Department of Economic & Social Affairs

DESA Working Paper No. 158
ST/ESA/2019/DWP/158

March 2019

Lessons for Today from Past Periods of Rapid Technological Change[a]

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ABSTRACT

We provide a history of past periods of rapid technological change starting from the Industrial Revolution continuing up to today. We find that it takes decades for technological breakthroughs to make a difference to the aggregate economy. The reason for this delay is that to realize the value of these breakthroughs requires complementary investments. Second, for good or for bad, government has played an important role in facilitating these transitions through both investments in physical infrastructure and legal reforms. We also emphasize that because technological breakthroughs are difficult to predict, the responses of governments are necessarily improvisational.

JEL Classification: O33, N10

Sustainable Development Goals: 8.2, 9.2, 9.C

Keywords: automation, technological anxiety, Industrial Revolution

a This paper was written as a background paper for the World Economic and Social Survey 2018. It builds on our earlier work with Joel Mokyr, who we thank but in no way implicate here. We also thank comments from an Expert Group Meeting at the United Nations and, in particular, Marcelo Lafleur.

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I Introduction

As far back as the invention of agriculture, recurring technological revolutions have transformed the economy. While it is broadly understood that these revolutions are the main source of economic progress, they have generated considerable cultural anxiety throughout history (Mokyr et al., 2015). Ancient myth echoes these worries, as for example the story of Prometheus cautions about the uncontrollable effects of technology. The reason for this anxiety is that all of these revolutions have brought on change and adjustments in the arrangement of society. Some of these adjustments reflected the fact that old ways of doing things were simply no longer profitable. For example, at some point after the introduction of the spinning jenny, it no longer made sense to produce cloth by hand. Other adjustments were necessary to fully reap the benefits of the new technologies. For example, enjoying the benefits of electricity required manufacturing establishments not simply to adopt electricity where steam power had been used previously, but instead to completely reorganize their shop floors.

Along with these individual adjustments, public action has played a major role in responding to technological change. Sometimes this activity has been in the form of public investment in physical capital, such as building roads for automobiles. Sometimes this action has been in helping to buffer individuals against the dislocations brought on by these changes. For example, Britain's Old Poor Law of 1600, while designed to help individuals subject to fluctuations in harvests, ended up supporting individuals affected by the technological change of the Industrial Revolution. Not all of these public actions (or inactions) have been salutary. The U.S. has failed through inaction over the last 30 years in responding to the changes brought on by advances in information and communications technology.

In previous work (Mokyr et al., 2015), we along with Joel Mokyr traced the history of angst over technological change and the reaction of the economics profession to it. That was a work of mainly intellectual history; our goal in this essay is to instead trace out policy responses to earlier periods of technological change, the economic consequences of these revolutions and policies, and then to identify lessons for the current period. We will consider the following periods: (1) the First Industrial Revolution (1770-1830) focusing on Britain; (2) the Second Industrial Revolution (1860-1930) focusing on the U.S.; and (3) the Information and Communications Technology (ICT) Revolution (1970-2000) focusing on western countries. Our discussion of these historical episodes centers mainly on developed countries for several reasons. First, many developing countries of today are still waiting for their own industrial revolution, so it is premature to consider whether that transition has been successful or not. Second, much of the academic literature has been focused on developed countries. This is not entirely due to parochialism on the part of academics, but it instead reflects the limitations when working with historical data. Data from western countries is just more readily available, though still not always easy to collect. That said, we do think there are a parallels to be drawn between developed countries long ago and developing countries today that we return to in the conclusion.

We emphasize the following features common to technological revolutions. First, there are considerable delays in implementing these new technologies. This leads to the apparent paradox of "obviously" rapid technological change and slow growth in the aggregate economy. Second, this delay in reaping benefits from technological change is heterogeneous across individuals, as in William Gibson's quip that "the future is already here – it's just not very evenly distributed." As a consequence industrial revolutions at least initially widen the gap in living standards within societies (Furman, 2018). The reason for this delay, and our third major point, is that implementing these technologies requires complementary investments that take time to build out. Sometimes these investments are pieces of physical capital, such as roads for automobiles to drive on. Other times these investments are in organizational capital, such as the reorganization of shop floors after the introduction of electricity. Sometimes these complementary investments are in the rearrangement or modification of existing property rights or the wholesale creation of new property rights. To return to the road example, the development of subdivision zoning codes was a crucial reason for why the automobile was able to contribute to the growth of the suburbs.

These complementary investments are a mixed bag in terms of the nature of the investment and who is doing the investing. This leads us to our fourth point, which is that government has played a role one way or another in facilitating (or hindering) these transitions. To be sure, relative to the most recent ICT revolution and perhaps the one we are experiencing right now, the role of the government in these earlier revolutions was quite small because the size and scope of government was limited. With that in mind, the governmental responses can be classified into "active" and "passive" ones. The first type of response are ones where governments deliberately take action as a response to technological change. For example, they may appropriate money to build railroads or pass laws that redefine (or define for the first time) certain property rights. Passive, or maybe better put automatic, responses are ones that derive from policies put in place before the transition began. For example, the Social Security Disability Insurance (SSDI) program in the U.S. was instituted for reasons unrelated to technological unemployment. Nevertheless, the growth in the program in recent decades has been one of the most important "responses" to the long-run decline in manufacturing employment (Autor and Duggan, 2003). The program is not about technological revolutions per se, as income support is provided to anyone who can show a permanent disability, but with the institution in place, changes in the economy automatically resulted in growth in the program.

The example of SSDI illustrates our last point. We are certain that no legislators at the time of the Social Security Act's passage in 1935 were thinking that this one piece of the law would turn into a major welfare program. They just could not have conceived of a world where manufacturing was no longer the dominant provider of middle class jobs (and perhaps of a Congress unable to respond to this change). Yet SSDI has come to play precisely this crucial role, which brings us to our final point. That is, the changes stemming technological revolutions are very difficult to predict. As summed up in Amara's Law, named after systems engineer Roy Amara, long-time president of the for-profit think-tank the Institute for the Future: "We tend to over- estimate the effect of a technology in the short run and underestimate the effect in the long run." This makes it that much more difficult to imagine what complementary investments will be necessary to fully implement these breakthroughs.

Because of this unpredictability, it should not be surprising that existing economic institutions and policies are almost never well designed for change. To use a slightly different example, Pelikan (1984) (pg. 66-67) notes "the recurring irony...in which theologians resisted scientific innovation [while] the tradition they were defending had in a previous age...made its peace after controversy with a scientific hypothesis it had originally dismissed as inimical to the faith." The same is true when it comes to the response of political institutions to economic dislocation, as the response always ending up being somewhat improvisational. It should be not be surprising then that sometimes these *ad hoc* responses work, and other times fail.

So what does this all mean when thinking about the current period of technological change that some are calling the fourth Industrial Revolution and perhaps its signal technology artificial intelligence (AI)? Trajtenberg (2018) notes that AI has the possibility of becoming a General Purpose Technology (GPT)–an innovation whose effects are felt throughout the economy. To make more concrete what we mean by "AI" in our context, in particular to distinguish it from machine learning, we will refer to the structure of Taddy (2018). An AI "is able to ingest human-level knowledge (e.g., via machine reading and computer vision) and use this information to automate and accelerate tasks that were previously only performed by humans". That is, machine learning is a tool for pattern recognition as part of a larger system along with data generation and domain structure, in which a complex problem is broken into components to which machine learning is applied. When put this way, it is easy to see how the newest developments in AI are greeted with a mixture of wonder and trepidation.

