies to expand digital skills for the machine age', IZA Policy Paper No. 123
Mason, A., and R. Lee (2007) 'Transfers, capital, and consumption over the demographic transition', In R. Clark, N. Ogawa, and A. Mason, eds., Population Aging, Intergenerational Transfers and the Macroeconomy, Cheltenham, UK and Northampton, Edward Elgar
Mason, A., and R. Lee (2007) 'Transfers, capital, and consumption over the demographic transition', In R. Clark, N. Ogawa, and A. Mason, eds., 'Population aging, intergenerational transfers and the macroeconomy', Cheltenham, UK and Northampton, Edward Elgar
Mason, A., R. Lee, and S. Lee (2010) 'The demographic transition and economic growth in the Pacific rim', In T. Ito and A. Rose (eds.) 'The economic consequences of demographic change in East Asia', Chicago: University of Chicago Press
Maurer, T., E. Weiss, and F. Barbeite (2003) 'A model of involvement in work-related learning and development activity: the effects of individual, situational, motivational, and age variables', J of Appl Psychol. 88(4), 707-24
Messinis, G., and A. Ahmed (2013) 'Cognitive skills, innovation and technology diffusion', Economic modelling, 30, 565-578
Michaels, G., A. Natraj, J Van Reenen, (2014) 'Has ICT polarized skill demand? Evidence from eleven countries over twenty-give years,' Review of Economics and Statistics, 96(1), 60-77
Mitchell, O. and J. Piggott (2016) 'Workplace-linked pensions for an aging demographic', in 'Handbook on the economics of population aging', Piggott and Woodland (eds) Elsevier, 865-904
Mitra, A., and A. Jha (2015) 'Innovation and employment: A firm level study of Indian industries', Eurasian Business Review, 5(1), 45-71
Muralidharan, K., P. Niehaus, and S. Sukhtankar (2016) 'Building state capacity: Evidence from biometric smartcards in India.' American Economic Review, 106(10), 2895-2929
Muro, M., and J. Parilla (2017) 'Maladjusted: It's time to reimagine economic adjustment programs', Tuesday, January 10, 2017
Nagdy, M., and M. Roser (2017) 'Intelligence', Published online at OurWorldInData.org
Ng, T. and D. Feldman (2008) 'The relationship of age to ten dimensions of job performance', Journal of Applied Psychology, 93 (2), 392– 423
O'Mahoney, M., C. Robinson, and M. Vecchi (2008) 'The impact of ICT on the demand for skilled labour: A cross-country comparison,' 15(6), 1435-1450
Oberdabernig, D., (2015) 'Technology and productivity in developing countries: A survey of the literature', Swiss Programme for Research on Global Issues for Development, Working paper 2015/9
OECD (2011) 'Help wanted? Providing and paying for long-term care', OECD, Paris
OECD (2016) 'Skills matter: Further results from the survey of adult skills', OECD Skills Studies, OECD, Paris
OECD (2017) 'Education at a glance 2017: OECD Indicators', OECD, Paris
OECD (2018a) 'Connecting people with jobs, towards better social and employment security in Korea', OECD, Paris
OECD (2018b) 'Economic outlook for Southeast Asia, China and India 2018: Fostering growth through digitalisation', OECD, Paris
Ogawa, R., R. Chan, A. Oishi, and L. Wang (2017) 'Gender, care and migration in East Asia', Springer
Ohtake, F., and Saito, M. (1998) 'Population aging and consumption inequality in Japan', Review of Income and Wealth, 44(3) 361-381.
Oreopoulos, P., Page, M. and Stevens, A. H., (2005) 'The Intergenerational effects of worker displacement,' Journal of Labor Economics, 26(3), 455-484
Osborne, M., and K. Borkowska (2017) 'A European lens upon adult and lifelong learning in Asia', Asia Pacific Education Review, 18, 269-280
Otto, G., and G. Voss (1994) 'Public capital and private sector productivity,' The Economic Record, 70(209) 121-132
Otto, G., and G. Voss (1996) 'Public capital and private production in Australia,' Southern Economic Journal, 62(3) 723-738
Otto, G., and G. Voss (2002) 'Public and private investment in the United States and Canada,' Economic Modelling, 19(4) 641-664
Ours, van, J., and L. Stoeldraijer (2011) 'Age, wage and productivity in Dutch manufacturing', De Economist, 159(2), 113-137
Park, A., (2017) 'Changing demand for tasks and skills in China', Presented in Warsaw, July 2017
Park, D., R. Nisbett, and T. Hedden (1999) 'Aging, culture, and cognition', The Journals of Gerontology Series B: Psychological Sciences and Social Sciences, 54, P75-P84
Peng, F., S. Anwar, and L. Kang (2017) 'New technology and old institutions: An empirical analysis of the skill-biased demand for older workers in Europe' Economic Modelling, 64, 1-19
Pereira, A., and J. Andraz (2013) 'On the economic effects of public infrastructure investment: A survey of the international evidence', Journal of Economic Development, 38, 4, December, 1-37
Phang, H., (2011a) 'Population ageing and productivity in Asian countries', Asian Productivity Organisation
Phang, H., (2011b) 'Issues and challenges facing population ageing in Korea: productivity, economic growth, and old-age income security', Journal of Comparative Social Welfare, 27, 1, 51-62
Preston, S., (1975) 'The changing relation between mortality and level of economic development' Population Studies 29(2): 231-48
Prettner, K., D. Bloom, and H. Strulik (2013) 'Declining fertility and economic well-being: Do education and health ride to the rescue?', Labour Economics, 22, 70–79

