ENABLING THE NEXT PRODUCTION REVOLUTION

Summary note of the interim findings from the OECD project: "Enabling the Next Production Revolution"

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INTRODUCTION AND SUMMARY

1. The next production revolution (NPR) entails a confluence of technologies ranging from a variety of digital technologies (e.g. 3D printing, Internet of Things, advanced robotics) to new materials (e.g. bio- or nano-based) to new processes (e.g. data driven production, artificial intelligence, synthetic biology). These technologies will be available in the near future. As these technologies have an impact on the production and the distribution of goods and services, they will have far-reaching consequences for productivity, skills, income distribution, well-being and the environment.

2. This note summarises an interim report on the OECD's NPR project, which is being implemented over the 2015-2016 biennium. The NPR project sketches the opportunities, risks and economic and policy ramifications of a set of technologies which are likely to be important for production over the near term (to 2030). As an interim report, a number of issues are only partially addressed. More study is being given, for instance, to the specific design characteristics of institutions for technology diffusion.[1]

Key messages

3. **A number of key technologies, from ICTs and robots to new materials, have more to contribute to productivity than they currently do.** Often, their use is predominantly in larger firms. And even in larger firms, many potential applications are underused. Unexploited opportunities exist throughout manufacturing. Well-designed policies could help to realise the opportunities for productivity growth and broaden the productive base.

4. While **new technologies will create jobs through many direct and indirect channels, and productivity-raising technologies will benefit firms and the economy overall**, the associated adjustments could be significant. Hardship could affect many if rapid labour displacement were to occur in a major sector, or in many sectors simultaneously. Policymakers need to monitor and actively manage the adjustments.

5. Compared to earlier industrial revolutions, induced by steam and electrification, the spread of inventions that can transform production will occur over a shorter time period. But **it could take considerable time for new technologies, once invented, to diffuse throughout the economy and for their productivity effects to be fully realised**. Moreover, the duration of this period is uncertain. The past has seen unrealistic enthusiasm regarding timescales for the implementation and diffusion of a number of production technologies.

6. **Diffusion of the technologies must include not only the hardware**, but also the complementary investments and know-how needed to fully exploit the technologies, ranging from skills to new forms of business organisation. Here, the efficient deployment and reallocation of human and financial resources will be essential. Aligning framework policies that promote product market competition, reduce rigidities in labour markets, remove disincentives for firm exit and barriers to growth for successful firms is critical. New firms will introduce many of the new production technologies and can help them reach scale.

7. **Effective institutions dedicated to technology diffusion will also be necessary.** Some of these institutions, such as technical extension services (which provide information and outreach, especially for SMEs), tend to receive low priority in the overall set of innovation support measures. But there is evidence

1 Table 1 provides examples of such institutions.

that they can be effective, if well designed (for instance, manufacturing extension services, which provide outreach, often to small firms, have been carefully evaluated).

8. **Data are at the centre of many of the NPR technologies.** Policy mixes are needed that encourage investments in data that have positive spillovers across industries, obstacles to the reuse and sharing of data should be examined carefully, and coherent data governance frameworks should be developed.

9. Rapid technological change could challenge **the adequacy of skills and training systems**. Some new production technologies raise the importance of inter-disciplinary education and research. Greater interaction between education and training institutions is often needed, and this need may grow as the knowledge content of production rises. Ensuring good generic skills – such as literacy, numeracy and problem-solving – throughout the population will be important.

10. **Public understanding and acceptance** of new production technologies is crucial. Policymakers and institutions need to be realistic about what can be expected from technology. Hyperbole is too frequent. Science advice should be demonstrated to be unbiased and trustworthy. And public deliberation is essential for building mutual understanding between scientific communities and the public.

11. Better anticipating trends through technology foresight could assist policy and the allocation of research funds. **Foresight processes can bring benefits in themselves, such as strengthened stakeholder networks.** They can also encourage policy co-ordination and organisational innovation and help direct **sound policies for science and R&D**. Many of the technologies covered in this report have arisen because of advances in scientific knowledge and instrumentation emanating from both the public and private sectors.