As Furman (2018) points out, the prospect of what AI will do the economy based on historical experience is not entirely reassuring; we think it is important highlight the history nonetheless. First, because of the unforeseen changes that are always associated with technological revolutions, there is a strong tendency to treat each one as *sui generis* and to insist that *this* time is different. While it is surely the case that history does not repeat itself, it does rhyme, and this is why we are able to identify commonalities in all technological revolutions. In fact, these worries have often appeared at times of flagging economic growth paired with apparently fast technological change. For example, the Great Depression brought the first models of secular stagnation in Alvin Hansen (1938)'s book *Full Recovery or Stagnation*?. Hansen drew on the macroeconomic ideas of John Maynard Keynes in fearing that economic growth was over, with population growth and technological innovation exhausted. Keynes (1930) himself was drawn into the debate and offered a meditation on the future of technology and unemployment in his well-known essay, "Economic Possibilities for our Grandchildren." This was written after a decade of economic underperformance in the United Kingdom (Pecchi and Piga, 2008).

Only time will tell if this time truly is different. That said, in our view, the current period of technological change has numerous echoes of previous ones, from the apparent implementation lag to anxiety over the changes to questions about how to respond to it. This does not mean that we should be overly sanguine about the possibility of making a successful transition. Yes, there have been cases in the past like the Second Industrial Revolution, particularly the mass movement of people from agriculture, where a large number of people economically dislocated suffered only temporary ill effects. Yes, there have been periods of rapid skill biased technological change before, such as the ICT Revolution. Yes, many of these historical periods of adjustments have taken place with, at least by modern standards, limited government support for those displaced. However, none of these successes were foreordained.

The responses to technological change will depend on particular historical circumstances and preexisting institutional frameworks. The First Industrial Revolution provides a good example of this contingency. An important driver of growth was the capacity of Parliament to respond flexibly in reorganizing property rights. The problem is that flexibility can devolve into randomly allocating property rights based on political circumstances or outright predation, which has historically been disastrous. So flexibility has to be paired with credibility that these powers will not abused. Developing the state capacity to be able to carry out these actions while restraining the arbitrary application of this ability is not easy and develops only slowly over time. Without this ability, though, the First Industrial Revolution could easily have failed.

Unfortunately, the lessons from history do not translate into easy policy recommendations. We think it is foolish to offer some list of bullet points of concrete proposals. This has not worked in the development context and there is no reason to believe it would work here. Instead we offer broad principles or goals that are specific to a country's level of development. For developed countries, we think that societies, and we emphasize the word societies as opposed to governments, need to seriously consider what a world of scarce work and abundant goods would be like. Thinking about this kind of reality is an old topic of inquiry going back to Keynes most prominently. In fact, this discussion goes even further back to the socialists of the 19th century who envisioned a world where all physical needs had been met. More generally, developed countries should take this opportunity to experiment. For example, studying the possible effects of a universal basic income would be an excellent idea, but governments should not jump prematurely into radical change.

As compared to developing countries, developed countries have the benefit of starting from a situation in which there is not widespread deprivation, though poverty is still a real problem. For developing countries, the usual model of development has been a transition from agriculture to manufacturing and eventually into services. If employment in that intermediate step of manufacturing disappears because of (even more) widespread automation, as discussed in Rodrik (2016), what will happen? Will the poorest countries be left with large parts of their population stuck doing subsistence agriculture? If this is a real possibility, then developing countries need to carefully consider how to make sure everyone shares in the gains from technological progress. For this reason, it will be all that more important for developing countries to develop the state capacity to act flexibly and credibly in response to these technological changes. How to actually going about doing this is a question we are not able to answer. Perhaps the necessary action will require expropriating certain forms of Western intellectual property, similarly to how the British in the Industrial Revolution abrogated certain property rights of existing landowners.

The essay proceeds as follows. In Section 2, we discuss the Industrial Revolution with a particular emphasis on the policy responses of the British government in sometimes hindering and sometimes helping the process along. Section 3 turns to the U.S. and the Second Industrial Revolution and what we call the Agricultural Transition. Section 4 considers the ICT Revolution for Western countries more generally. Section 5 concludes with a focus on the current situation.

II The Industrial Revolution

The Industrial Revolution was a period, roughly from the late 18th century to early part of the 19th century, that saw the advent of what we now consider "modern" economic growth–growth that is driven by technological change. For the Industrial Revolution, these technological changes are often characterized as an increasing mastery of the use of energy, relieving the "ultimate bottleneck" on production in a pre-industrial, Malthusian economy (Goldstone, 2002). While this change is most commonly associated with the steam engine, it actually encompassed an entire engineering culture, including advances in physics and chemistry. Viewing the Industrial Revolution as merely about steam or even energy more broadly, however, is in our view too narrow a conception of the nature of the change. As McCloskey (1981) put it, "The Industrial Revolution was not the Age of Cotton or of Railways, or even of Steam entirely; it was an age of improvement." These changes included unprecedented rates of urbanization, the production of new goods, and advances in health such as vaccination for smallpox.

By modern standards for economic growth, the period of the Industrial Revolution was anything but a revolution. While estimates are somewhat conjectural, there is robust evidence from a variety of sources that there was little total factor productivity growth during the "classical" Industrial Revolution (Mokyr, 2004). Real wages failed to increase until perhaps the middle of the 19^{th} century, a lifetime after the "revolution" had begun (Feinstein, 1998). This disconnect between apparent technological change and a stagnant aggregate economy is not as strange as it sounds. In fact, a recurring feature of the diffusion of so-called "general purpose technologies" (GPTs) is that it is a slow process, with energy being a paradigmatic example. The contributions of GPTs to growth can be modest for many decades following their initial invention. Crafts (2004) shows steam contributed little to aggregate growth in the Industrial Revolution before 1830. Part of the reason is that complementary investments are needed to fully reap the benefits. For steam, further innovations such as high-pressure steam were necessary before even this seminal invention could provide long lasting, widespread increases to aggregate living standards. Another reason that living standards grew slowly was that much of the gains to productivity were initially dissipated as population growth during the "post-Malthusian" period between Malthusian stagnation and modern economic growth (Galor and Weil, 2000). During this era, population growth was still positively correlated with technological progress, but not so strongly so as to wipe out any gains to per capita standards of living.

Even to the extent that there was an increase in wages during the first part of the Industrial Revolution, these gains were modest and arguably did not represent true improvements in living standards. The price of these higher wages was longer work hours, often performed in appalling conditions (Voth, 2001) as well as living in urban areas where there was a large mortality penalty (Cain and Hong, 2009). The British Parliament in 1837 published a report titled "Evils of the Factory System: Demonstrated by Parliamentary Evidence," partially focused on child labor. It contained graphic descriptions of accidents involving "the integuments, and the muscles, and the skin stripped off down to the bone, and in some instances a finger or two might be lost" (Wing, 1837) (p. clxxii). Many economic historians have been dismissive of these costs of industrialization. Williamson (1981) suggested that the disamenities of urbanization during the Industrial Revolution were not very important. For example, take coal. Cheaper fuel in the form of coal greatly improved urban lives by allowing for better lighting and heating. At the same time, the costs of coal use for health were very real. Beach and Hanlon (2017) find that a one standard deviation increase in coal use raised infant mortality by around 7%. Based on these results, coal use can explain 1/3 of the urban mortality penalty in 19th century Britain.

Besides questions about whether changes in aggregate income accurately reflected changes in living standards, there were additional worries at the time over the distributional effects of these technological changes. In previous work with Joel Mokyr, we examined the contemporaneous response of the economics profession to these developments (Mokyr et al., 2015). Economists were divided about the prospects that machinery would replace manual labor, as for example in Mortimer (1772) and Ricardo (1821). These writers usually distinguished between short run dislocations and long run effects. Even thinkers opposed to the societal changes resulting from technological development in general conceded that they were powerless to stop the developments, because even if they could, other countries would simply outcompete them (Mildmay, 1765). In the end, worries about massive numbers of people being unemployed and unemployable were mostly unfounded. However, if we consider more broadly changes in the income distribution, the somewhat spotty evidence suggests that there was a rise in inequality over the Industrial Revolution (Lindert, 2000). In addition, the economic dislocations of this period did show up along other social dimensions including protests movements such as the Luddites and criminal activity. For example, Vickers and Ziebarth (2016) argue that the economic losses for certain groups due to mechanization shifted the distribution of criminals towards older men.

