Impact of digital innovation on new products, processes and competition

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Introduction

Economic theory has traditionally has had a poor record of understanding and analysing new technologies and, by corollary, devising technology policy. The result is that we have inherited technology polices and institutions crafted mainly by lawyers, research scientists and businesspeople. A greater part of economists' intersection with tech policy has been in the realm of competition policy. Yet, much discussion about competition focusses on price-setting behaviour rather than the efficient creation and diffusion of new technologies. Policies and institutions should evolve to suit the constraints and opportunities technology offers and we should be on the forefront of socialising policy ideas to fit 21st century economies. We are not there yet.

This paper will present the major stylised facts about new technologies since the industrial revolution; how the recent digital wave of technologies differs from the past; and empirical evidence on its impact on productivity. We finish with a discussion of where our current set of policies and institutions might be reformed.

Potted history of new technologies

Technologies leverage human labour to produce more and better products. Early tools such as the pulley, lever, and wheel are simple examples that amplified manual labour. Later technologies replaced manual labour with skilled labour and alternative forms of power (from animals, water, timber and minerals).

Digital technologies represented a step-change by replacing skilled labour (although the technologies of writing and printing were very early examples). The first substitution of skilled labour came with automation. Automation provides negative feedbacks and is a control system that eliminated need for expert human attention. James Watt didn't invent the steam engine, he invented automation. The pre-Watt steam engines needed people to let the steam in and out of the chambers by opening and closing the valves. Watt automated this aspect.

In the early 1800s, Joseph-Marie Jacquard invented punched cards to control a sequence of operations on a weaving loom and thus automate the production of complex patterns. His principle was applied to the first computers in the 1950s.

In the 1830s, Charles Babbage invented the first computer, a mechanical 'analytical engine'. He understood that a pattern of holes can represent an abstract idea. However, without electricity, this and other 19th century inventions (the washing machine, the fridge), did not gain traction.

It was two inventions by scientists in Bell Labs, in the 1940s, that launched the digital revolution. These were the invention of transistors - on/off switches – to amplify noise on a telephone (Bardeen, Brattain and Shockley) and information theory, which translates language, numbers and commands into binary format (Shannon). Together, with the accumulated prior inventions, they set the stage for the modern computer.

Where are we today?

Few people in the 1940s and 1950s, would have predicted that electronic computers, which were then the size of a building, would drive cars and aeroplanes, replace mail and most forms of communication, recognise faces, control machinery and so on. But this unpredictability is the very essence of a general purpose technology. According to Bresnahan and Trajtenberg (1995), general purpose technologies have three characteristics: First, they are pervasive and can be used in many or most industries. Secondly, they are continuously improved, often by being applied to new uses. Persistent learning-by-using is the norm. And finally, they have strong synergies and complementarities with other technologies. The archetypal general purpose technologies are the steam engine, electricity and electronics.

A contemporary definition of digitisation is the conversion of text, pictures, or sound into a digital form that can be processed by a computer e.g. store information, automate physical processes, make calculations and pattern recognition activities. Other than computers, modern incarnations of digital technologies include artificial intelligence (AI), big data, virtual reality, robotics, smart production, connectivity, drones, internet-of-things, sensors, 3D printing, algorithms, natural language processing, machine learning, GPS, and predictive analysis. The point about machine learning systems is that they use algorithms (e.g., neural networks) to replace manual mappings of one set of data to another, thereby replacing skilled labour and improving accuracy. The outstanding features of machine learning and AI are that it teaches itself to improve accuracy and can share algorithms and large volumes of data instantly over vast distances.

And this is where we can see that conventional economic theory lets us down. Standard economic models, which place ‘price’ at the forefront, typically treat technology as a black box. Either technology change is deemed ‘manna from heaven’, or when represented as an investment (i.e. as R&D), does not differentiate a general purpose technology from a potato peeler. The upshot being that the same policies need be applied to general purpose technologies as potato peelers. Empirical models do better, but largely bolt on a technology variable to a cobb-douglas functional form. Left opaque in both theoretical and empirical models are the treatments of uncertainty of development, the invisible channels of knowledge flows and collaboration, learning-by-using, complementarities and, how new ideas are diffused across the economy – all key features of general purpose technologies.

