Technology and work

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Introduction

Work is central to human existence. It provides for the necessities of life as well as defining what people do and are. Technology and work have been tied together since antiquity, and the dreaming of new technologies that can perform functions that previously were the province of people is at least as old as Hephaestus's twenty golden tripods that could, according to Homer "run by themselves to a meeting of the gods and amaze the company by running home again" (*Iliad*, xviii, 368*ff*.) Nowadays concerns centre on the factors affecting the adoption of new technologies in the workplace, the degree to which future technologies (in the workplace) can be predicted, and what the future effects of new technologies (especially those centred around information and communication technology) will be. In this paper we will consider the following main questions:

1. What are the motivations for technology adoption in the workforce? And how do perceptions of technology affect the motivation to adopt it?
2. How well can one predict future technology, and technology adoption, and how might this impact on our ability to predict workforce impact?
3. How has changing technology impacted the workforce in the past? And what might we generalise from this regarding what might occur in the future, in particular what will be the workforce impact of "intelligent" information and communications technology?

We also briefly consider the importance of training and education for facilitating adaptability which seems crucial for the rapid adoption of new technologies.

What are the motivations for technology adoption in the workforce?

There is no single reason for new technology adoption in the workplace as industry, employee and regulator motivations are varied and conflicting. In order to understand the effect new technologies might have on the workplace, it is helpful to distinguish several different motivations for adopting new technology (Table 1).

Workplace stakeholder	Motivation to adopt new technology
Industry	Profit (long or short term); perception (influencing consumers about the "modernity" of their company); responding to pressures from consumers (e.g. web access); bandwagon / fashion effects; OH&S regulation
Employee/union	Decreased work time; safer more amenable work process; convenience
Government / regulator	Respond to public concerns raised; pre-empt problems; recovering or reducing public costs (e.g. pollution)

Table1 Technology adoption motivation in the workplace.

Industries are directly answerable to a number of different stakeholders with different priorities. The main drivers to adopt technological innovation include improving profit margins, whether in the form of decreasing capital or labour costs or increasing productivity.

Understanding the behavioural changes that significantly affect technology adoption by the workforce is challenging because of the range of factors involved. The adoption of new technology by the workforce is heavily dependent on the perceived effect of the technology on the workers position. Should a new technology be perceived as a workplace threat it is unlikely to be adopted (Abukhzam and Lee 2010, Riedel 2014).[1]

Another factor that influences technology adoption in the workplace is regulation. Industrial activity without regulation can lead to adverse results for society because of industrial impacts that do not show up on a business' profit and loss ledger (harmful materials, pollution etc.). Thus regulation can be seen as a driver of innovation in the workplace because business needs smarter ways to comply with regulation by working with the system or getting around it. Regulation is also a driver of technological innovation in the workplace particularly when technologies affect occupational health and safety issues. By contrast, regulation can also inhibit technological innovation and increase the cost of a workforce/business; new technologies may seem daunting to a business if they come with new regulatory requirements.

The perception of problems associated with new technologies is also a factor. There is a well documented asymmetry between risks people are willing to bear (typically those they are familiar with) versus those they are not (P. Slovic et al. 1982, Paul Slovic 1987). Contrast the general acceptance of an average of 1.24 million deaths per year in traffic accidents (World Health Organization 2014), with the much more widespread worry about nuclear power generation which is responsible for 1000-10000 times fewer deaths per year even taking the most pessimistic analysis of accidents to date (Wang 2011) (Wikipedia 2014b).

Examples of industry uptake of innovative technology

Our first example illustrates a general point that we have seen as important in our larger study on *Technology for Australia's future:* almost all categorisations of technology have fuzzy boundaries. For example, looking back several decades, one would hardly have classified advanced lasers, hyperspectral imaging, sensor networks, atomic clocks, and satellite based positions systems as "agricultural technologies", but these are now widely used in what has come to be known as "precision agriculture" (Wikipedia 2014c). This illustrates the difference between the end-use of a technology and what it is first developed for. Rosenberg (1996) has described the astonishing extent to which technological innovations as substantial as the laser, the transistor, the computer, the airplane, and the telephone when first developed, were envisaged as solving problems which nowadays we think are irrelevant or inconsequential, and that their current pervasive uses were utterly unimagined.

The agricultural sector has integrated technological innovations such as laser technology and GPS into agricultural machinery to improve profit margins. These innovations increase the efficiency of the machinery and the use of materials as well as decreasing the need for highly skilled labour. Combine harvesters are now equipped with GPS tracking systems to efficiently work the land with

[1] An example of workplace adoption driven primarily by employees is the current phenomenon known as BYOD, "bring your own device" (Wikipedia 2014a) which is a shorthand to describe the increasingly common occurrence of workers wishing to use their own smartphones to access corporate IT systems, in contrast to the workplace providing a special device solely under corporate control. The phenomenon illustrates the gradual spread of technologies through all sectors. As unit prices drop, and the perception of ownership as something essential increases, in western countries one can see BYOD occurring in school education: in the US in 2013, some 89% of high-school students have access to internet connected smartphones, and nearly 2/3 of students connect to the internet at home from such devices (Riedel 2014).

minimal human labour. In addition, boom sprays can now detect weeds automatically without the need for human labour using infra-red technology. The technology locates weeds amongst crops and can specifically target unwanted plant species with pesticide (Alberta Farm Machinery Research Centre).

Emerging technologies such as autonomous vehicles have the capacity to transform business sectors and substantially change the nature of work, but their potential impact is very hard to judge prospectively. For example, an innovative use of autonomous airborne drone technology is to deliver packages within cities. If one reads articles on the web about this, one would be forgiven for believing it is about to happen (Bender 2013). However, the reality is rather different as the company itself says "This won't happen next week - there's a lot of technical and regulatory stuff to do to make sure it's safe and reliable enough to fly around busy cities - but it will happen!" (Flirtey). Other companies evince a similar optimism, but explicitly point out the limitations even if the regulatory issues are removed (Amazon 2014). Even if the optimism is justified and this does in fact come to pass, it is impossible to predict whether it will account for 0.1% of packages delivered or 99.9%. That will depend upon social acceptability and the market structure, which are nearly impossible to predict far in advance.

The impact of perceptions of technologies on technology adoption

There is a crucial difference between a technology, and a group's *perception* of the technology. A given technology might be empirically very safe compared to alternatives, but it can be perceived otherwise (recall the earlier comparison of motor cars and nuclear power). There are many examples in the literature of both how perceptions matter, and how perceptions were *manipulated*. Two classical examples of manipulation are 1) the marketing done by General Electric regarding the electric refrigerator as being superior to the gas fridge because electricity is "more modern" (Cowan 1999) and 2) General Motors famous fabrication of the link in consumers' minds between automobile ownership and "success" (Vintage Everyday 2014). More recently, one can see the role of perceptions by considering the use of software in the office workplace that can monitor keyboard usage[2]. Even if an employer did this for reasons solely in the employee's interest (reduction of Repetitive Strain Injury by enforcing breaks), since it could, and is at least sometimes, used to ensure the opposite (no "goofing off"), the perception of this technology by workers is likely to be ambivalent at best. These examples show that even if a technology is technically feasible, solves a real problem, and the price is acceptable, without social acceptability, it will not be widely adopted.