For our purposes, we do not want to focus on the question of why the Industrial Revolution *started* in Britain or western countries more broadly. The literature on this so-called "Great Divergence", that is, the pulling away of Europe and more specifically England from the rest of the world in the Industrial Revolution, is too vast to survey here. Explanations for the unprecedented development of sustained economic growth have ranged from those based in superior factor endowments of coal as argued by Allen (2009) and Pomeranz (2000), to natural selection (Clark, 2007), and to cultural characteristics such as a more "Enlightened" approach to progress (Mokyr, 2009) or a rhetoric which promoted commercial values (McCloskey, 2010). It is fruitless to try to settle this debate, and we argue unnecessary for taking lessons from the Industrial Revolution to the present.

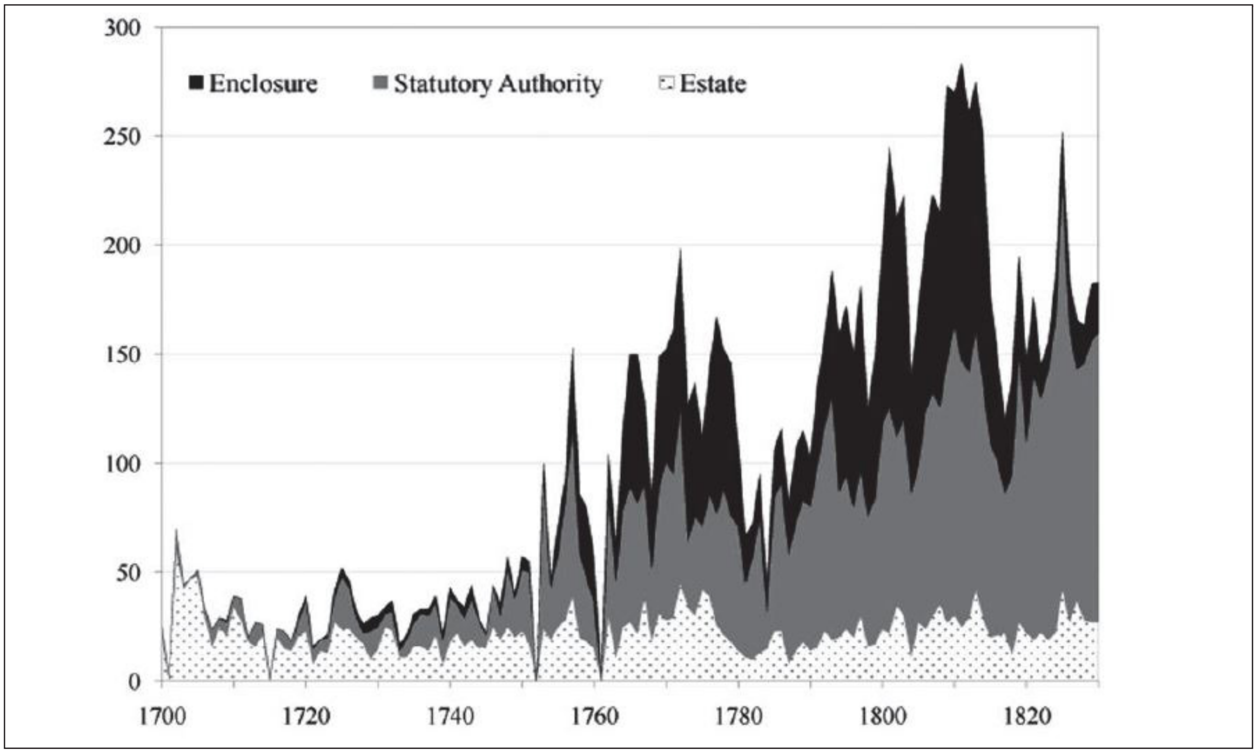
Instead we want to focus on the policy and institutional responses to these technological changes, in particular to what extent did these policies facilitate these economic changes or, at a minimum, ensure that they were not snuffed out. The question of why England was able to avoid having the Industrial Revolution prematurely extinguished is one of the most important lessons for today: What institutional factors, once growth begins, can prevent the elites from using "extractive economic institutions", in the language of Acemoglu and Robinson

(2012), to gather the fruits of growth for themselves and preventing broad-based prosperity from taking root? For England before the Industrial Revolution, there were any number of extractive economic institutions and exclusionary political institutions that fell short of modern institutions. One obvious example was the restriction on female participation in economic or political life. In many other ways, England had economic institutions generally considered to be favorable for economic growth in the ways the World Bank or IMF would define "good" institutions today. These included low tax rates, price stability, low public debt, secure property, and relatively competitive markets (Clark, 2007). England was not unique in this regard; Pomeranz (2000) argues that institutions in China were equally favorable for growth compared to those in England. So the important question for us is what, in an institutional sense, distinguished England from other countries. For us, the "institution" which most distinguished England is the flexibility it achieved in rule making. What made England different was not merely that it had institutions conducive to growth (Mokyr, 2009). More importantly, it possessed the "meta-institution" of Parliament, which was sufficiently strong to change the rules under which other institutions operated. This gave England a degree of flexibility crucial to responding to the challenges of the Industrial Revolution, as few institutions are suitable for growth under all possible circumstances and, by construction, institutions develop in relationship with *past* economic changes not in anticipation of future ones.

This flexibility is not easy to characterize as being "conservative" or "liberal" in the modern American political dichotomy. For example, since Coase (1960), economists have recognized that the presence of transaction costs can prevent private agents from reaching efficient allocations. The pre-Industrial economy was characterized by an outdated and inefficient system of allocating property rights. The meta-institution of flexibility, achieved through Parliamentary supremacy, allowed for a reallocation of property when technological circumstances rendered previous arrangements inefficient. Myriad property rights were reorganized by English authorities, including estate acts which eliminated restrictions on the uses of particular property and the more famous enclosure acts. As Bogart and Richardson (2011) argue, this process was not driven primarily by the desire of Parliament. Figure 1 taken from their work shows the large increase in the number of such acts during the period of the Industrial Revolution. Instead of driving the process themselves, Parliament responded elastically to demands of property rights holders for reorganization in a process that was "rapid, affordable, and consensual." Today we are often taught that secure rights are essential for developing countries if they want to grow (de Soto, 2000). However, while arbitrary changes in property rights are doubtless harmful, overly strong property rights can themselves be a constraint on growth. For example, Rosenthal (1992) argues that extensive litigation caused by overlapping rights prevented the draining and redevelopment of marshes in France before the Revolution.

We would emphasize that not all of these acts *weakened* individual property rights. In particular, the enclosure acts specifically *created* individual property rights by restricting what had been heretofore a public right to use commons as a pasture. Enclosure had a clear positive impact on the British economy. McCloskey (1975) among others estimates the net gain in 1770 to be around 1.5% of national income or 3.5% of agricultural income. At the same time, these gains were not equally shared. *Ex post* those who ending up owning the newly created property right won and those who no longer had access to the pasture lost, and it was not luck who ended up owning the newly enclosed farm. Thompson (1966) calls enclosure "a plain enough case of class robbery" with rich landowners using the state to expropriate the public lands from the local peasants. While this rather stark view of the distributional consequences of enclosure is not universally shared (Thompson, 1981), this case still stands as an example of how property rights reorganizations can lead to enriching those that already have economic and political power. These examples also highlight how the distributional effects

Figure 1
Number of Acts of Parliament Reorganizing Property Rights



Notes: This figure is taken from Bogart and Richardson (2011).

of industrial revolutions are not purely due to "economics," but, in some cases, the effects of policy choices themselves driven by economics.