Competition and competition policy has a notable overlap with the technological development of a region. However, the theoretic view of competition has narrow roots centred on the number of competitors and market concentration. A more useful conception of competition is that of a race to supply, or buy, better and cheaper products through more pervasive distribution outlets. This cannot be summarised into a simple Herfindahl index. Competition conceived as a race may enhance the impact of technology via spreading new ideas through supply chains, peer-to-peer imitation or sheer rivalry. Competition, however, may also stifle it via secrecy and hold-up. It has not been established whether either of these behaviours correlate to market concentration or other static measures of competition (Cohen 2010).

How we differ from the past

Compared with the steam engine and electricity, digital technologies are different in two important respects. First, digital technologies are non-rivalrous and generally hard-to-exclude. It is hard to prevent code from being copied. By contrast, electricity and steam engines were embodied in machines and infrastructure which are excludable. The non-rivalry aspect is easy to see and implies that whereas there is a need for multiple manufacturing plants for engines and multiple generators of electricity, we only need one version of a word processor. The presence of network externalities and economies of scope further concentrates market power in one producer. This winner-takes-all feature creates a potential imbalance of power in the economy which may pose a threat to civil society.

The second difference between digital technologies and past general-purpose technologies is that it affects all sectors of the economy. Past transformations largely replaced manual labour in the primary and secondary sectors. AI technologies are now transforming not just the work of lawyers, radiologists, book-keepers, and journalists, but is changing who does what in the value chain.

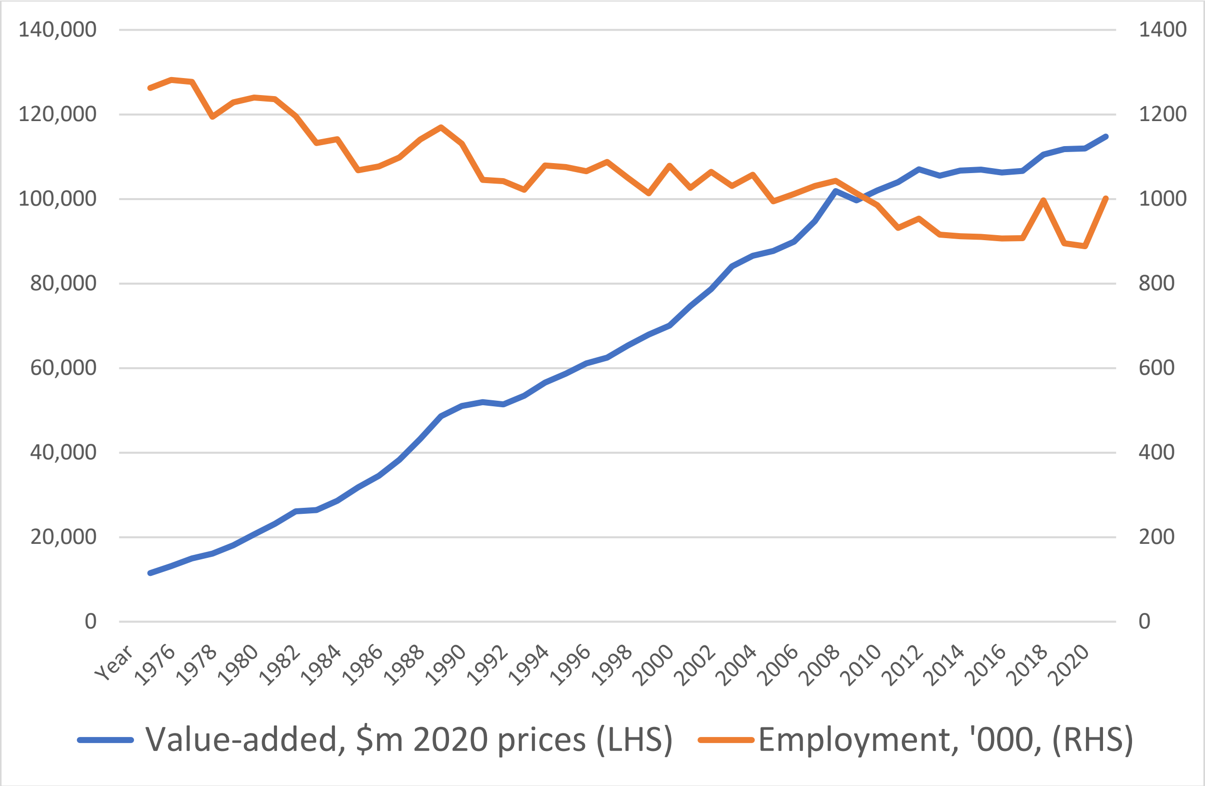
Some examples from local Melbourne companies are illustrative. Anatomics makes personalised cranium plates for neurosurgeons in California. Scans of the patient's head in the US are sent to Anatomics in Melbourne, where they create digital design and transmit it back to the US. In the US, the cranium plate is 3D printed and the surgeon inserts it into a patient. There is two-way real time interaction between surgeon and Anatomics.