12. **Long-term thinking is essential.** Leaders in business, education, unions and government must be ready to examine policy implications and prepare for developments beyond typical election cycles. A long-term perspective on policy also requires **reflection on how policy priorities might need to evolve**, for instance as a consequence of technological change itself. For example, **major challenges to the intellectual property system** could come from the emerging ability of machines to create (at least one machine-derived invention has already been patented).

13. **While the NPR will present a challenge to developed countries, it could be especially challenging for emerging and developing countries.** New production technologies could erode the low wage advantage of some developing economies, leading to shifts in global value chains. Development models predicated on successive stages of industrialisation may be challenged and the gap between the technologically advanced countries and the rest may grow. But this scenario might be mitigated by several factors including rapidly declining costs of many of these technologies and improved channels of knowledge diffusion.

14. More work is needed to better analyse this issue, but the NPR project will provide relevant insights from recent developments in the People's Republic of China (hereafter: 'China'). Issues facing China that are likely to pose similar challenges for other emerging economies that seek to take advantage of the NPR include a rising demand for skilled managers, researchers and technicians, and pressures to upgrade digital capabilities and information security management. While China has important unique characteristics, the evolution of China's policy approaches and tools also holds lessons for other emerging economies. As major enabling technologies increasingly pass from the laboratory to industry, direct government investments and incentives are giving way to systemic reforms (such as policies to promote market mechanisms, encourage private-sector R&D, support SMEs and start-ups, facilitate technology transfer, strengthen intellectual property protection and develop skills). International co-operation, and

policies on infrastructure (especially large-scale public research infrastructures) and data access, have also been a part of the government’s toolkit.

Conclusion

15. The more governments understand how production could develop in the near future, the better placed they will be to prepare for the risks and reap the benefits. The NPR raises multiple complex policy challenges. But through judicious policy, the opportunity exists to influence the next production revolution now. Final results from the NPR project will be available in early 2017.

1. Productivity and the technologies of the next production revolution

16. Today, raising rates of economic growth is a priority for most governments. Shrinking working-age populations, combined with natural resource constraints in many countries, mean that the future of growth will increasingly depend on productivity-raising innovation. Emerging production technologies will affect productivity through mechanisms that are many and varied. For instance:

- By being faster, stronger, and more precise and consistent than workers, robots will raise productivity in an expanding range of sectors and processes;

- The combination of new sensors and actuators, big data analysis, cloud computing and the Internet of Things is enabling autonomous productivity-enhancing machines and intelligent systems;

- Progress in materials science and computation will permit a simulation-driven approach to developing new materials. This will reduce time and cost as companies perform less repetitive analysis.

17. The technologies considered in the OECD's work have more to contribute to productivity than they currently do. Often, their use is predominantly in larger firms. Even in larger firms, many potential applications are underused. Unexploited opportunities exist throughout industry.

18. It could take considerable time for the productivity gains from new technologies to be realised. The past has seen unrealistic enthusiasm regarding timescales for the delivery of some industrial technologies. And realising the benefits of a technology often requires that it be bundled with investments in complementary assets such as new skills and business models (OECD, 2013).

Work, automation and the new technologies of production

19. Among the general public, policymakers and business leaders, growing concerns have recently been voiced regarding the employment implications of digital technologies. Fears also exist that digital technologies could alter the nature of labour markets to the detriment of some workers.

20. Progress in computing is yielding novel machine capabilities. Many significant innovations are underway. For instance, recent software can accurately interpret some human emotions, presaging new forms of machine-human interaction. And autonomous vehicles might soon substitute for large numbers of commercial drivers.

21. In recent decades, in OECD labour markets, the share of employment in high- and low-wage jobs has increased, while the share of employment in middle-wage jobs has fallen. This polarisation has been linked to the falling share of employment in occupations that involve many tasks more easily described by computer code (Goos and Manning, 2007).