Why was England able to "engage in local violations of property rights if these were considered necessary for the public good" (Mokyr, 2009, p.418)? And why did people believe that these were simply "local" violations? On the first question, the Glorious Revolution and Bill of Rights in 1689 encouraged additional legislative activity, and professional solicitors and clerks helped move petitions through Parliament. Combined with the political stability of the regime, this system allowed for the recombination of property rights in an efficient manner, from an expanding network of turnpike roads during the Lancashire cotton boom to the redevelopment of agricultural land on the London periphery to more efficient residential use. As for the second question, in some sense, people came to believe these were local violations because they were local and did not descend into whole scale expropriation. Some, such as North and Weingast (1989), have argued that credible commitment to uphold property rights in general can be traced back to the Glorious Revolution of 1688 and the controls it placed on the exercise of the arbitrary and confiscatory power of the Crown.

While these constitutional changes were surely important, we do not think this happy outcome was pre-ordained: Parliament could have buckled under the pressure of entrenched interests, as happened in countless other societies. The government of England could have responded to the difficulties of industrialization by trying to stop the changes taking place. Caprettini and Voth (2017) argue that the introduction of the threshing machine was responsible for political instability, showing that in areas with a higher rate of diffusion of this technology there was a higher probability of participation in the Swing riots. Importantly, the response to these developments was not a reactionary turn against modernity. Instead, the response was a broadening of political participation, or a move towards more "inclusive" institutions. Aidt and Franck (2015) show that the

Swing riots induced voters to vote for more reform-oriented politicians after experiencing the riots. The Great Reform Act of 1832 which followed these events was part of a transformation of the English political system. The act itself redistributed Parliamentary seats from the so-called “rotten boroughs” to growing industrial cities. It also extended the franchise by lowering property requirements. This evidence is consistent with a “threat of revolution” story of the extension of political power, though the authors are careful to acknowledge that this played a role in only one of several hurdles the reform bill had to pass. Other factors such as rivalry within the elite and bargaining between the King and Parliament also played a role.

A recurring theme in this essay is the necessity of building complementary investments to reap the benefits of technological innovations. As an example for the first Industrial Revolution, obviously steam power was a necessary prerequisite to building a railroad system, but there are many other complementary investments that are necessary to have a functioning system. Here, even though British railroads were financed by private individuals as opposed to the continental system of direct government financing and construction, Parliament played an active role in helping to enhance the value of the technology. One way to think about these interventions is that they were aimed at solving a coordination problem and, in particular, a holdup problem on the part of existing property owners. An example discussed in Mokyr (2009) is the development of the Railway Clearing House. This was set up by companies to compute the balance when shipping or personal transportation was conducted over multiple railroads. They also instituted a standard timekeeping system as well as other technical standards. To aid this scheme, the railroads themselves sought the passage of the Railway Clearing Act in 1850, which compelled members to be subject to the provisions of the law. The investment here was in organizational capital, rather than physical, but the point remains that without expending the effort to build this organization, the benefits of the development of the railroad would have been reduced. In other places, the role of the government was more direct. The United States federal government played an important role in developing railroad networks through its *allocation* of property rights (Mercer, 1982).

Another important role of the government was in providing social insurance under what is now known as the Old Poor Law, an early form of relief for the unemployed, and its amendment in 1834. While not the first instance of tax-based poor relief, this act in 1601 was the first public poor relief system that required all parishes to levy taxes to provide for their poor. It nicely illustrates how institutions designed in response to one set of circumstances and, in many cases, in response to temporary shocks end up with a whole new purpose as circumstances change. In particular, Slack (1995) argues that the Old Poor Law was born out of an unusually severe period of economic distress following the disastrous harvests of 1596 and 1597. By the 19th century, this law had come to serve as a means of dealing with a lagging agricultural sector (Blaug, 1964). Greif and Igiyum (2013) find that it was successful in reducing food riots up through most of the 18th century. This was a “passive” response to industrialization, as the law was developed under different economic circumstances.

Passive responses, however, were not enough, and eventually more active government responses to industrialization occurred. Following the Swing Riots of 1830, the Poor Law system came to be seen as fomenting social unrest and not up to the challenge of the technological changes taking place in the 19th century. In 1832, a Royal Commission was created to prepare a report on the system and propose possible reforms. They argued that the existing system was in fact undercutting wages of laborers through the “roundsmen” and Speenhamland systems, which were approaches that local parishes took to providing relief. Both systems served to provide a minimum level of subsistence to the pauper. The Speenhamland system functioned like a negative income tax with the level of relief aimed at maintaining a certain level of consumption. The Poor Law Commissioners’ Report of 1834 contained criticism of the system which showed considerable economic insight. Cast in the language of modern economics, it was that the this wage subsidy was captured by employers, not the workers it was aiming to help. This analysis in many ways echoes the argument made by Lee and Saez (2012) that wage subsidies and minimum wages are complementary policies. In light of the Commission's findings, the Poor Law Amendment Act of 1834, or what came to be known as the New Poor Law, attempted to ban so-called outdoor relief and require those needing to relief to enter a workhouse designed to be so dreadful as to discourage people from entering in the first place. This evolution nicely illustrates the contingent nature of policy evolution and is another example of the flexibility that the British Parliament brought to responding to the Industrial Revolution. The Old Poor Law is just one example of the fact that much of the institutional framework which allowed England to respond to technological changes existed long before the Industrial Revolution. The turnpike trusts created by Parliament over the 18th century resulted in large reductions in shipping costs and increased speed, along with increases in aggregate expenditure (Bogart, 2005). These trusts took over roads previously maintained by parishes and maintained them by charging tolls, while issuing mortgage debt. This contrasted with the parish roads, which were financed by property taxes and labor from residents, a system which led to widespread inadequacy in maintenance. Thus it was not a "response" to industrialization that England developed more flexible property rights. This emphasizes one of our broader points that institutional responses are improvisational with pre-existing sets of rules and policies being shoehorned into situations they were never designed to handle.

To be sure, the policy responses were not perfect. The government failed in addressing the coordination problem involved in the production of pollution through the use of coal. The negative externalities associated with this pollution slowed down economic development itself. For example, Hanlon (2016) finds that the externalities of coal smoke were so severe that plausible increases in coal use efficiency through some form of pollution regulation could have led to substantially higher rates of urbanization. This is despite the fact that Parliament commissioned the 1871 Coal Commission Report, which was a detailed study of coal use that highlighted precisely these inefficiencies and simple low-cost improvements. In addition, at least as far back as the Statute of Labourers of 1351 following the Black Death, political forces in England have responded to increases in wages with regulations which decreased the bargaining power of workers. During the Industrial Revolution, some of these changes took the form of increased use of the Master and Servant Laws, which made breaching an employment contract a criminal offense until 1875. Naidu and Yuchtman (2013) show that positive shocks in the textile, iron, and coal industries increased prosecutions under this law, and that wages rose in counties which had previously experienced high rates of prosecution after the law was abolished. Here, the English system responded negatively to industrial changes.

Whether good or bad, what all of these policy responses of the British state at this time underline is its "capacity" to act. Dincecco (2017) thinks of this state capacity as the ability of the government to raise funds through taxation. In fact, Dincecco and Katz (2016) find that fiscal centralization, the introduction of uniform systems of taxation at the local level, were associated with significantly higher rates of growth in the 19th century. They also find that "limited government", defined as national parliaments with an ability to monitor state expenditures, had a limited direct effect, but an important interaction with fiscal centralization. It is certainly the case that Britain at this time would look capable along this dimension. Indeed, the English were taxed at higher rates than anyone in the world other than the the Dutch (Mokyr, 2009). But what these examples show is that state capacity is much more than being able to raise funds to pay for public goods, be they military protection or building a railroad network. State capacity is an ability to reorganize local property rights for the public good (Mokyr, 2009).