> *Technology Prediction* The world of A.D. 2014 will have few routine jobs that cannot be done better by some machine than by any human being. Mankind will therefore have become largely a race of machine tenders…
>
> Indeed, the most sombre speculation I can make about A.D. 2014 is that in a society of enforced leisure, the most glorious single word in the vocabulary will have become work! (Asimov 1964)

[2] There is software such as http://www.publicspace.net/ergonomix/ which is clearly designed for the purpose of helping the worker. But of course exactly the same technology can be used to invade the worker's privacy, which is why it can be perceived negatively.

In order to foresee the impact of new technologies on the workplace, one needs to be able to foresee new technologies and their impacts more generally. In this section we briefly summarise what is known about our ability to do this.

Is technology prediction possible?

The accurate anticipation of technological change can play an important role in strategic planning for a company or government. Technology prediction and forecasting are used to understand the potential rate and effects of technological change. Over the past 40 years, there have been many quantitative and qualitative techniques developed to predict future technology development: expert opinions, trend analysis, scenarios, horizon scanning, bibliometrics and modelling. Other types of prediction include emerging technology lists, science fiction and 'hypotheses of technological progress' such as Moore's law.

In a study looking at predictions made by Americans between 1890 and 1940, technology predictions were compared to the actual outcomes. The predictions were all of a form that they predicted a binary outcome (something would occur, or it would not). Overall, less than half of the 1,550 predictions have been fulfilled or are in the process of fulfilment; one would have predicted as well by tossing a coin. The accuracy of predictions appears at best weakly related to general technical expertise, and unrelated to specific expertise. One expert (or non-expert) appears to be as good a predictor as another. For instance, the domestication of the computer was predicted as highly unlikely. The challenge is that predicting whether a given technology will be widely adopted implicitly relies upon predicting much of society and the economy as a whole and the relationship of the technology to contemporary and future technologies (Wise 1976b).

One way of dealing with the poor track-record of technology prediction is to focus on the s*ocietal problems to be solved*, rather than the *particular technology (technique)* that might be used. An example of this is the set of predictions made by the sociologist S. C. Gilfillan in the 1937 report to the US president (National Resources Committee (Subcommittee on Technology) 1937). Recognising that the prediction of *which* technology may solve a problem was impossible, he (correctly) predicted that technological means would be found to land airplanes in fog. He listed some 25 different technologies that might do the trick. *But he did not predict which one would be successful.* Another of his predictions is worth highlighting. He also predicted (in 1937) that television would be three-dimensional within 10-15 years (prototypes of this technology were in existence already in 1928). As it turns out it is only now that 3-D TV is starting to become deployed, and it is likely to be some time yet before it is widely adopted, if ever (BBC 2013b, BBC 2013a).[3] The reasons for its slow take-up are not technical, nor are they market related (one can buy well functioning 3D TV receivers cheaply now). But rather it seems that not many people *want* 3D TV; it this lacks social acceptability.

Predictions of technological improvement in the narrow sense are significantly more accurate than predictions of technology adoption (Wise 1976a). Several models have been proposed to predict specific technological improvement e.g. Wright's Law, Moore's Law, Goddard's Law etc. In testing the ability of six different postulated laws to predict future costs Wright's law produced the best forecasts with Moore's law not far behind. Figure 2 below illustrates two representative examples

[3] The BBC is 'to suspend 3D programming for an indefinite period due to a "lack of public appetite" for the technology'. The Sports network ESPN also closed its 3D sports channel in 2013 because of lack of uptake.

for the production and cost of two specific technologies (polyvinylchloride and Dynamic Random Access Memory (DRAM) chips) plotted as a function of time. The results of this analysis show that specific technological progress can be accurately forecastable, with the square root of the logarithmic error growing linearly with the forecasting horizon at a typical rate of 2.5% per year (Nagy et al. 2012).

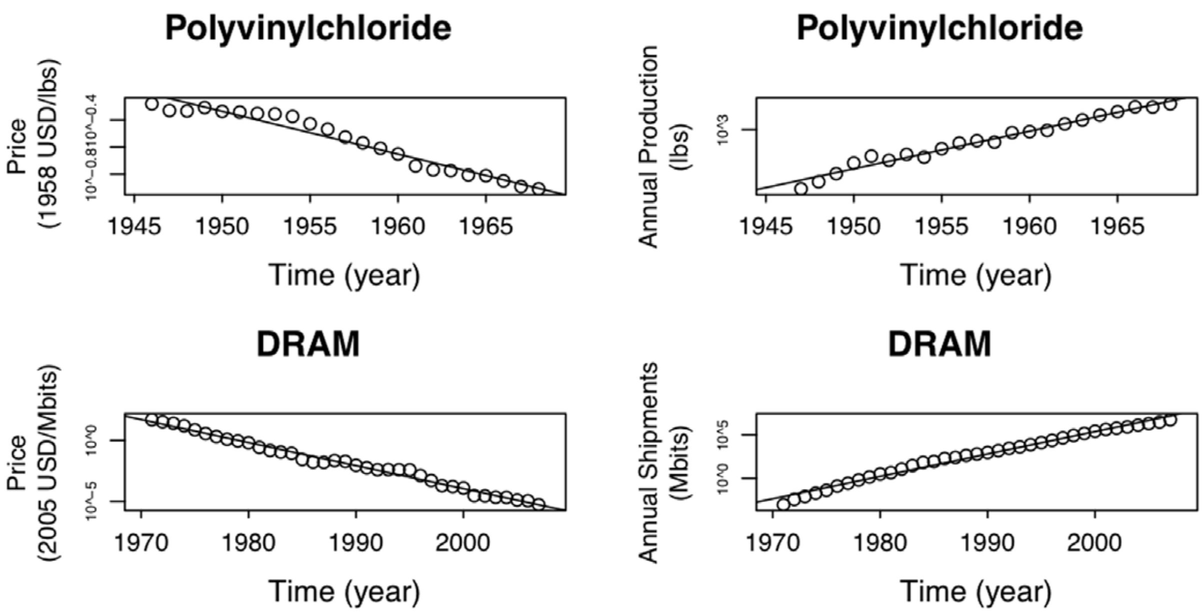

Figure 2 Two examples of accurate long-term technological prediction. The graphs show the logarithm of price as a function of time in the left column and the logarithm of quantity of production as a function of time in the right column, based on industry-wide data (Nagy et al. 2012).

It seems somehow contradictory that these technological parameters can be forecast so well, yet the forecasting of the adoption of new technologies is so difficult. Although hardly a rigorous proof, viewing this conundrum from the perspective of evolutionary theories of technological change offers a simple explanation (that leads to an obvious open question regarding its validity). Evolutionary models of technological change are almost as old as evolutionary models in biology (Nelson and Winter 1982, Basalla 1988, Arthur 2007). They also offer a plausible explanation of "disruptive" or "radical" inventions[4]. There is no contradiction between gradual change in the performance

[4] Renowned economist Brian Arthur has written strongly in support of evolutionary models of technological change. Interestingly, and pertinently for the present purpose, while he acknowledges the explanatory power of evolutionary models in many instances, he claims that radical innovations (the ones that have the big and surprising effect) are very different, and not at all well explained by an evolutionary model (Arthur 2007). Arthur claims that the evolutionary model "does not hold up for what interests us here: radical invention by deliberate human design. Radar certainly did not emerge from the random variation of 1930s radio circuits." The case is interesting because in fact radar *did* so emerge, as is well documented in histories of the technology (Swords 2008). The development of the magnetron was crucial to the improvement of performance to a level where it could be widely used. But radar as a technology itself, had a gradual evolution. And the magnetron itself can be seen as a step in the gradual evolution of vacuum tube devices (Boot and Randall 1976). There are several general conclusions that can be drawn: inventions that look radical are often not because the earlier history is forgotten by many. A given technology can be substantially improved by developments with other technologies. Hence there is no simple way to draw a sharp boundary around a given technology.

characteristic of a technological component and rapid or even “discontinuous” change in adoption of the technology. Adoption depends on the broader environment (Dosi 1982, Anderson and Tushman 1990). As a technology gradually evolves it can reach the point where it is suddenly economically viable and thus takes off (Mokyr 1990b, Mokyr 1991, Loch and Huberman 1999). This phenomenon can be seen to be analogous to the appearance of “punctuated equilibria” in the biological evolution record. The effect demonstrates the crucial point that it is the overall economic environment that is ultimately responsible for whether a particular technology will take-off and become widely adopted. One can not predict a technology’s impact without predicting the broader economic environment and market.