Saltwater Foods uses email and WhatsApp to order fish from boats in New Zealand, the Maldives, Pacific islands, Sri Lanka, and Australia; grade the quality of the fish; barcode it; and sell to markets around the world including high-end Japanese restaurants.

Finally, Dulux, a paint factory, is so automated that staff only venture onto the shop floor for maintenance and repair. These plants are called dark factories as there is no need to turn the lights on.

Australians worry about our shrinking manufacturing workforce (7.3% in 2021) and believe that we don't produce anything anymore. This is not correct – we have become more efficient. As shown in Figure 1, manufacturing value-added since the 1970s has risen continuously despite a declining workforce. It should be hoped that, like agriculture and mining, we can produce sufficient manufacturing value-added with 1-2 per cent of our workforce in the future.

Figure 1: Manufacturing value-added and employment, Australia, 1975-2021



What is the evidence?

It should be self-evident that new digital technologies improve productivity. Anecdotally we see widespread reductions in unit costs, as both standalone software and software embodied in new equipment and infrastructure, is substituted for both skilled and unskilled labour. Not only has it automated many activities, but it has led to a reorganisation of the 'shopfloor' and faster and decentralised information flows between workers and activities. Geolocation tracking and improved information and manufacturing precision has further fragmented value chains, especially across borders (Athukorala, Talgaswatta and Majeed 2017, Obashi and Kimura, 2021). We expect that the ability for people to work remotely and better matching of workers to jobs would improve access to skills and improve productivity. Finally, digital technologies enable us to do things not previously possible, using satellite technology and GPS, pattern recognition, AI, sensors and genomics.

Given this wide and diverse array of activities, affecting the process of production of existing products and creation of new products, the lack of widespread evidence is surprising. Most studies of the impact of digital technology either focus on one sector or activity, are case studies, or, merely document the arrival of new digital products and decline of old products (Evangelista, Guerrier and Meliciani, 2014; Freund and Weinhold 2004, Brynjolfsson, Rock and Syverson 2018, Draca, Sadun & Van Reenen 2006, Brynjolfsson and Hitt 2003, Tambe, Hitt, Rock & Brynjolfsson 2020, Bessen & Righi 2019, and the NBER Economics of Digitization Program).[1] Nearly all these studies reveal a reduction in unit costs (Goldfarb and Tucker 2019). Some also document the uneven spread of digital assets between firms.

There are some broader studies. Katz and Koutroumpis (2013) have mapped the GDP per capita of 242 countries against a composite Digitization Index (comprising the ubiquity, affordability,

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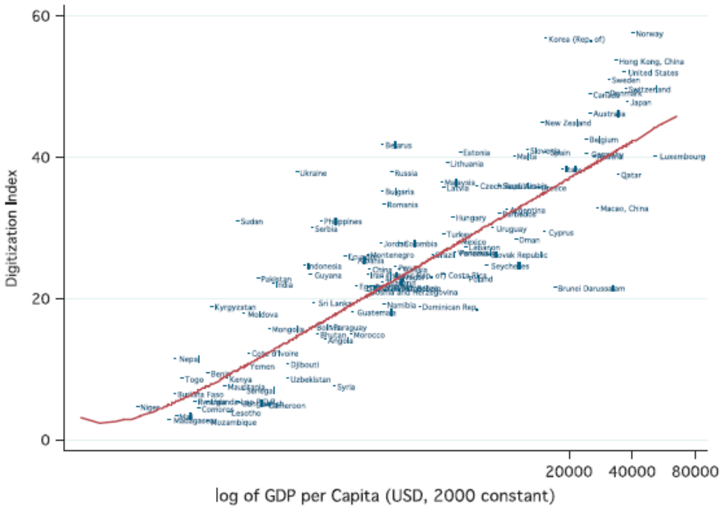
[1] https://www.nber.org/programs-projects/projects-and-centers/economics-digitization?page=1&perPage=50.

reliability, speed, usability of digitisation) and find a strong positive correlation (see Figure 2). Correlation is not causation, but it is suggestive.