III The Second Industrial Revolution and the "Great Leap Forward"

The Second Industrial Revolution is usually dated from about 1870 to the the early 20th century, the time from the end of the American Civil War to the start of World War I. This was a period of major technical advances in any number of areas: steel, iron, rail, electricity, communications, petroleum, internal combustion engines, rubber, and fertilizer (Landes, 1969). In terms of economic changes, the Second Industrial Revolution was more wide reaching than the first. As Gordon (2016) notes, it covered "virtually the entire span of human wants and needs, including food, clothing, housing, transportation, entertainment, communication, information, health, medicine, and working conditions." Though such things are difficult to measure with any precision, Smil (2005) suggests that this period was the era with the fastest growth in technological knowledge in history.

We include in this discussion the 1930s, which, though usually not considered part of the Second Industrial Revolution was also a period of rapid technological change, a "Great Leap Forward" as Field (2012) calls it. In fact, based on examining productivity growth rates, Field (2003, p. 1399) argues that the period from 1929 to 1941 was "the most technologically progressive of any comparable period in U.S. economic history." Field goes much further, examining in the detail the technical changes in particular industries and sectors. To give one example, major advances in chemical engineering during this period led to the creation of Lucite, Teflon, and Nylon, all very important materials for clothing and other fabrics. Unlike the First Industrial Revolution, which was in many ways concentrated in a single industry, textiles, the Depression saw advances not just in manufacturing (Bernstein, 1987) but in communications, utilities, and transportation.

The Second Industrial Revolution and the "Great Leap Forward," like many other technological transitions, was characterized by long lags between the invention and implementation of the new technologies. Even though many of the inventions that came to define the Second Industrial Revolution go back to the late 19th century, Figure 1, taken from Crafts (2002), shows that it was not until the 1920s and 1930s that the economy began to experience rapid productivity growth based on these inventions. The fastest productivity growth for the U.S. did not occur until the period of 1940 to 1970, largely as a spinoff of the technologies of the Second Industrial Revolution (Gordon, 2016). The same delay is true for the "Great Leap Forward." Field claims that, while these advances were not necessarily felt or appreciated during the Great Depression, they were crucial for the economic miracle of WWII and the post-war economy. This experience illustrates the lags in actually implementing new technological breakthroughs.

An under-appreciated aspect of this revolution was the remarkable numbers of people that left the farm and moved to the city. This was due as much to the "push" of the mechanization of agricultural labor as the "pull" of new jobs in manufacturing. When Abraham Lincoln took office, approximately 16% of the population was living in an urban area. This percentage had more than doubled by 1900, rising to nearly 40% (Sutch and Carter et al. (2006)). Despite this migration, there was little evidence of technologically-induced unemployment *per se* even if it was a subject of public concern. Most prominent economists at the time, such as Wells (1889) and Hadley (1896), dismissed worries about technological unemployment. Besides effects on the aggregate economy, these technological changes also had at least two important distributional changes. First, one of the largest economic problems created by the Second Industrial Revolution was an increase in inequality. As noted above, the First Industrial Revolution was also associated with increasing inequality, but this process seems to have accelerated with the Second Industrial Revolution. Based on U.S. federal tax records, the share of income going to the top 10% peaked in 1929 (Piketty and Saez, 2003). One dimension along which inequality increased during the first part of the 20th century was skill as proxied for by education. The ratio of high skilled to low skilled earnings peaked right on the eve of the Depression. This compression

Table 1
Contributions of Electricity to U.S. GDP Growth

	1899-1929	1919-29
Electrical Machinery Industry TFP Growth	1.5	3.5
Output Share[a]	0.8	0.8
Electrical Machinery TFP Contribution	***0.01***	***0.03***
Electric Utilites Capital Stock Growth	8.8	7.4
Income Share[a]	2.4	2.4
Electric Utilities Capital Contribution	***0.21***	***0.18***
Electric Utilities TFP Growth	5.3	2.4
Output Share[a]	0.9	0.9
Electric Utilities TFP Contribution	***0.05***	***0.02***
Electrical Capital Goods Stock Growth	15.2	8.0
Income Share[a]	0.6	0.6
TFP Growth Spillover	0.2	0.7
Electrical CapitalGoods Contribution	***0.29***	***0.75***
Total Electricity Contribution	***0.56***	***0.98***
(as % GDP/Person growth)	***(28.2)***	***(47.0)***

Notes: Numbers are in percentage points per year. This table is taken from Crafts (2002).

in the skill premium accelerated in World War II, resulting in the most equal income distribution in recorded American history (Goldin and Margo, 1992).

Now the quantitative relevance of various factors in explaining changes in inequality is still debated, with some such as Goldin and Katz (2009) arguing for supply-and-demand induced changes in the skill premium, and others pointing to changes in unionization, the minimum wage, or other institutions. We think it is quite clear that the nature of the technologies here played an important role in changing the returns to skill in the first part of the 20th century. Similar to the ICT Revolution that we discuss later, many innovations of this period increased the relative demand for high skilled labor. As an example, Chin et al. (2006) show that the introduction of the steam engine in the merchant shipping industry resulted in a widening of the wage distribution in the industry, as able-bodied seaman were replaced by unskilled operatives and the demand for skilled workers, specifically engineers, increased. They find that switching from all sail to all steam would have increased the wage ratio by 40%. Gray (2013) finds that electrification was associated with a "hollowing out" of the skill distribution of employment. In a study of the concrete industry during the Depression, Morin (2013) shows that decreases in the price of electricity caused a decrease in the labor share.

As we see in all industrial revolutions, the government response to these changes depended on the technologies themselves. A characteristic feature of the technologies of the Second Industrial Revolution, far more so than the first, was that they generated large returns to scale in production (Mokyr, 1998). Some of these economies of scale were physical, as in for example the chemical industry, where the cost of capacity, its surface area, was proportional to the square, while the volume of output was proportional to the cube. Other sources of these returns to scale were organizational, such as taking advantage of the increased availability of interchangeable parts. The consequences of this increasing returns to scale included the increasing dominance of a small number of very large firms in key industries. This move towards concentration culminated in a wave of mergers in the last decade of the nineteenth century and the first part of the twentieth (Lamoreaux, 1985).

As a result of this concentration, the relationships between business, labor, and government changed in many ways. First of all, this period saw the rise of government action to restrain monopoly power, a major change in the relationship between government and business. These changes occurred because of the nature of the industries generated by these new technologies and included numerous pieces of legislation: the Sherman Antitrust Act of 1890; the Clayton Antitrust Act of 1914; the Federal Trade Commission Act of 1914; and the Robinson-Patman Act of 1936. Actual enforcement action itself reached its apotheosis in the case of *Standard Oil* of 1911 in which the Supreme Court held that this company was guilty of monopolizing behavior and required breaking up the company. All of this served to limit the scope of a company's "property rights" and what types of actions that could engage in.