The economy is complex, by choosing a specific indicator such as cost it is possible to look at the potential effect of future technological innovation on the workforce. The Light Detection Ranging (LIDAR) based system that allows the Google car to create a 360-degree map of its surroundings using light waves currently costs $70,000. The rate of adoption will most likely increase once the technology is more affordable (Silberg et al. 2012). A dramatic decrease in the cost of this technology could have enormous ripple effects on the future workforce by decreasing the need for manned vehicles. However, the likelihood of a significant decrease in the production cost of LIDAR technology (such as the 2 orders of magnitude decrease predicted by the CEO of LIDAR manufacture company Velodyne) needs to be treated with some scepticism. Achieving a cost decrease of this magnitude would likely require radical design changes. It is much more likely, as was the case for the prediction of technology to aid in the landing of airplanes in fog, that different technologies will be developed or perfected to replace the LIDAR. One candidate is multiple camera computer vision, which can presently infer the 3D structure of an environment, but not well enough to replace LIDAR (Brynjolfsson and McAfee 2014). In any case, one can be reasonably certain that until the cost comes down substantially, such autonomous vehicles will not become widespread.

Technological predictions are usually undertaken for a purpose: most predictions are not made dispassionately – there is often an underlying agenda (Dublin 1989). For example, in the widely discussed paper forecasting a decline in US economic growth Gordon (2014, page 27) cites some predictions from (Watkins 1900), and can not resist the lure of what might be called the “Nostradamus effect” – interpreting vaguely stated future predictions in a positive light, and carefully selecting which ones to look at to conclude that “here were enough accurate predictions in this page-long three-column article to suggest that much of the future can be known”. Gordon makes this argument for a reason: he is trying to demonstrate that the rate of technological advance is slowing (as that supports the thesis is trying to defend)[5]. Perhaps the only safe thing to conclude from this is when reading any technological predictions, to ask *why* the author wants to make them in the first place!

[5] Consider his comments on the use of “Big Data” (Gordon 2014, page 33): “What is lost by the enthusiasts for big data is that most of it is a zero-sum game. The vast majority of big data is being analyzed within large corporations for marketing purposes.” Even if that were true at present (very doubtful), it is almost certainly not going to remain true for the future – the real economic benefit of data analytics lies in the vast amount of data that is *not* marketing (such as bioinformatics, mineral exploration, health care records, etc) which completely dwarfs the volume available for marketing. To be clear, Gordon may well be right about future economic growth of the US (for the other reasons he argues, especially the increasing income inequality), but his conclusions regarding technological innovation and its effects are quite suspect.

There are many reasons (some 100 are identified by Adamson (2010)!) why a new technology will not "work" or be widely adopted. But in order to predict accurately, it suffices to get three things correct (Christopher Freeman et al. 1982):

1) Correctly predict the technical advance (is it actually feasible?);
2) Correctly predict the social impact (how the technology will be used?); and
3) correctly predict the future market (because if the price is not favourable, the technology will be replaced by something else).

Most longer term predictions of future technologies fail on at least one of these points.

Predicting the impact of future technologies on the future workforce

Standard supply/demand employment forecasts are a useful tool to understand possible baseline levels of future employment and they can aid in understanding incorrect estimations. These forecasts use existing data on many aspects of society to extrapolate estimates for the future workforce including; demographic projections, labour force participation rates, future GDP, industry output and productivity trends by sector (to determine employment by industry). Generally, there is no formal feedback or adjustment mechanism to equilibrate the anticipated supplies and demands once a forecast is completed, except perhaps in the short term. Mechanical (econometric) workforce projections struggle to incorporate changing behavioural patterns under changing market conditions which can have significant effects on medium to long-term forecasting (i.e. the projection of the number of women entering the workforce) (Richard B. Freeman 2002).

Almost all new technologies affect different groups of people differently. This makes it difficult to infer (for example) the general degree of technological advance from economic indicators. While it is now widely accepted that a large part of the economic growth seen in the last century or two is due to technological advance, when one looks in more fine grained detail, it is harder to see what might happen in future. It has been noted (Gordon 2014) that in the last three decades 99% of US households have experienced no increase in their real disposable incomes, whereas the incomes of the top one per cent of households have been increasing over those thirty years at an annual average rate of 2¼ per cent. Median household income showed no growth at all for the last 14 years. It can be conjectured that this top 1 per cent of households have mainly prospered by creating and seizing economic rents, and the overall story is of very poor productivity growth, which does raise the question of how rapid has technological progress been since the 1970s? This difficulty in analysis is generic – the time delay between when technological advances occur, and when the broader economic benefits are seen can be very long indeed; see (Christopher Freeman et al. 1982). This effect is particularly acute with general purpose technologies (such as ICT) that have a very diverse applicability (David and Wright 1999) (Lipsey et al. 2005) (Bresnahan 2010).

The effect of technology adoption on the workplace

We now consider the various effects that technological change has on the workplace and employment. Given the complexity of the evolution and adoption of technology, and separately the complexity of work in all its forms, it is not surprising that understanding the conjunction is difficult.

Technological change and technological unemployment

> At least since the Industrial Revolution began in the 1700's, improvements in technology have changed the nature of work and destroyed some types of jobs in the process. In 1900, 41 percent of Americans worked in agriculture; by 2000, it was only 2 percent. Likewise, the proportion of Americans employed in manufacturing has dropped from 30 percent in the post–World War II years to around 10 percent today—partly because of increasing automation, especially during the 1980s. (Rotman 2013).

For centuries, technological change has been a pervasive part of society with significant effects on the nature of jobs and the number of jobs. There has been a dramatic adoption of new technology in the workplace and an increase in the number of people in paid employment (Volti 2014, Chapters 10-11). While new technologies create *jobs* (plural), there is a substantial concern by workers regarding their particular *job*. The disappearance of existing jobs due to their becoming redundant or unprofitable due to technological change is called "technological unemployment." Often seen as a temporary problem that has to be somehow fixed (US Congress Office of Technology Assessment 1986), as argued long ago it will always be present:

> The conclusion is inevitable: there is no mechanism within the framework of rational economic analysis that, in any situation, would secure the full absorption of displaced workers and render "permanent" technological unemployment in any sense impossible. How long the unemployment will last can be answered only by "economic biology," which, in an all-embracing economic-sociological approach, tries to evaluate the strength of all forces working in the society. (Neisser 1942)

Although technological change disrupted the careers of individuals and the health of particular firms, it also produced opportunities for the creation of new, unrelated jobs (Babbage 2011). As technological improvements increase demand and lower prices of goods and services, there is increased capacity to stimulate growth in other sectors of the economy (Miller and Atkinson 2013).