Productivity-raising technologies benefit the economy

22. Historical evidence is overwhelmingly positive regarding the aggregate economic and labour market effects of technological change. To cite just one country-level study: from 1964 to 2013, against a background of accelerating automation, the United States economy created 74 million jobs (Levy and Murnane, 2013). In firms and industries productivity-enhancing technology causes job losses in some cases and job gains in others (Miller and Atkinson, 2013). But employment growth is more frequent than employment contraction. Key issues of policy relevance here are: 1) the relative speed of displacement versus the creation of new work and the length and depth of the adjustment period; and 2) the nature of the jobs (e.g. skills, wages) created relative to those being displaced.

Policymakers need to monitor and prepare for adjustment processes

23. The first industrial revolution, characterised by mechanisation, brought unprecedented improvement in living standards. But the translation to higher average living standards often took longer than the average working lifetime (Mokyr, Vickers and Ziebarth, 2015). The pace and scale of future adjustments are unknown. Labour might be displaced on a scale and at a speed not seen before, robots could make income distribution vastly more unequal than today, and the wages of the unskilled could fall below socially acceptable levels. Policymakers need to monitor and prepare for such possibilities.

Box 1. How large are the productivity effects?

Evidence on productivity impacts from new production technologies come mainly from firm and technology-specific studies. A sample of these studies is given here. However, the studies follow a variety of methodological approaches, and often report results from a few, early-adopting technology users, making aggregate estimates difficult to derive:

- In the United States, output and productivity in firms that adopt data-driven decision making are 5% to 6% higher than expected given those firms' other investments in ICTs (Brynjolfsson, Hitt and Kim, 2011).
- The Internet of Things reduces costs among industrial adopters by 18% on average (Vodafone, 2015).
- Autonomous mine haulage trucks could in some cases increase output by 15-20%, lower fuel consumption by 10-15% and reduce maintenance costs by 8% (Citigroup-Oxford Martin School, 2015).
- Warehouses equipped with robots made by Kiva Systems can handle four times as many orders as un-automated warehouses (Rotman, 2013).

2. Digital technologies and future production

24. Two trends make digital technologies transformational for production: (i) their falling cost, which has allowed wider diffusion; and, (ii) their combination and convergence with other technologies. Figure 1 depicts key ICTs enabling the digital transformation of production. The technologies at the bottom of Figure 1 enable those on top, as indicated by the arrows.

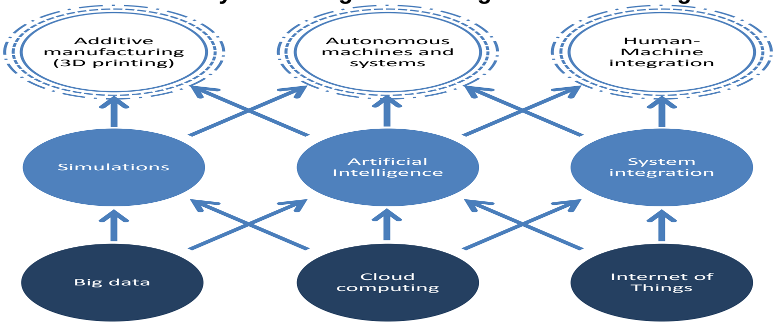
25. 'Big data' promises to significantly improve products, processes, organisational methods and markets, a phenomenon referred to as data-driven innovation (DDI). Cloud computing allows computing resources to be accessed in a flexible on-demand way with low management effort. Many high-potential industrial applications of ICTs, such as autonomous machines and systems, require supercomputers. And the term 'Internet of Things' (IoT) refers to the connection of devices and objects to the Internet. The IoT can improve process efficiencies, customer service, speed of decision-making, consistency of delivery and transparency/predictability of costs.

Box 2. ICT policy considerations - data as a new infrastructure for 21st century production

Obstacles to the reuse and sharing of data should be examined carefully. Non-discriminatory access regimes, including data commons or open access regimes, should be explored.