Figure 2: Digitization index with log of GDP per capita in 2010



Source: Katz and Koutroumpis (2013)

Closer to home, Palangkaraya, Balaguer and Webster (2021) have modelled the effect of spending on R&D related to Information, communication technology and computer sciences by R&D-active Australian firms. They found that although the returns to the investing firm from this technology are similar to other technologies, the spillover effects to other firms are relatively very large. Whereas all R&D combined has an external rate of return of 27.1 per cent, for Information, communication technology and computer sciences, this rate was 51.5 per cent (see Table 1).

Table 1: R&D Rates of Return in year 1 (%) by technology

Technology group	Own R&D	External R&D
All technology groups	12.0	27.1
1 Basic sciences	9.6	-3.3
2 Agriculture and environment	8.5	-28.7
3 Medical and health	9.2	12.1
4 Engineering	7.7	7.4
5 Industrial technology	8.8	-11.8
6 Information, communication technology and computer sciences	9.9	51.5
7 Education, commerce, social science, law and humanities	9.2	5.9

Notes: These rate of return estimates are computed assuming each firm has the same amount of real value-added at the median level of the distribution and invests the same amount of R&D at the median level of the distribution, the rate of return of own R&D is computed as $\hat{\gamma} \times Value\ Added_{it}/R\&D\ Stock_{it}$ and the rate of return of external R&D is computed as $\hat{\theta}_f\ \times Value\ Added_{it}/R\&D\ Stock_{it}$ where $\hat{\gamma}$ and $\hat{\theta}_f$ are the corresponding value added elasticity estimates.

Source: Palangkaraya, Balaguer and Webster (2021). Processed from BLADE-RDTISO database

These studies are somewhat at odds with economy-wide productivity studies that show a slowdown in productivity growth since 2000. Brynjolfsson, Rock and Syverson (2018) claim that studies investigating mismeasurement as an explanation (a known problem, which has always existed), find limited support. Instead Brynjolfsson, Rock and Syverson argue that the profound nature of digital technologies means that considerable time is needed for industry to readjust and therefore for the full impact on the economy to be revealed. We need a sufficient accumulation of new capital but also the invention and diffusion of complementary skills, processes and assets before a change is reflected in the aggregate data. Why is it so slow? This is still an area of research but Henderson (1993), Brynjolfsson, Rock and Syverson (2018) and Bloom *et al*. (2013) have suggested the curse of proficiency (in old technologies and ways of doing things) leads to resistance by organisations. In addition, complementarities between IT, skills and workplace organization (as found by Bresnahan, Brynjolfsson and Hitt 2002) mean that conditions for a large one-off investment need be present for the productivity potential to be realised.

This theory has echoes of the past. The impact of the steam engine could be said to take over a century, especially when we consider that it took 68 years before the technology was applied to motion (rather than pump water). It took over 100 years between Humphry Davy’s invention of the electric light (1809) and the pervasive use of electric motors (1930s in the US).

Are existing institutions fit for-purpose in digital age?

Diffusion is the key to productivity growth given that almost all innovation is new-to-the-firm and not fundamentally original. Although, our discussion is mainly about inter-firm institutions, this is not because what matters inside the firm is less important. Bloom *et al*. (2013), for example, undertook an experiment on a sample of 28 Indian plants and found that better management practices improved productivity by 11 per cent. They also inquired why firms had not already adopted best-practice. The reasons were three-fold: first, many firms were not aware of best-practice; secondly, firms had heard of these practices but thought they did not apply to them. Owners prior beliefs took time to change. Thirdly, owners were severely time constrained, were reluctant to delegate and did not know how to implement the change profitably.