> While such changes can be painful for workers whose skills no longer match the needs of employers, Lawrence Katz, a Harvard economist, says that no historical pattern shows these shifts leading to a net decrease in jobs over an extended period. Katz has done extensive research on how technological advances have affected jobs over the last few centuries—describing, for example, how highly skilled artisans in the mid-19th century were displaced by lower-skilled workers in factories. While it can take decades for workers to acquire the expertise needed for new types of employment, he says, "we never have run out of jobs. There is no long-term trend of eliminating work for people. Over the long term, employment rates are fairly stable. People have always been able to create new jobs. People come up with new things to do." (Rotman 2013).

The effect of the adoption technological innovations on the workforce

Over the last two centuries economic development was profoundly affected by major technological innovations including the steam engine (1820-1913), electricity-based technologies (1913-1950), new production organisations (1950-1973) and the IT revolution (1973-present). Each of these so-called General Purpose Technologies (GPTs) (Bresnahan 2010) became pervasive in society and therefore had significant effects on the workforce. Electrification and information and communication technologies are described as general purpose technologies. General purpose technologies are key functional components embodied in hardware that can be applied as elements or modular units of the engineering designs developed for a wide variety of specific operations or processes (i.e. steam engine, electricity, ICT) (David and Wright 1999, Lipsey et al. 2005, Cantner and

Vannucci 2012, Cantner and Vannucci 2013). GPTs are technologies that can affect an entire economy, hallmarks of a GPT include; pervasiveness; improvement and innovation promotion (Jovanovic and Rousseau 2005). They often require remaking of infrastructure environments, business models and cultural norms (R.A. 2012).

One does not have to ascribe any determinism to these waves of innovation (they are often referred to as Kondriatev Waves and broad general conclusions drawn regarding their evolution) for them to be helpful to understand the questions we are considering. The key point for our purposes is that it is primarily a result of the *general purpose nature* of certain technologies that gives rise to clusters of innovations and that explains the apparent waves (Ayres 1990a, Ayres 1990b). This technological interdependence (Rosenberg 1979) at once makes simplistic models of technological change useless, and explains why the effects of technological innovation can take a long time to be seen.

Historically, technological innovation during the industrial revolution in the form of the steam engine, and later refrigerated transport, drastically lowered the cost of bulk transport over long distances enabling global trade. The global economy was comparatively liberal during this period as global economies and financial systems were in their infancy.

> The period 1820-1913 was one of very free international trade, with no quantitative restrictions and with mostly low or no tariffs on raw material and food imports, varying degrees of industrial protection, extremely free international movements of labor and capital, and a fixed nominal exchange rate under a gold-sterling-standard (Adelman 1998).

The industrial revolution led to unprecedented increases in labor productivity, and per capita income as well as a 30-fold increase in world export volume over almost 100 years (Table1).

Industrial Revolution 1820-1913 - OECD countries	
Economic Indicators	***Transformative Impacts***
7x ↑Labour productivity	Creation of global economy
6x ↑ Real per capita income GNP	Creation of financial systems
3x ↑ per capita income	Large intercontinental capital and population movements
66% ↓ Agricultural employment	Patterns of specialised production and trade emerged
30x ↑ World export volume	Creation of a middle class
	New forms of employment
	New forms of politics

Table 1 Economic indicators of OECD countries during the Industrial Revolution 1820-1913 compared to 1700-1820 (Adelman 1998)

There are many factors the resist the adoption of new technologies. A convenient and descriptive collective term coined by the economic historian Joel Mokyr is “technological inertia” (Mokyr 1990a, Mokyr 1992, Mokyr 1998a). A key contributor to technological inertia is resistance by those who believe their current power and status will be eroded. This behavior can sometimes be seen in employers, and sometimes in employees. “There is no general rule as to how technological change reallocates power" (Mokyr 1992). It is reasonable to expect these forces of technological inertia will continue to play their part in how technology changes the nature of work.

Current technological change in the workforce – Information Communication Technologies

> The current era is most analogous to the forty-year span of invention-clusters and slow growth preceding the Industrial Revolution. Like the steam-engine of the Industrial Revolution era, the current electronic Communication Revolution is in the process of altering all aspects of the national and global economy, society and polity. (Adelman 1998)

Nowadays Information and Communication Technology (ICT) has the capacity to alter the status quo just as technological change did during the industrial revolution. ICT has created new employment sectors, high worker mobility (Fallick et al. 2006, Tambe and Hitt 2014) , new ways of doing business by promoting comparative advantage and driving innovation (Table 3). A report evaluating the impact of the internet on economic growth, jobs and prosperity states ICT creates high paying jobs, comprises a significant share of GDP and drives productivity and GDP growth (Table 2); (McKinsey Global Institute 2011, Atkinson and Stewart 2013). The technological interdependence issue raised earlier is illustrated by the fact that 75% of internet impact arises from traditional industries.

Table 2 Economic impacts of ICT (Sourced from McKinsey Global Institute 2011)

Economic Indicators
2 billion internet users worldwide
Internet accounts for 3.4% GDP growth in 13 countries studies and 21% GDP growth of mature countries (2006 – 2011)
2.6 jobs created for every 1 job lost
10% increase in productivity for small and medium businesses from internet usage
SME's that heavily use web technologies grow and export 2x as much as others (vs. SME's with minimal or no online activity)

Table 3 Transformative effects of ICT on industrial structure, industrial organization and workplace within the OECD countries include (I Adelman 1998)

Transformative Impacts of ICT
Altering working- patterns , new level of decentralization of productive employment
Innovating the technology of long distance communication
Changing international patterns of division of labor
Far reaching changes in economic and social structure; and leading to the eventual transformation of the domestic and global economy, society and institutions
New kinds of transnational firms, engaging in global specialization
Financial and capital markets have become globalized, and respond instantly to changes in any part of the globe

Will robots steal our jobs?

One of the most hotly debated current topics regarding technology and work is that current technological progress, especially automation and Artificial Intelligence (AI), will lead to structural re-organisation and widespread unemployment. The negative perception or fear is not new, and it is helpful to distinguish two factors: 1) technology just advances autonomously, beyond human control; and 2) automation and AI are intrinsically technologies that will benefit the few rather than the many. Regarding the first, which is like the magic brooms in Goethe's 1797 poem *Der Zauberlehrling* (The Sorcerers' Apprentice), this is not a new concern:

> One symptom of a profound stress that affects modern thought is the prevalence of the idea of autonomous technology – the belief that somehow technology has gotten out of control and follows its own course, independent of human direction. (Winner 1978, page 13)
>
> Autonomous technology is ultimately nothing more or less than the question of human autonomy held up to a different light. And those who remain supremely confident about our prospects there have not been paying attention to what is happening everywhere about them. (Winner 1978, page 43)

Other commentators (e.g. Kelly (2012)) are much more optimistic about the widespread benefits to be had from these modern technologies. The fearful view ignores the fact that the adoption of a new technology depends greatly on social factors, and societies do have a choice, and fatalistically presuming technology is autonomous is simply tantamount to giving up on that choice. Indeed, the different capacities for social change are a major factor in explaining the variability of speed of adoption of new technologies across different societies (Christopher Freeman et al. 1982, pp71ff). It is furthermore intrinsically variable; there is no steady smooth rate of progress; see the various charts in (Christopher Freeman et al. 1982).