Coherent data governance frameworks should be developed. Access to data should not necessarily be free or unregulated. A balance is needed between openness (and the social benefits from access to and the reuse of data), and the legitimate concerns of those whose privacy and IPRs may be negatively affected.

Figure 1. The confluence of key technologies enabling the industrial digital transformation



Barriers to ICT diffusion, interoperability and standards should be lowered

26. Many businesses, in particular SMEs, lag in adopting ICTs. For instance, the adoption of supply chain management, enterprise resource planning (ERP), and radio frequency identification (RFID) applications by firms is still much below that of broadband networks or websites. But it is these advanced ICTs that enable digitalised industrial production.

Box 3. ICT policy considerations - diffusion, interoperability and standards

Governments need to act if regulatory barriers are preventing adoption. For instance, liberalising access to IMSI numbers has enabled Enexis, a Dutch energy network, to deploy 500 000 SIM cards (not tied to a mobile operator) to its smart meters.

Barriers to Internet openness, legitimate or otherwise, can limit the inter-operability of data-driven services in particular in economies where deployment of data-driven services is poor due to failures in ICT infrastructure markets.

The increasing role of software in production gives intellectual property rights (IPRs) - in particular copyright - strategic importance.

Issues of liability, transparency, and ownership need to be resolved

27. Data analytics leads to new ways of making decisions. This can raise productivity. But data-driven and AI-enabled decision making can also produce mistakes. The risk of erroneous decisions raises questions of how to assign liability between decision-makers, the providers of data and ICTs (including software). New ICTs also raise concerns relating to privacy, consumer protection, competition and taxation. Existing regulatory frameworks may be ill-suited for some of the new challenges.

Box 4. ICT policy considerations - privacy, liability and competition

Policymakers need to acknowledge that transparency requirements may extend to the processes and algorithms underlying automated decisions.

Governments need to address privacy concerns. Promoting privacy-enhancing technologies and the empowerment of individuals through more transparent data processing, and data portability, via such initiatives as MesInfos (France), should be considered.

3. Bio-production and industrial biotechnology

28. Several decades of research in biology have yielded synthetic biology – which aims to design and engineer biologically-based parts, novel devices and systems – and gene editing technologies. When allied to modern genomics – the information base of all modern life sciences – the tools are in place to begin a bio-based revolution. Bio-based batteries and materials, artificial photosynthesis and micro-organisms that produce biofuels are just some among recent breakthroughs (OECD, 2016a forthcoming). Industrial biotechnology could improve the productivity and competitiveness of the OECD chemicals sector. Biotechnology also offers unique solutions to dependence on oil and petrochemicals.

Box 5. Bio-production and industrial biotechnology - main policy considerations

Governments could help to create sustainable supply chains for bio-based production. For instance, there are currently no standard definitions of sustainability (as regards feedstocks), no ideal tools for measuring sustainability, and no international agreement on the data from which to make measurements. And there are no environmental performance standards for bio-based materials.

One of the greatest challenges in bio-based production is its multi-disciplinarity. Research and training will have to create not only the new technologies required, but also a cadre of technical specialists.

A priority in support for research should be synthetic biology and metabolic engineering approaches to reducing the innovation cycle time of industrial biotechnology. Targeted research could help bring products to market more quickly.

Governments should focus on three objectives as regards regulation: reduce barriers to trade in bio-based products; address regulatory hurdles that hinder investments; and, establish a level playing field for bio-based products with biofuels and bioenergy. Governments could also ensure that waste regulations are more flexible, enabling the use of agricultural and forestry residues and domestic wastes in bio-refineries.

4. Nanotechnology – an enabler to the next production revolution

29. The term 'nano' describes a unit prefix (i.e. 1 nm = 1×10^{-9}m. A sheet of paper is about 100 000 nm thick). Despite disappointing progress in the 1980s, techniques for large-scale production of nanotechnology-based materials have improved significantly over the last 10 years. Command over materials on the nanometre-scale can enable innovation in all existing industrial sectors.