Prskawetz, A., D. Bloom, and W. Lutz (2008) 'Population aging, human capital accumulation, and productivity growth', Population and Development Review, A Supplement to Vol. 34, 2008

Rege, M., K. Telle, and M. Votruba (2011) 'Parental job loss and children's school performance', Review of Economic Studies, 78(4) 1462-1489

Rodin, J., (1986) 'Aging and health: Effects of the sense of control', Science, 233, 1271-1276

Schubert, T., and M. Andersson (2015) 'Old is gold? The effects of employee age on innovation and the moderating effects of employment turnover', Economics of Innovation and New Technology, 24:1-2, 95-113

Skirbekk, V., M. Stonawski, E. Bonsang, and U. Staudinger (2013) 'The Flynn effect and population aging', Intelligence, 41, 169-177

Strauss, J. and D. Thomas (1998) 'Health, nutrition, and economic development', Journal of Economic Literature, 36, 766-817

Syverson, C., (2017) 'Challenges to mismeasurement explanations for the US productivity slowdown', The Journal of Economic Perspectives, 31(2), 165-186

Thang, L., (2011) 'Population aging, older workers, and productivity issues: The case of Singapore', in Asian Productivity Organisation, Population Aging and Productivity in Asian Countries, 55-80

UN (2017) 'World population prospects, the 2017 revision', UN, New York

UN (2018) 'Employed population by age, sex and industry', UNSD Demographic Statistics, United Nations Statistics Division, United Nations, New York

UNESCO (2018) 'Innovation-active manufacturing firms for which hampering factors were highly important', UNESCO Institute of Statistics, UNESCO, Montreal

Vandenberghe, V., (2013) 'Are firms willing to employ a greying and feminizing workforce?', Labour Economics 22, 30–46

Vandenbussche, J., P. Aghion, and C. Meghir (2005) 'Growth, distance to frontier and composition of human capital', CEPR Discussion paper 4860

Vivarelli, M., (2014) 'Innovation, employment and skills in advanced and developing countries: A survey of economic literature' Journal of Economic Issues, vol 48, no. 1, pp. 123-154

Vogel, E., L. Alexander, and A. Borsch-Supan (2017) 'Aging and pension reform: Extending the retirement age and human capital formation', Journal of Pension Economics & Finance, 16, 81-107

WEF [World Economic Forum] (2017) 'The Global Competitiveness Report 2017–2018', World Economic Forum, Geneva

Weil, D., (2005) 'Economic growth', Boston: Pearson, Addison-Wesley

Weil, D., (2013) 'Health and economic growth, chapter 3', in P. Aghion and S. Durlauf (eds) 'The Handbook of economic growth', Volume 2, Elsevier

Weinberg, B. (2004) 'Experience and technology adoption', IZA Discussion Paper No. 1051

WHO [World Health Organisation] (2018) 'Noncommunicable diseases are the no. 1 killers in the South-East Asia Region', http://www.searo.who.int/entity/noncommunicable_diseases/en/

WIPO [World Intellectual Property Organisation] (2018) 'WIPO statistics database', accessed at www3.wipo.int

World Bank (2007) 'Project appraisal document on a proposed loan in the amount of US$19.4 Million to the Dominican Republic for a social protection investment project', Washington, DC: World Bank

World Bank (2016) 'World Development Report 2016: Digital Dividends', World Bank, Washington DC

World Bank (2018) 'World Development Indicators', World Bank, Washington DC

Zacher, H., (2015) 'Successful aging at work', Work, aging and retirement, 1, 4-25

Zwick, T., (2015) 'Training older employees: What is effective?', International Journal of Manpower, 36, 136-150