In contrast to the evidence of the positive economic effects of ICT, public debate re-surfaces in an ongoing manner correlating technological change to increased unemployment. This is usually against a backdrop of overestimating the ability of computers to substitute for humans and assuming current trends will continue or accelerate (Miller and Atkinson 2013).

> Many economists, journalists, and policymakers now routinely claim that technology, instead of being a key driver of increased standards of living, is to blame for our economic doldrums. Throughout history as macroeconomic factors have led to recessions and periods of high unemployment, the same worries about technology and automation have resurfaced (Miller and Atkinson 2013).

The fear that 'robots will steal our jobs' may have multiple sources. It may be the perception of the severe conditions the general public endured during the industrial revolution due to the introduction of automated machinery into the workplace. Compared to the present day the industrial revolution was a time of free-market capitalism, there were almost no workforce regulations and very few citizen rights. Dramatic societal re-organisation occurred during the 19th century due to the integration of machinery into society. This led to improved workforce conditions through union development. Or there may be particular fears that robots are somehow not merely going to take our jobs, but may eventually take over the planet (human beings become superfluous). Whatever the reason, there is much emotive debate about the degree to which robotics and artificial intelligence will turn out to be a good thing for 'the average worker'.

'Robots' can mean many things; for the purpose of this discussion we will consider 'robots' as either automated machinery for manufacturing purposes or artificial intelligence (machines with the capacity to solve difficult problems previously only done by people). Note that by this definition a modern photocopier is arguably a robot.

A recent book written by two MIT economists has amplified the debate that an increased level of automation will significantly decrease employment. They state that the pace of automation is increasing rapidly and this automation is pushing into white-collar areas of the work force, jobs that were believed to be beyond the scope of computers (Brynjolfsson and McAfee 2011).

The concern about robotics varies across countries, in the same way that the current deployment of robotics technology does. One figure states that Germany has twice the robot-worker density (number of robots per 10,000 workers) as the US (Markoff 2013).

While automation may transform the work force and eliminate certain jobs it also creates new kinds of jobs, McKinsey reports 2.6 jobs are created for every 1 job lost (McKinsey Global Institute 2011). In addition, technology-dependant jobs in the IT sector are generally better payed on average as they are highly skilled. In the US in 2011 IT employees earned an average salary of $78,584 which was 74% more than the average US employee ($45,230) (Atkinson and Stewart 2013).

Much of the more hysterical commentary, e.g. (Drum 2013), is based on an overestimation of what is actually possible with the technology. Some commentators largely take it for granted that 'strong AI' is just around the corner. There is very little evidence of this; it seems largely wishful thinking – most enthusiastic predictions of strong AI are timed to (just) fall within 15-25 years, which is a time horizon longer by far than has been used to predict radically new technologies in the past (Armstrong and Sotala 2012). The very notion of a single form of general intelligence that can be replicated artificially is not acceptable to many technologists; there are such enormous uncertainties regarding whether it is possible even in principle. In any case, as we shall argue below, focussing on strong AI is a distraction from the more important issue of how to ensure that the benefits of such technological progress is shared more widely amongst the population rather than facilitating yet further concentrations of wealth in a small subset.

Predicting whether jobs will be lost to robots is no easier than the more general prediction of technology, which as we showed above is usually done very poorly. And the introduction of fancy data-analytic techniques does not necessarily help. A recent study (Frey and Osborne 2013) uses a Gaussian process classifier to predict how susceptible 702 jobs are to computerisation. This paper reduces all the factors and uncertainties relevant to technology adoption and the workforce into a single probability for a single occupation. Values for occupations that are susceptible to computerisation range from 0 (not automatable) to 1 (fully automatable), the following are some examples; 0.95 nuclear power reactor operators; 0.95 animal breeders; 0.95 jewellers and precious stone and metal workers; 0.54 massage therapists; 0.57 cost estimators; 0.0035 occupational therapists and 0.0049 fabric and apparel patternmakers. The overall conclusion is that 47% of jobs are at risk of computerisation. Were the numbers from this extraordinarily dubious study not widely quoted[6] in the press it would be ignorable.

Is it different this time?

Are there any historical forecasts of technological impact on workforce that proved accurate? If so what aspects of them lead to their accuracy?

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[6] Do a Google search for "47% jobs automated" to see how widely such simplistic and unjustified numbers are believed.

Many commentators while recognising that there has been technological unemployment before, and nevertheless the net social welfare typically improves with advances in technology, believe that this time (robots and AI) is different[7]. It would be interesting to know (we currently do not) to what extent this is merely an artefact of the asymmetry of history and the future: We can understand all the things in the past, because they have happened. But we don't know (and more to the point) cannot really imagine the future. It *might* be that the pattern of technological unemployment will be much worse (it is after all logically possible), and since we do not *know* we might pessimistically assume the worst (this seems to generate more compelling headlines). In fact a stronger argument is possible: as Mokyr notes (Mokyr 1998b, Footnote 42), even after the fact it is nigh on impossible to say for certain that particular technologies induced substantial technological unemployment: "None of the theoretical demonstrations that in certain unlikely configurations some (temporary) unemployment can be caused by the introduction of "machinery" is tantamount to a demonstration that such technological unemployment did in fact occur on a large scale."

The common concern with new technologies is the destruction of jobs. Job destruction happens as a matter of course in the normal running of an economy. Figure 3 shows the year's job creation and destruction in the US. As Atkinson says:

> It should be noted that, in aggregate terms, there is a substantial degree of labor market turnover every year. In other words, there are always lots of jobs destroyed by firms going out of business or downsizing, while new firms are being created and others are growing. The commonly cited statistic for the "number of new jobs created" is a net number; in reality, many more jobs than that were added, but others were also lost. For example, in 2011, 15.7 million jobs were created, but net job creation was only 2.6 million because 13.1 million jobs were destroyed. On average around 15 percent of jobs are newly created every year in developed countries (US department of labor (Bureau of Labor Statistics)). Thus, when we talk about technology destroying jobs, what we are really talking about is technology increasing the job destruction rate relative to the rate of job creation (Miller and Atkinson 2013).

[7] Another way of framing the question is whether it is revolution, rather than evolution (Kranzberg 1985).