This period also saw a sea change in the relationship between labor and the government with the rise of unions. Unions began to form organically in the mid 19th century in response to the rise of big business during this period. In 1842, *Commonwealth vs. Hunt* found for the first time that unions were legal. In the latter part of the 19th century, businesses actually used the Sherman Antitrust Act, which prohibited "[e]very contract, combination in the form of trust or otherwise, or conspiracy, in restraint of trade or commerce among the several States," to get court injunctions barring unions from striking. The first case of this strategy was the Pullman Strike of 1894 and, though the injunction was ignored by the union leader Eugene Debs, it set the stage for a number of additional cases using the Sherman Act in this way. While the Clayton act exempted unions from these antitrust prohibitions, it was not until the Norris-La Guardia Act of 1932 that courts were barred from issuing injunctions against strikes. In addition to these laws that protected union work stoppages, other pieces of New Deal legislation such as the National Industrial Recovery Act explicitly encouraged collective bargaining. Following this, unionization increased to its maximum level during World War II (Freeman, 1998). The Depression also laid the framework other important parts of the relationship between business and labor over the next 50 years. For example, the development of the forty-hour workweek was greatly stimulated by the "work-sharing" provisions of the National Industrial Recovery Act (NIRA) and the Fair Labor Standards Act of 1938.

Besides these revisions to the relationship between business, labor, and government, the period also saw changes in the relationship between the government and the individual. These changes were driven by political pressure to respond to a period of seemingly never ending period of high unemployment in the form of Great Depression, a period of time when the U.S. became a "temporarily underdeveloped country." While in hindsight the unemployment problem of the Depression was clearly cyclical and not structural, at the time solving the apparent problem of technological unemployment stimulated discussion as to the proper role of government, which crystallized in the New Deal and particularly the second New Deal.

Like in the First Industrial Revolution, government action played an important role in shaping the Second Industrial Revolution. One way in which policy during this period differed from the First Industrial Revolution was a much more active role in funding the complementary investments necessary for the new technologies to be fully realized. For example, roads were not build with private funds, but rather from the public purse. The period also saw major public investments in sanitation and sewage that took advantage of the advances in electricity (Cutler and Miller, 2005). It is true that private funds were used to build much of the infrastructure associated with the Second Industrial Revolution, often including electrical utilities, telephone networks, and public transportation. However, even in these cases there was substantial government involvement, more so than with the new industries spawned with the First Industrial Revolution. In many cases, the affected industries eventually came to be run directly by the government, as private but heavily regulated monopolies such as AT&T, or be subject to stringent regulation.

So how should we assess the overall performance of political institutions in the United States in response to the Second Industrial Revolution and the "Great Leap Forward"? Total factor productivity in the United States did grow at its fastest rate in history from 1920 to 1970 (Gordon, 2016). It is more subjective when "living standards" grew at their fastest rate, but these too arguably increased faster in this period than any other in history. In some respects, then, policy has little for which to apologize. As Scheidel (2017) shows, throughout history a move towards less inequality has almost always been brought about by severe crises such as revolution or state collapse. So the fact that the U.S., at least, was able to reduce inequality following the Great Depression without any of these terrible things seems like a great success. Despite this, we argue that the response to the challenges of the Second Industrial Revolution was not some well planned approach and instead ended up being a response to a crisis, the Great Depression, which was only tangentially related to the technological changes themselves. This fact should make us somewhat pessimistic about a possibility of responding to, for example, an increase in inequality coming from increased automation.

In keeping with the recurring theme of the highly improvisational nature of the responses to technological revolutions, think of the New Deal. We often think of this as mainly aimed at addressing cyclical problems exacerbated by the Depression, such as deposit insurance through the Federal Deposit Insurance Corporation. The fact is that the New Deal was much more than that, and, though we often look to the War on Poverty as the crucial turning point in the role the government had in eradicating poverty, it was really a change in degree rather than kind from polices started in the New Deal. Perhaps the most important piece of legislation in the whole New Deal was the Society Security Act of 1935, which ushered in for the first time a federal government-run income support program. It is true that this act was not created ex nihilo but rather built on similar programs at the state level. A key part of the Social Security Act is in providing funds for the elderly, but the provisions were much broader than that including unemployment relief as well as relief for handicapped and children without fathers. The response to structural change, then, was to a large degree improvised during a cyclical crisis.

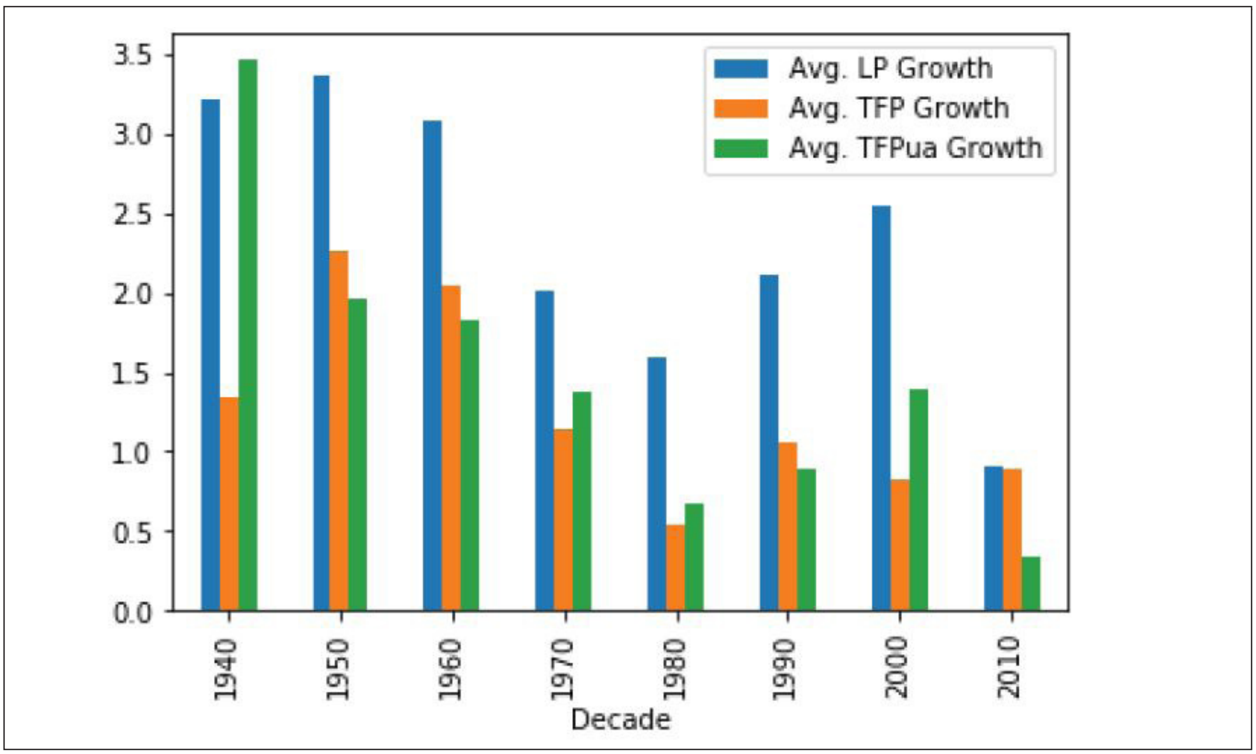
The other obvious way for governments to affect redistribution is through direct taxation, particularly wealth or income taxation. While this is surely an important lever today, its historical role as a response to *technological change* is basically nonexistent. The first income taxes introduced in the United States and United Kingdom, respectively, were in response to demands for war funding and variation in the revenue raised by these governments at least up to WWII was mainly driven by these external pressures. Our point is not to argue that taxation had no effect on income inequality. It is rather that policymakers only recently began to view this as a politically feasible response. To simplify drastically, arguments over taxes before the post-war period were about how to raise a certain amount of revenue. They were not about engineering the tax system to achieve a certain distribution of income. In 1910, the federal government raised only 2.0% of GDP through taxation (Schuyler, 2014), and the bulk of this was through tariffs and excise taxes, inherently regressive forms of taxation. Only after the World Wars, and particularly World War II, did redistribution play a pivotal role.