Box 6. Nanotechnology - main policy considerations

Nanotechnology requires increased efforts in international collaboration. The suite of research and engineering tools needed for a comprehensive nanotechnology R&D infrastructure is hard to gather in a single institute.

Support is needed for innovation and commercialisation in small companies. The high cost of nanotechnology R&D is a limitation for many small companies. Policy makers could seek to improve SMEs' access to equipment.

Regulatory uncertainties regarding risk-assessment and approval of nanotechnology-enabled products must be addressed. Products awaiting market entry are sometimes shelved for years before a regulatory decision is made.

5. 3D printing, production and the environment

30. 3D printing is expanding rapidly owing to falling printer and materials prices, the rising quality of completed objects, and innovation. Recent innovations permit 3D printing with novel materials – such as glass and metals – as well as printing of multi-material objects, such as batteries and drones.

31. Currently, most 3D printing is used to produce prototypes, models and tools, with only 15% producing parts in sold goods (Beyer, 2014). Expansion of 3D printing into other industries depends on the technology's evolution in print time, cost, quality, size and choice of materials. Costs are expected to decline rapidly, but it remains difficult to predict how fast this technology will be deployed.

3D printing's potential for enhancing environmental sustainability is high

32. 3D printing can enable more sustainable material use because: it permits many materials to be shaped in ways previously possible only with plastics; it lowers barriers to switching between materials by reducing economies of scale in some processes; and, it can allow fewer chemical ingredients to yield more variation in material properties by varying printing processes. 3D-printed parts can also lower the environmental impacts of some products by: (i) printing replacement parts for legacy products that would otherwise be discarded; and (ii) reducing weight or otherwise improving a product's energy efficiency (G.E.'s lighter 3D-printed parts for a jet engine improved fuel efficiency by 15% (Beyer, 2014)).

Box 7. 3D printing, manufacturing and sustainability - main policy considerations

To support sustainability in 3D printing, policy should encourage low-energy printing processes and low-impact materials with useful end-of-life characteristics. Policies to achieve these priorities could include:

- Targeting grants or investments to commercialising research in these directions;
- Removing intellectual property barriers to 3D printing of repair parts for products that lack existing supply chains;
- Creating a voluntary certification system to label 3D printers with different grades of sustainability across multiple characteristics. Such a voluntary certification system could be combined with preferential purchasing programmes.

6. New materials and the next production revolution

33. Advances in scientific instrumentation, such as atomic-force microscopes and X-ray synchrotrons, have allowed scientists to study materials in more detail than ever before. Developments in computational simulation tools for materials have also been critical. Today, materials are emerging with entirely novel properties, such as solids with densities comparable to that of air.

34. The era of trial and error in materials development is coming to an end. In the next production revolution, engineers will concurrently design the product and its constituent materials. A simulation-driven approach to materials development will reduce time and cost as companies perform less repetitive analysis. And large companies will increasingly compete to develop materials (*The Economist*, 2015). Among other things, the importance of new materials for manufacturing is reflected in the United States' Materials Genome Initiative (MGI), introduced by President Obama in June 2011.

Box 8. New materials and the next production revolution - main policy considerations

New materials will raise new policy issues and give new emphases to long-standing policy concerns. For instance, new cybersecurity risks could arise because, in a medium-term future, a computationally-assisted materials "pipeline" could be hackable. Progress in new materials also requires effective policy in areas important for pre-existing reasons, often relating to the science-industry interface (Nature, 2013).

Interdisciplinary research and education are needed. Materials research is inherently interdisciplinary. Beyond traditional materials science and engineering, contributions come from physics, chemistry, chemical engineering, bio-engineering, applied mathematics, computer science, and mechanical engineering, among other fields.