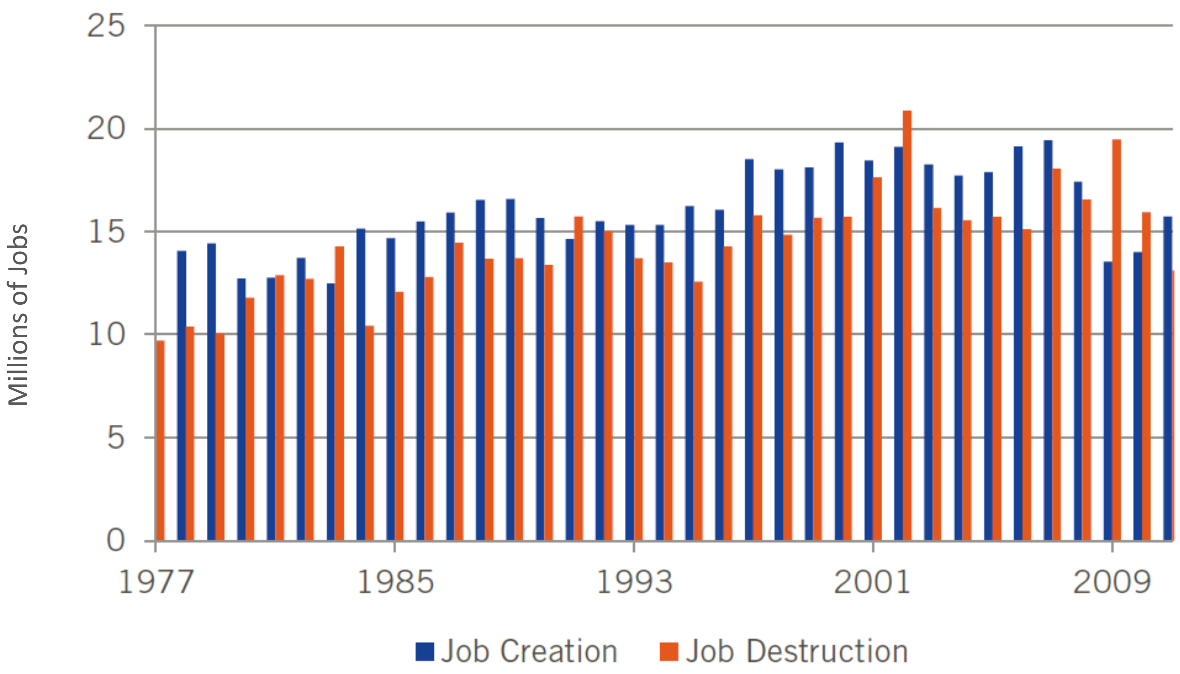

Figure 3 US job creation and job destruction (US department of labor (Bureau of Labor Statistics) , Miller and Atkinson 2013)

Technological progress and the economy

> Technological innovation itself creates questions and problems that need to be fixed through further technological progress. (Mokyr 2013)

A separate, but equally topical, concern is that current new technologies not only are progressing less rapidly, but they are also contributing less to economic growth.

Gordon (2014) and Vijg (2011) claim that economic growth and technological progress is slowing down and living standards are unlikely to rise much in future. Such conclusions rely on particular ways of quantifying the rate of technological progress for which there is hardly any consensus after half a century of study (Sanders 1962, Archibugi and Planta 1996, Issoufou 2011, National Research Council 2013). Given what is known regarding technology prediction in complex situations (no better than chance) what would be more useful is understanding how technological progress occurred in the past to help understand technology progress in future. Mokyr suggests an alternative view where technological progress will continue and this progress will create new jobs that are likely as unimaginable as social media consultants were in 1914.

> If technology replaces workers, what will the role of people become? From Kurt Vonnegut to Erik Brynjolfsson, dystopias about an idle and vapid humanity in a robotised economy have worried people. There will be disruption and pain, but the new technology will also create new demand for workers, to perform tasks that a new technology creates.
>
> In 1914 who could have imagined occupations such as video game programmer or identity-theft security guard? Physical therapists, social media consultants, and TV sports commentators are all occupations created by new technology.
>
> It seems plausible that the future, too, will create occupations we cannot imagine, let alone envisage. Furthermore, the task that 20th-century technology seems to have carried out the easiest is to create

> activities that fill the ever-growing leisure time that early retirement and shorter work-weeks have created. Technological creativity has responded to the growth of free time: a bewildering choice of programmes on TV, the rise of mass tourism, access at will to virtually every film made and opera written, and a vast pet industry are just some examples. The cockfights and eye-gouging contests with which working classes in the past entertained themselves have been replaced by a gigantic high-tech spectator-sports industrial complex, both local and global (Mokyr 2013).

Connecting reduced technological progress to decreased US economic growth is a debate lacking conclusive evidence. Gordon's rebuttal (Gordon 2014) is a working paper which describes the main causes of US economic downturn as four headwinds (demographic shifts, educational attainment, inequality, long-term decrease in the ratio of debt to GDP) and faltering innovation. The topic of this paper has been much debated and gained significant public exposure. Gordon concedes to critics that his prediction of future declining innovation is not provable but points to accurate forecasters of the past who could reliably forecast the future of technological innovation, which our analysis has found to be 50% accurate at best for complex situations (Gordon 2014). But Gordon also states

> In this sequel, there is no need to forecast that innovation in the future will "falter," because the slowdown in the rate of productivity growth over the past 120 years already occurred more than four decades ago. This sequel paper explains why the pace of innovation declined after 1972.

There is a perception, but a lack of evidence, directly linking productivity growth and technological innovation. Literature describes a 'productivity paradox', the apparent contradiction between the remarkable advances in computer power and the relatively slow growth of productivity at the level of the whole economy from 1970-1990 (Brynjolfsson 1993). Solow is quoted to have said 'You can see the computer age everywhere but in the productivity statistics' with regard to this topic (Solow 1987). However the pessimistic view regarding the positive economic impact of new technologies (such as ICT) is soundly refuted when one looks at firm level data (Brynjolfsson 1993, Brynjolfsson and Hitt 1998, Brynjolfsson and Hitt 2003, Hempell 2006, Acemoglu et al. 2007, Acemoglu et al. 2014). This illustrates a more general point: one cannot properly understand the impacts of technology if one works at too broad a level; the effects are complex, and vary enormously. One needs instead to work in the "middle range" (Merton 1949).

There is a historical precedence for an economic slowdown in a time of pervasive technology adoption. Just over a century ago there was a pronounced slowdown in industrial and aggregate productivity growth between 1890-1913 in Britain and the US during the 'Electrical Age', a time when electrical technology adoption by specific sectors of the workforce was substantial (David 1990). A comparison between the actual ubiquity of computers in offices by 1990 and the number of dynamos in Industry by 1913 could explain these observations: By the early 1920's only slightly more than half of mechanical drive capacity had been electrified (David 1990).

Electricity vs. ICT – Workforce lessons from mass adoption of general purpose technologies

Taking a historical view on the workforce effects of a pervasively adopted technology can give insights into the possible effects of current pervasive technology on the workforce. General purpose technologies appear to be adopted slowly. Figure 4 reports 70% of US households had electrical connections over 30 years after its initial availability (by 1929) and 60% of US households adopted the internet in 15 years (Felton 2008). Like all measurements this graph is influenced by the characterisation of its values, such as the initial date of technology availability. The internet is a prime example of a technology with various initial dates of availability. In addition, it is noted that the ICT GPTs are powered by electricity for the most part. Nonetheless pervasive adoption of both electrification and ICT has occurred with significant effects on the workforce.