IV The Information and Communications Technology Revolution

The most recent technological revolution, which depending on how one defines the revolution may have already concluded, is what is known as the information and communication technologies (ICT) revolution, roughly from 1980 to 2000. These changes involved a set of connected advances associated with the rise of the computer and the first wave of internet technologies. At their core, all of these technologies rely on the transistor and the ability to represent information as a sequences of ones and zeros.

The most remarkable economic fact about the ICT revolution was famously summed up in a quip by Robert Solow: "You can see the computer age everywhere except for the productivity statistics." Solow was an academic, so he saw all around him changes engendered by these technological advances. Pools of secretaries hired to type up professors' papers were let go or retired, lost to the rise of the personal computer and word processor. Communications that used to take place over the telephone were replaced by email. Rather than having to be mailed to journals for submission, manuscripts could instead be uploaded instantly through a website. Yet Solow seemed to remain skeptical about what all of this amounted to, and the statistics supported him. For example, Baily and Gordon (1988) found that over the period 1979 to 1987, productivity in the non-electrical machinery industry, which includes computer production, rose at nearly 12% per year. Yet during this period of time, the U.S. economy experienced aggregate productivity growth more than 1.5 percentage points lower than during 1948-1973. Figure 2 shows that, in fact, the 70s and 80s were the worst period for productivity growth in the U.S. during the 20th century. Private-sector nonfarm labor productivity growth did recover somewhat in the 1990s, averaging around 2.2% per year, close to the historical average. In fact, some took to calling this acceleration in productivity a "miracle" (Bloom et al., 2012). Since then, except for the first couple years of the 2000s and two years in the Great Recession, annual productivity growth has never gotten above 2%. This slowdown is not unique to the United States. On the contrary, Europe appears to have fallen further behind the U.S. in terms of labor productivity during this period.

Figure 2
U.S. Productivity Growth During the 20th Century



Notes: This figure is taken from Bynjolfsson et al. (2017).

This disconnect between apparently rapid technological change and slow aggregate productivity growth sparked a long literature debating whether this was some artifact and, if it was not, what explained the disconnect. Triplett (1999) provides a useful summary of many of the proposed solutions. For us, what is most interesting is the set of explanations which reached for historical parallels. David (1991) likened the computer to the electrical dynamo, arguing that just like it took time for electricity to revolutionize the economy, the same is the case for the computer and ICT. Crafts (2002), drawing on historical quantitative evidence, suggested that there was no reason to expect rapid productivity so quickly after the introduction and adoption of these technologies. In the end, the consensus seemed to be just wait and the productivity growth will come.

The problem with this plea for patience is that the ICT Revolution may now be essentially over. Marshaling a wide range of historical sources and examples, Gordon (2016) builds this case, and moreover concludes the ICT Revolution was a bust compared to previous revolutions. He documents a number of areas in which productivity has actually seemed to regress, such as the speed of travel. As he points out, many one-time-only conversions from analog to digital have come and gone. No longer are there wooden cabinets holding card catalogs at libraries. Mechanical calculators have been completely replaced. There are barcodes on everything. We do not claim that these technologies cannot be improved further, as anyone who has ever used a university library's website to try to find a source will surely attest to. In fact, many of the "new" technological changes that we discuss later are precisely about making these digital records more useful. The problem is still why did these initial transitions seem to not make any difference in measured living standards.

Assuming the ICT Revolution is complete, its effects on living standards pale in comparison to the previous two. GDP per capita in the U.S. has advanced much more slowly during this revolution than in previous ones (Gordon, 2016). Some have argued that GDP mismeasures the value of many of services associated with the ICT Revolution, as well as those in current technological changes, because the services are "free." As we discuss later, even under the most rosy scenarios in valuing these "free" products, they can come nowhere close to making up for the "lost" output due to slow productivity growth. The thing is that this disconnect between GDP and value or living standards is not something unique or even most applicable to the current economy. People enjoyed "free" services in watching television, and yet economists in the 1950s did not worry about all of this missing GDP.

Given these pessimistic conclusions about the effects of these technologies, why do we even talk about the ICT Revolution as a revolution? For us, it is because the ICT Revolution represents a shift towards a certain *type* of technological progress. Economists going all the way back to Solow (1957) have often modeled technological progress as raising the marginal productivity of *all* factors of production, so-called Hicks neutral technical change. This type of technological change has the implication that the optimal ratio of inputs only depends on the relative price of the factors of production and not on the level of technology. One way to think about the ICT Revolution is that it has changed this optimal ratio of input use for any level of the input price ratio and shifted demand towards skilled workers and capital (Krusell et al., 2000). More precisely, what is unique about this period of time is the set of *tasks* that computers substitute for. Autor et al. (2003) draws it out as a difference between computer capital *substituting* for workers "carrying out a limited and well-defined set of cognitive and manual activities, those that can be accomplished by following explicit rules", or "routine tasks", and computer capital *complementing* "workers in carrying out problem-solving and complex communication activities", or "nonroutine tasks". This dichotomy has had important effects on the labor market, as these "routine, non-manual" jobs have disappeared and the labor market has become "polarized" (Autor and Dorn, 2013).

We would argue that part of what has made the ICT Revolution seem so jarring is that these changes in the labor market have happened at the same time as a sharp increase in globalization and world trade. Like the skill biased technological change of today, globalization is nothing particularly new in history. For example, the period roughly overlapping with the Second Industrial Revolution is usually regarded as a period of globalization akin to the current period (O'Rourke and Williamson, 1999). However, the pattern of trade seems different today than in the first wave of globalization. This first wave involved an "invasion of grains from the New World" (O'Rourke and Williamson, 1994), which led to a convergence in real wages across countries. In a parallel fashion, there is an "invasion" of manufactured goods and a convergence of living standards between developing and developed countries. Still, the scale of these wage differences are quite different. Chinese GDP per capita in 2016 at PPP is still only about 15% of U.S. GDP per capita. This is even after the last twenty years of very rapid Chinese growth. In the first wave, U.S. wages were "only" about 2/3 higher than the British wages (O'Rourke and Williamson, 1994). In addition, the factor content of trade has shifted away from being land intensive in the form of foodstuffs in the first wave to being much more unskilled labor intensive today.

This shift in the factor content in trade, combined with the fact that the most recent wave of globalization has not coincided with a rapid development in manufacturing for Western countries, has led to an "unmasking" of the distributional effects of trade. In a very influential article, Autor et al. (2013) argue that Chinese imports have depressed local labor markets in the U.S. exposed to this trade while not leading to an offsetting increase in employment elsewhere. Perhaps most striking is the persistence of these negative effects on particular regions, with wages and employment remaining depressed even after a decade. At a global level, these changes in technology and globalization have led to a situation where the top and bottom percentiles of the world income distribution have seen dramatic increases in real income between 1988 and 2008 (Milanovic, 2016). The bottom and upper middle (the middle class of the developed world) percentiles have seen basically no real income growth over this period. At least in the early 2000s, there was a housing boom and sharp increase in construction employment in the U.S. that "hid" these structural changes (Charles et al., 2016). We know how that ended.

Government investment was a crucial component of the ICT revolution just as in earlier ones. In contrast to the earlier period, however, direct funding of research by the government played a prominent role in developing the technologies themselves. In 1950, research funding for computing from the government exceeded that of industry by a factor of three (NRC, 1999). Much of the infrastructure of the internet evolved from government programs such as ARPANET. These investments were clearly complementary to the later booming private sector investments in ICT. Massive infrastructure spending came from the private sector in building out telecommunication and fiber optic networks. Mazzucato (2015) goes further, arguing that the Untied States government during this period did not just simply fix market failures but actively created new market opportunities. She is right to highlight the number of ways the U.S. federal government has spurred innovation and to push back against a narrative of purely private sector driven innovation. This is a strong argument for spending on government supported scientific research. The argument that the government take a more active role in directing innovation is weaker. As Westlake (2014) notes, the most entrepreneurial states generally fund research with unrestricted grants, and it is far from clear that this model, funded by normal taxation, is inferior to a national "innovation fund". Indeed, the successes of government funded research in the past rarely involved the government taking an equity share in innovative activity, and it is not clear why this should change with AI or automation. Even if the effects from the ICT Revolution on the aggregate economy have been limited, it seems clear that these technological changes along with the rise of globalization have had profound implications on the distribution of income across the globe and, particularly, the distribution within western countries. One might have imagined that these changes would have sparked major policy responses to soften the blow on the most affected workers. Instead, on globalization and trade, policy makers in many western countries have seemed unwilling to reconsider the costs and benefits of the current global trading system. They have doubled down on globalization in the form of proposals such as the Trans-Pacific Partnership.