7. The diffusion of new production technologies – what can governments do?

35. A critical issue is how already-developed technologies diffuse. Small firms, for instance, tend to use key technologies less frequently than larger firms. OECD (2015) has identified several factors that influence the diffusion process at national and international levels: (i) global connections via trade, FDI, GVCs and the international mobility of skilled labour; (ii) connections and knowledge exchange within the national economy, such as between scientific and higher education institutions and businesses; (iii) the scope that exists for experimentation by firms with new technologies and business models; and (iv) the extent of complementary investments in R&D, skills, managerial capabilities and other forms of knowledge-based capital. If firms which could lead the next production revolution are unable to attract the human and financial resources to grow, the development of technology and its diffusion will be stunted.

Beyond framework conditions, it is important to design effective institutions for technology diffusion

36. Institutions for technology diffusion are intermediaries, structures and routines that facilitate the adoption and use of knowledge, methods and technical means. Table 1 offers an initial typology. Some of the institutions involved, such as technical extension services, tend to receive low priority in the standard set of innovation support measures. But they can be effective if well designed.

Table 1. Initial typology of institutions for technology diffusion

Type	Operational mode (primary)	Example
Dedicated field services	Diagnostics, guidance and mentoring	Manufacturing Extension Partnerships (United States)
Technology-oriented business services	Advice linked with finance Capacity development	Industrial Research Assistance Program (Canada)
Technology transfer offices	Intellectual property licensing	University TTOs (multiple countries)
Applied technology centres	Contract research	Fraunhofer Institutes (Germany), TNO (Netherlands)
Technology information exchange	Technology community networking	Knowledge Transfer Networks (United Kingdom)
Demand-based behavioural change	Knowledge transfer incentives	Innovation vouchers (multiple countries)
Technology partnerships	Collaborative applied research Prototyping and standards	National Network for Manufacturing Innovation (United States)
Open source sharing	Open source sharing Virtual networks	Registry of Standard Biological Parts (United States)

Box 9. The diffusion of new production technologies - main policy considerations

Technology diffusion institutions need realistic goals and time horizons. Introducing new ways to integrate and diffuse technology takes time, patience and experimentation.

Misalignment can exist between the stated aims of technology diffusion institutions and their operational realities. For instance, there is often a focus on disseminating the latest advanced technology, when many enterprises and users do not use current technologies to their fullest extent.

A better understanding of organisational designs and practices for technology diffusion is vital. Institutions need to be able to discover new approaches and to embed innovative methods in their operations.

8. Public acceptance and new technologies – why does this matter and what options are open to government?

37. In the past, public concerns have blocked the development and implementation of some new technologies. This has happened even when a technology’s technical and economic feasibility has been demonstrated, and where large investments have been made. While public concerns can constrain technology, they can also increase safety and acceptability. For instance, scientific studies and environmental protest in the 1960s and 1970s led to stricter regulation of pesticides and other chemicals.

38. Recently, biotechnology-related risk has attracted persistent public attention. Governments will have to anticipate public concerns around the most recent biotechnological advances, especially gene editing. But the next production revolution could raise societal issues not seen before. For instance, as machine autonomy develops, when and how should control be exercised?

Box 10. Public acceptance and new technologies - main policy considerations

Having realistic expectations about technologies can help maintain trust. “Hype” must be avoided.

Science advice must be trustworthy. Countries must put resources into making systems of expertise more robust by encouraging more exchange with publics, encouraging clear communication about sources of uncertainty, and making processes of appointment and operation more accountable (Jasanoff 2003).

Ethical and social issues should be included in major research endeavours. Since the Human Genome Project, science funders in many OECD countries have sought to integrate attention to ethics, legal and social issues.

Public deliberation is important for mutual understanding between scientific communities and the public, and should inform innovation policy. Deliberation can take various forms. For instance, citizen panels and town halls have been pioneered in Denmark and elsewhere for a broad range of emerging technologies relevant to the NPR.