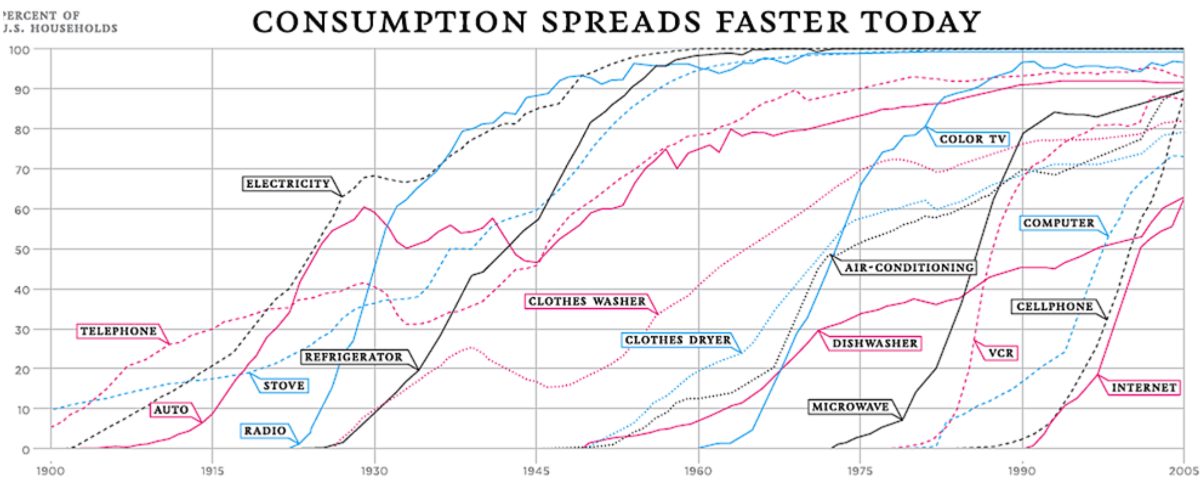

Figure 4 Percentage of US households adopting various technologies, or technological artefacts (Felton 2008). Note that the degree of generality of the various technologies listed varies – comparing dishwasher or cellphone adoption with that of electricity is perhaps a little odd. Furthermore the figures are for *household adoption*, not workplace adoption. The heading (from the original source) is hardly well justified by the data!

By comparison, US household electrification and the personal computer (which can be defined as general purpose technology) show similar rates of adoption. Measuring electrification in terms of households obtaining an electric service (from 1894) and the availability of the first PC (1971) shows households adopted electricity approximately as rapidly as they adopted the PC (Figure 5) (Jovanovic and Rousseau 2005). When one looks in a more fine-grained fashion, one sees the variability alluded to earlier (Figure 6).

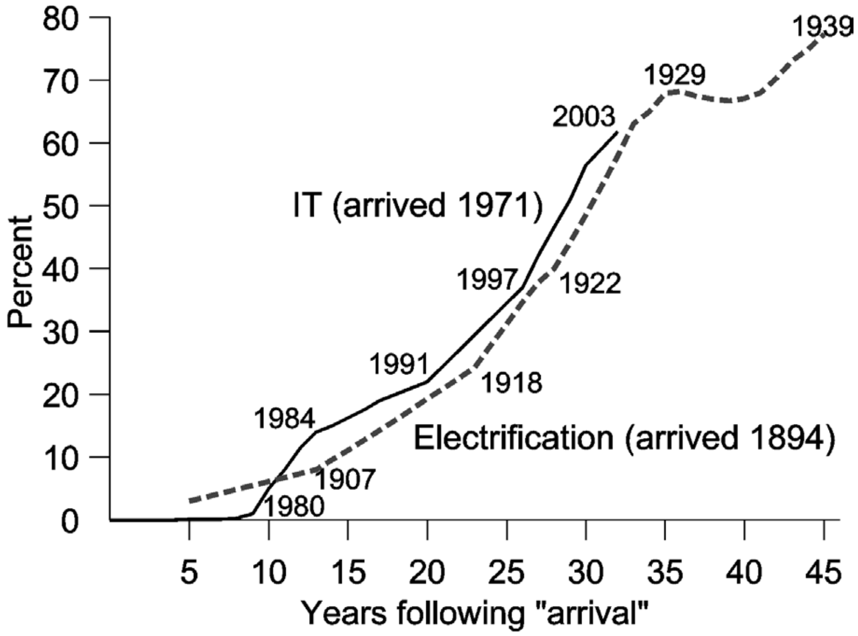

Figure 5 Percent of households with electric service and PCs during the two GPT eras. Sourced from (Jovanovic and Rousseau 2005).

The rate of adoption varies across different industry sectors.

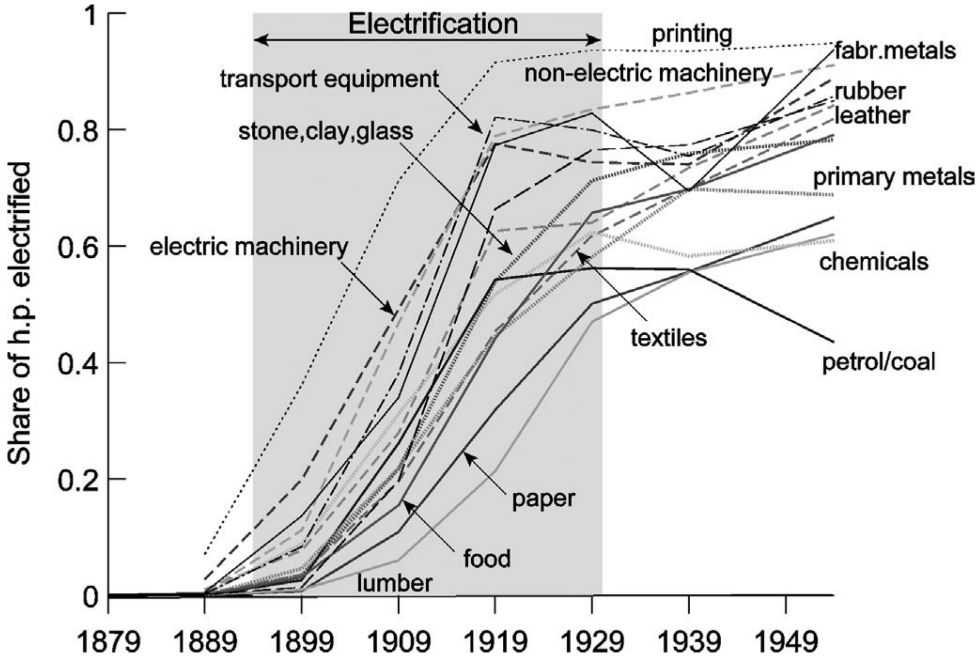

Figure 6 Rate of adoption of electricity across different industry sectors; from (Jovanovic and Rousseau 2005).

Adaption, large employee turnover and survival were hallmarks of the American workforce at the turn of the 20th century. Labour was restive at this time, but only partly due to the pervasiveness of new technologies such as electricity. Most American industries (meat-packing plants, textile mills, machine works and automobile factories) had a labour turnover of 100% in the first decades of the 20th century, this was a time of mass adoption of electricity by industry (Rodgers 1978, Nye 1992). For example, merely 10% of manufacturing horsepower was derived from electricity in 1905 but by 1925 this electric power in this area jumped to 70% (Goldin and Katz 1996).

> The US Department of Labor Statistics found in 1913-1914 that 'normal' labor turnover was 115% a year. It is thus inaccurate to picture a stable workforce labouring together with traditional methods suddenly confronted with new technologies

The widespread introduction of electricity brought opportunities and barriers to the workforce just as ICT does now. Electricity allowed American industry managers to maximise economies of scale by constructing large, continuous pace manufacturing plants. The move from mechanical to electrified plants created a safer, quieter, cleaner and brighter workplace overall. By contrast, on an individual employee level new risks included electric shock or electrocution, generally for the young or newly employed. Attitudes to electrification technology at the time were negative as textile workers felt they were expected to complete ever-increasing amounts of work and had nightmares about keeping up (Hall et al. 1986, pp.270-271). Compare this to 24/7 perception of ICT on work.

Electrification led to new management practices as university-trained engineers became responsible for managing work process in factories which led to the re-design of production and promoting long-term reliable labour as investment in new electrical machinery made high labor turnover unprofitable; compare this to the rise of code writers now and their effect on business models (Nye 1992).