Nonetheless, as is obvious to anyone who has travelled across borders, the rules, habits and ways-of-doing things in an economy can explain a lot too. Take intellectual property (IP) systems (which originated as grants of monopoly rights by the crown to favourites). Over time, they have been tailored to encourage the creation and commercialisation of tangible devices. However, in an environment of winner-takes-all and network externalities, the patent, design and copyright systems may exacerbate market concentration and reduce development and diffusion without a compensating rise in productivity. There are, however, existing variations to the IP systems that can be better used and promoted to limit these negative effects. These include licenses-of-right, standards and rights around inter-operability, use of open networks, and Fair Reasonable And Non-Discriminatory (FRAND) pricing requirements. There is evidence that patents, and especially slow and convoluted patent administration, has held back improvements and diffusion of general purpose technologies (steam, electricity, automobiles, radio) in the past (Boldrin and Levine 2008; Selgin & Turner 2011[2]; Howells 2008). Faster, more transparent application and examination systems, with clearer property boundaries and clarity about reach-though rights may assist here.

The existing term of copyright (70 years post-mortem) has no economic or technological justification and should be limited to something like 20 years. With discounting, royalty streams beyond a 20-year horizon have scant effect on the financial incentive to create music, movies and so on. There is clear evidence that ease of access to digital products is the major factor affecting whether people will pay for music, books and other copyrightable products and thus furnish authors and publishers with the necessary incentives (Aguiar and Waldfogel 2018).

The rise of mega-companies and monopoly capitalism, has caused considerable angst especially since the 1940s. Originally there was concern these behemoths used their market power to pay themselves handsomely and luxuriate in technical inefficiency. Subsequently, most developed countries strengthened their anti-monopoly enforcement. In the US, this led to stronger anti-trust enforcement and some deals between the Government and major technology companies such as AT&T (Bell Labs),[3] IBM,[4] Du Pont,[5] and Microsoft[6] among others. In the case of AT&T, a 1956 quid pro quo deal allowed the telephone monopoly to exist (and thereby provide Bell Labs, the R&D arm of AT&T, with profits for its intensive research), if it licensed all its current and future patents either royalty free or for a nominal fee (Gertner 2012, 16-19, 168-171). In the digital era, other tools to

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[2] Selgin and Turner (2011, 859) said that ‘the patent did prevent rival inventors from building atmospheric or low-pressure engines that improved on Watt's design or from building any sort of engine that used a separate condenser’ although their basic thesis is that the patent encouraged desirable inventing around Watt’s ideas.

[3] One reason for continuing to allow the AT&T monopoly over telephone connections was that Bell Labs would contribute to civic society and allow US businesses to use all current and future patent for a small or zero fee (Gertner 2012, 16-19, 149-151, 168-171).

[4] A landmark 1956 consent decree restricted IBM's control of the data-processing industry and encouraged competition. The decree lasted 40 years. Customers complained that IBM forced them to lease, rather than buy, the equipment and charged artificially high prices. The Government also sought to break up the company in the 1960s.

[5] In 1956, the courts charged du Pont with monopolizing, attempting to monopolize and conspiracy to monopolize interstate commerce in cellophane.

6 In 1999, a coalition of US governments Microsoft for excluding the Netscape browser from their Windows platform.

keep markets contestable include ensuring a wide and representative membership on Standards Setting Organisations (SSOs), regulating footloose digital giants, forcing monopoly platforms accept competitor products and other aspects of fair dealing.

Conclusion

Alfred Whitehead, an English philosopher from the early 20th century, said that 'civilization advances by extending the number of operations we can perform without thinking – using symbols, formulas and the price system' (cited in Hayek 1945). In this sense, the digital revolution promises to enhance civilisation and free people from drudgery and difficult work.

Knowledge, in the broad sense of new ways of working and institutions as well as new technologies, are the only source of long-run economic growth or improvement. We know this deductively. Material resources and physical matter in the world is fixed. If we just increase our capital stock with more-of-the-same physical infrastructure/equipment, marginal returns will diminish to zero. The same applies to more-of-the-same stocks of skills. Accordingly, economic per capital growth will not continue unless we adopt and suitably exploit digital technologies.

There are several levels at which society can better exploit new technologies. At the firm level, measures can be taken to lessen the obstacles that are slowing down the diffusion of new technologies (ignorance, belief that new ways do not apply to them and uncertainty about how to make the transformation profitable and less risky). At the institutional level there are pivots we can make to the IP system and standards setting organisations to smooth interoperability and technology diffusion across both industries and national borders. At the economy level, governments can ensure that planning for public infrastructure thinks ahead to new forms of transport and communication and ways of working. Governments need also consider the best social and economic model for the creation and distribution of our non-rivalrous networked products.

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