9. Developing foresight about future production: what should governments do?

39. Greater foresight in science and technology is sought by most governments. For instance, a goal of the America Competes Act is the identification of emerging and innovative fields. Better anticipation of trends could clearly assist policy development and the allocation of research funds and other resources.

40. Foresight should ideally be an institutionalised practice. The links between foresight processes and decision-making should be close, but foresight exercises must also enjoy intellectual autonomy. Patent and bibliometric data can be a useful adjunct to foresight methods, but have limitations (such as sampling

biases). Expert opinion can be particularly useful in exploring areas of uncertainty where data are limited and possible outcomes are many and skewed.

10. Cross-cutting policy considerations

Sound science and R&D policies are essential

41. The technologies covered in this report result from science. Synthetic biology, new materials and nanotechnology, among others, have arisen because of advances in scientific knowledge and instrumentation. Many policy choices determine the strength of science and research systems and their impacts on production.

Governments must create an environment which fosters business dynamism

42. Research over recent years has highlighted the role of new and young firms in net job creation and in nurturing radical innovation. New firms will introduce many of the new production technologies. Governments must attend to a number of conditions which affect this dynamism (Calvino, Criscuolo and Menon, 2016).

Technological change is raising new challenges for the intellectual property (IP) system

43. One among a number of challenges to the IP system comes from the ability to digitalise physical objects. For example, if 3D-printed human tissue improves upon natural human tissue, it may be eligible for patenting, even though naturally-occurring human tissue is not. Governments need to ensure the suitability of IP rules in the context of rapidly changing technologies.

Distribution rather than scarcity will be a primary concern

44. The distributional effects of new production technologies require policies beyond the domains of science and innovation. The possible measures are many, from earned income tax credits to the provision of resources for lifetime learning and job retraining. Tackling an uneven distribution of skills is a key to lowering wage inequality.

Education and skills systems will need constant attention

45. Rapid technological change could challenge the adequacy of skills and training systems to match demand and supply for new skills. For some production technologies, current skills supply is insufficient. Improving the efficiency of skills matching in labour markets supports productivity (Adalet McGowan and Andrews, 2015). Developing a high level of generic skills throughout the population will also be important. Good generic skills help to 'future proof' human capital.

Some new production technologies raise the importance of inter-disciplinary education and research

46. Many of the technologies examined in this report require more interdisciplinary education and research. The increasing complexity of some scientific equipment also demands the use of multiple skill types. But some education systems and individual institutions may not be responding as well as is needed.

Greater interaction with industry is needed, and this need may grow as the knowledge content of production rises

47. Aspects of postgraduate training may need adjustment. In the United States, current life sciences PhD level education is still focused on training for academic careers. However, data published in the

National Science Board's (NSB's) 2014 *Science and Engineering Indicators* show that just 29% of newly graduated life science PhDs (2010 data) will find a full-time faculty position in the United States.

NPR may bring changes to labour market policies too

48. One important issue is whether a new generation of production technologies is likely to change the scale, frequency or character of labour market shocks. Without perfect foresight, governments should plan for scenarios in which future shocks are large and arrive quickly, such as could occur if the remaining technical obstacles to self-driving vehicles were quickly overcome.

Policymakers need to engage in long-term thinking

49. Leaders in business, education and government must be ready to examine policy implications and prepare for developments beyond the next ten years (for instance with respect to progress in machine learning). As a possible model, in Germany, the Federal Ministry for Economic Affairs and Energy and the Federal Ministry of Education and Research have created a co-ordinating body bringing together stakeholders to assess long-term strategy for Industry 4.0 ("Plattform Industrie 4.0").

The next production revolution is likely to affect the future location of production in global value chains, but exactly how is uncertain

50. Over recent decades, the world has witnessed a growing international integration of markets for capital, intermediate inputs, final goods, services and people. New production technologies could influence GVCs in complex ways. For instance, European companies which intensively use robots are less likely to locate production abroad. The NPR project is examining developments in production in China. China's goal of increasing the knowledge content of domestic production will expand the range of markets in which China competes and will also contribute to the development of production technologies in those markets.