Changes in Work Practices

There are many ways to break down the completion of a piece of work. American Telephone and Telegraph had a strong anti-union policy. The linemen (cable splicers and trouble-shooters) they needed were highly unionised by the early 20th century (due to many factors, WW1 was one of them) and therefore became employed as sub-contractors by American Telephone and Telegraph in order for work to be completed with minimal confrontation between workers and management. Piecework saw a revival in the 1920's in America as almost half the labour force worked on a piecework basis, payment per piece produced as opposed to a daily wage. A main advantage to management was the employee incentive to produce more in a given amount of time. ICT has enabled a current revival in sub-contracting work but is not the sole causative factor (Nye 1992). Incentives for a revival in sub-contracting work include due to ICT; working from any location, ease in locating sub-contractors globally to perform parts of the workload.

Interaction between general economic effects and employment

The general economic effects (concerns such as Solow's paradox) and the worry about technological unemployment, are intimately related – as shown in chapter 7 of (Antonelli 1999) there is a strong relationship between high R&D expenditures and low unemployment. High R&D leads to higher rates of innovation, which increases employment opportunities.

The Role of Education and Training in facilitating Technological Change

Technology and work is a very broad topic; this paper merely scratches the surface. Of the many topics omitted, one is particularly worthy of further investigation – the extent to which people can be trained to adapt more readily to new technologies. If (as we have argued) one cannot *predict* major technological changes very far in advance, then being able to *adapt* more quickly is a sensible response. What is needed is some rigorous empirical work on how best to train for adaptability (or "life-long learning") to follow up on the obvious and appealing suggestion of (Nelson and Phelps 1966) that

> *We suggest that, in a technologically progressive or dynamic economy, production management is a function requiring adaptation to change and that the more educated a manager is, the quicker will he be to introduce new techniques of production. To put the hypothesis simply, educated people make good innovators, so that education speeds the process of technological diffusion.*

While economists have long recognised the significance of education in the ability to adapt to new technologies, what is missing is empirical evidence on the best *type* of education and training to facilitate quicker adoption of new technologies. Jovanovic (1995) estimates the cost of adopting to new technologies in the US is around 10-15% of GDP and speculates that education and training plays a role in this. Higher rates of technological change unsurprisingly correspond to higher levels of worker training (Bartel and Sicherman 1998). But disentangling the roles of education and experience is problematic (Weinberg 2004).

Where does this leave us? It leaves us with, in the felicitous phrase of Goldin and Katz (2008), "the race between technology and education" where the outcomes of the race are economic growth and wage inequality. Presumably *because* educated workers are more adept at implementing new technologies (Bartel and Lichtenberg 1987) it is generally accepted (Karoloy and Panis 2004) that technological change favours the more highly skilled worker. However even a traditional university degree is no guarantee of a high-wage job. The ability to think in a *non-routine manner* is suggested as a key differentiator (Goldin and Katz 2008). With few exceptions there is little empirically based evidence on *how* this is best achieved. Enlightened educators recognise the dissonance between the Schumpeterian creative destruction characteristic of technological change and tradition-bound and overly standardised curricula:

> *Yet instead of fostering creativity and ingenuity, more and more school systems have become obsessed with imposing and micromanaging curricular uniformity. In place of ambitious missions of compassion and community, schools and teachers have been squeezed into the tunnel vision of test scores, achievement targets, and league tables of accountability. And rather than cultivating cosmopolitan identity and the basic emotion of sympathy, which Adam Smith called the emotional foundation of democracy, too many educational systems promote exaggerated and self-absorbed senses of national identity. In many parts of the world, the rightful quest for higher educational standards has degenerated into a compulsive obsession with standardization. (Hargreaves 2003, p.1)*

Technological change requires continual training (Llorens et al. 2002-3) and thus "life-long learning" and there are educational approaches (problem based learning) (Wood 2003) that demonstrably improve (Shin et al. 1993) the ability of people to continue to learn after they have left an educational institution. Problem based learning, introduced in medical education in North America several decades ago (Boud and Feletti 1998) seems a particularly suitable approach to engender the key competencies and skills for dealing with technological change: adaptability to change and polyvalence; creativity and innovation; empathy; identification of opportunities in the given context; and mental flexibility (Llorens et al. 2002-3).

Conclusions

We draw some tentative conclusions:

- Technology and work are inextricably linked.
- New technologies affect workers differently. The better educated generally benefit more.
- There is an economic advantage to adopting new technologies, so a country that wished to prevent the perceived workplace problems of a new technology, might end up facing a larger competitive problem from other countries that chose to adopt it.
- Prediction of adoption depends on getting technology, sociology and market right.

- The Evolutionary perspective of technological change is helpful for understanding how gradual changes in technology can lead to rapid shifts in adoption, and hence why it is so hard to accurately predict the future adoption of new technologies.
- ICT seems different, but much of that difference can be explained by it being a General Purpose Technology – one that can be used in every industry sector, albeit adopted at different rates.
- The evidence is still far from clear regarding productivity and employment effects of ICT and other recent technologies.
- Work is important for people's identity as well as earning a living. Thus there will always be resistance to taking away people's identity.
- High R&D leads to higher rates of innovation, which increases employment opportunities.
- There are many stakeholders who affect the adoption of new technologies in the workplace – not just management.
- Modern information and communication technologies are argued by many to be fundamentally different to earlier technologies in terms of the effect they will have on work. However the evidence is ambiguous at best.
- Education and training systems that are open to change, and encourage openness to change, uncertainty and working "backwards" such as problem based learning are likely to be engender greater adaptability and hence faster adoption of new technologies.

New technologies can be adopted and adapted by society in many ways. What seems to matter more is the degree to which the benefits are shared or hoarded by the few (Acemoglu and Robinson 2012). There is *always* choice in the development and adoption of new technologies. Feenberg (1999, page 131) goes so far as to say "technology should be considered as a new kind of legislation, not so very different from other public decisions." Acemoglu has argued that recent (the last several decades) technological change has been "skill-biased" (benefit differentially those with greater skills) and this partially explains the widening wage spread that has been observed in many countries (Acemoglu 2000). He argues (page 9)

> "we are most likely not in the midst of a 'technological revolution'; what has changed is not necessarily the overall rate of progress, but the types of technologies that are being developed."

He concludes, as do we, by observing that "how technical change and institutional change interact are important areas for future research." His subsequent and recent book *Why Nations Fail* (Acemoglu and Robinson 2012) suggests a broader conclusion: insofar as new technologies continue to be the "lever of riches", as Joel Mokyr (1990a) has felicitously put it, the crucial choice is to what extent are the economic benefits shared by the many or hoarded by the few; the latter seems a much more substantial concern than technological advance per se.

The very technologies that there is most concern about (Information and Communication technologies) also hold the most promise of enhancing democratic free speech (de Sola Pool 1983); the personal computer revolution, arising from the Homebrew computer club (Slattery 2007) illustrates the extent to which humanistic and egalitarian concerns can be powerful influences in the development of technologies (Illich 1973).

All this reinforces one of Melvin Kranzberg's "laws" of technology and history:

> Although technology might be a prime element in many public issues, nontechnical factors take precedence in technology-policy decisions. (Kranzberg 1986).

Thus the most important issue regarding technology and work is well summarised in the Economist:

> [T]he benefits of technological progress are unevenly distributed, especially in the early stages of each new wave, and it is up to governments to spread them. In the 19th century it took the threat of revolution to bring about progressive reforms. Today's governments would do well to start making changes needed before their people get angry. (The Economist, Editorial, 18 January 2014)

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