11. Next steps in the NPR project

51. The OECD is working to prepare a final publication on its NPR project. At present, chapters on the following themes are planned (in addition to an overall synthesis): ICT, big-data and production; biotechnology and future production; nanotechnology and future production; new materials and future production; 3D printing and its environmental impacts; public acceptance and future production; how should governments use foresight?; supporting advanced manufacturing production in the United States; diffusing production technologies – what can governments do?; connecting manufacturing with research – what can governments do?; and, skills and the next production revolution.

BIBLIOGRAPHY

Adalet McGowan, M. and D. Andrews (2015), "Skill Mismatch and Public Policy in OECD Countries", *OECD Economics Department Working Papers*, No. 1210, OECD Publishing, Paris. DOI: http://dx.doi.org/10.1787/5js1pzw9lnwk-en

Beyer, C. (2014), "Expert View: Strategic Implications of Current Trends in Additive Manufacturing", *Journal of Manufacturing Science and Engineering*, Vol. 136, pp. 064701–1.

Brynjolfsson, E., L.M. Hitt and H.H. Kim (2011), "Strength in Numbers: How Does Data-Driven Decisionmaking Affect Firm Performance?", Social Science Research Network (SSRN), 22 April, http://papers.ssrn.com/sol3/papers.cfm?abstract_id=1819486.

Calvino,F., C. Criscuolo and C. Menon (2016), "No Country for Young Firms?: Start-up Dynamics and National Policies", *OECD Science, Technology and Industry Policy Papers*, No. 29, OECD Publishing, Paris. DOI: http://dx.doi.org/10.1787/5jm22p40c8mw-en

DSTI/ICCP/IIS(2014)6), "ICTs and Jobs: Complements or Substitutes – The Effects of ICT Investments on Labour Demand in 19 OECD Countries."

Goos, M. and A.Manning, (2007), "Lousy and Lovely Jobs: The Rising Polarization of Work in Britain", *Center for Economic Performance Discussion Papers* DP0604, December.

Jasanoff, S. (2003), "(No?) Accounting for Expertise." *Science and Public Policy* 30 (3): 157–62. doi:10.3152/147154303781780542.

Levy F. and R.J.Murnane (2013), "Dancing with Robots: Human Skills for Computerized Work". http://dusp.mit.edu/sites/dusp.mit.edu/files/attachments/publication/Dancing-With-Robots.pdf

OECD (2015), *The Future of Productivity*, OECD Publishing, Paris. DOI: http://dx.doi.org/10.1787/9789264248533-en

Miller, B. and R.Atkinson (2013), "Are Robots Taking Our Jobs, or Making Them?", The Information Technology and Innovation Foundation". http://www2.itif.org/2013-are-robots-taking-jobs.pdf

Mokyr, J., C.Vickers and N.L Ziebarth (2015), "The History of Technological Anxiety and the Future of Economic Growth: Is This Time Different", *Journal of Economic Perspectives*, Volume 29, Number 3, pp 31-50.

Nature (2013), "Sharing data in materials science", 28th November, Vol. 503, pp.463-464.

OECD (2013), *Supporting Investment in Knowledge Capital, Growth and Innovation*, OECD Publishing, Paris.

OECD (2015), *The Future of Productivity*, OECD Publishing, Paris. http://dx.doi.org/10.1787/9789264248533-en

OECD (2016a forthcoming), "The convergence of industrial biotechnology with green chemistry: an issues paper", OECD Publishing, Paris.

Rotman, D. (2013), 'How Technology is Destroying Jobs', MIT Technology Review, June 12th.

The Economist (2015), "New Materials for Manufacturing", Technology Quarterly, 8th December, http://www.economist.com/technology-quarterly/2015-12-05/new-materials-for-manufacturing

Vodafone (2015), "M2M Barometer 2015 report", Vodafone, http://m2m-mktg.vodafone.com/barometer2015.