The policy response to the ICT revolution has then been quite muted. One often-suggested responses to these changes is increasing educational attainment. This "race" between education and technology has been going on since the 19th century (Goldin and Katz, 2009). What is particularly strange about this period of time that has seen rising demand for skill is that there has been no concordant rise in the *supply* of skill. In fact, Card and Lemieux (2001) document a slowdown in rate of growth of educational attainment for cohorts born in the 1950s in the United Stakes, United Kingdom, and Canada. While it is no doubt difficult to raise educational attainment, it has been the case through U.S. history that both the federal and state governments have seen the importance of education and acted accordingly. The G.I. Bill following WWII dramatically expanded educational attainment and particularly college enrollment (Bound and Turner, 2002). Going back to the 19th century, the U.S. states were leaders in the high school movement (Goldin, 1998). If anything, the U.S. during this period of time has seen a retreat on the part of governments in funding higher education. State funding of universities has declined by 30% since the 1970s (Archibald and Feldman, 2006).

There has been some passive response to the ICT revolution. Consider the social security disability program mentioned above. Legislators at the time could have hardly predicted that the component of relief for handicapped would turn into the *de facto* most important program the U.S. federal government has for responding to structural unemployment today. Between 1985 and 2014, the fraction of the U.S. population collecting these Social Security Disability Insurance benefits has more than doubled, from 2.2% to 4.8% (Social Security Administration, 2014). Autor and Duggan (2003), while noting the importance of changes in the replacement formula as well as liberalization in eligibility, also estimate that a 1 percent state log employment contraction yielded 1.3 additional disability applications per 1000 nonelderly residents. The relationship between employment changes and disability applications is over nine times stronger in the five year period between 1993 to 1998, versus the earliest five year period in this study between 1979 to 1984.

We would consider the transition in response to the ICT Revolution as overall a failure. Part of this failure is due to policy inaction. At the same time, the role of luck should not be underestimated. We have previously argued that overall the transitions in the First and Second Industrial Revolutions did not seem to be associated with large increases in unemployment. Some, such as Bernstein (1987), have argued that there was a failed transition in the Great Depression in response to the continued technological progress of the 1920s and early 1930s. Based on this admittedly small sample of data points, what seems crucial for a successful transition is the existence of a "booming" sector to absorb the surplus labor at least in the short-run. Manufacturing played that role in the First and Second Industrial Revolutions and failed to play that role in the Depression. The construction industry, particularly home building, actually played this role before the Great Recession. Having a booming manufacturing or construction sectors in these two periods was not some explicit policy. Instead it was luck that these were growing rapidly at just the right time.

V Lessons for the Age of Artificial Intelligence

The Current Period of Technological Change

This brings out us to the current period of rapid technological change and the perennial question "Is this time different?" It is easy to think this with stories of cars driving themselves and computers being able to abstract the concept of "cat" from thousands of images. As historians, we are taught to push back on this and emphasize the continuities and echoes of the past. So it is worth recalling that such claims regarding the radically different nature of a certain period have been made repeatedly in the past. For example, 20 years ago, Rifkin (1995) described the spread of technology as "[l]ike a deadly epidemic inexorably working its way through the marketplace, the strange, seemingly inexplicable new economic disease spreads, destroying lives and destabilizing whole communities in its wake" (p. 3) and cited approvingly a union leader who predicted that within thirty years, as little as 2 percent of the world's current labor force "will be needed to produce all the goods necessary for total demand" (p.8). Apparently, this has not come to pass (yet).

Since Schumpeter (1942), economists have distinguished between *process innovations*, which tend to result in less employment, and *product innovations*, the development of entirely new products which tend to increase employment. Pianta (2004) shows that which of these has been more important has varied across time and space. Luckily, in the past, breakthroughs like electricity, while serving as a process innovation, have also been the source of numerous product innovations. Nineteenth century economists such as David Ricardo or James Steuart who worried about technological unemployment could scarcely have imagined the new jobs of today such as "social media managers" or "cyber security specialists." The fact of the matter is that it is always much easier to imagine all of the current jobs that might be destroyed by a new innovation (think of drives of all sorts of vehicles and autonomous vehicles) than it is to imagine new jobs. It is tempting to conclude that relative to past major breakthroughs, AI will result in relatively more process innovation and relatively less product innovation. Grace et al. (2018) report results from a survey of AI experts who think by 2053, even AI will be able to outperform human surgeons. These experts put a 50% chance of AI being able to automate all human jobs within 120 years.

At the same time, history cautions against us thinking that perhaps technological change and many of these ballyhooed breakthroughs in artificial intelligence are overblown. The question of whether sustained progress, technological or otherwise, is possible has deep roots stretching back to Classical Antiquity. Nisbet (1980) in his book *History of the Idea of Progress* argued that the ancients were the first to ascribe to the "Idea of Progress," the claim that improvement in the moral and economic lot of man was possible. This optimism continues through the Romans particularly in Lucretius' *De Rerum Natura*, where he sketches out perhaps the earliest evolutionary account of the universe starting from atoms in the void. Yet many classical economists of the early 19th century thought about technology in a way close to Lord Kelvin's view about science that "our future discoveries must be looked for in the sixth place of decimals." It was not that these thinkers thought that no progress was possible. Rather, when it came to economics, the key question was one of distribution. Mill (1848) writing about the "stationary state" in his *Principles of Political Economy* (Book IV, Chapter VI) claimed "It is only in the backward countries of the world that increased production is still an important object; in those most advanced, what is economically needed is a better distribution." Apparently, this has not come to pass either.

So bold predictions, both optimistic and pessimistic, about how this time is different are nothing new. Instead what we think is different about the current period of technological change, particularly for many western countries, is a bit of cognitive dissonance over whether technological change is actually too fast or too slow. It is certainly the case that all of these breakthroughs in machine learning and artificial intelligence have not translated into much by way of rapid output growth, let alone employment growth. Instead, Solow's 1987 quip about "seeing the computer age everywhere but in the productivity statistics" seems to apply *a fortiori* to today, just replace "computer" with "big data." The years since the Great Recession have witnessed economic, investment, and employment growth slow by historical standards, especially following a very sharp recession. In fact, Fernald (2014) finds that this slowdown started even before the Great Recession.

This disconnect between "perceived" rapid technological change and slow economic and productivity growth has led to a whole cottage industry of authors attempting to argue that GDP, our usual measure of economic growth, has been drastically underestimating the value of "free" products such as Google, email, or Facebook. It does seem clear that these services have real value given that people are willing to spend their scarce leisure time using them. The question is how to quantify that value. Goolsbee and Klenow (2006), in a very optimistic calculation, estimate that these free services are worth 3% of total income. But even if we added this (upper bound on the) value, or consumer surplus, back into GDP, at best this could explain 1/3 of the missing $3 trillion in lost GDP from slow productivity growth over the last decade (Syverson, 2017). In casting further doubt on this "mismeasurement" hypothesis, Syverson points out that this calculation implies that if this surplus would have been captured as value added, the real value added of the industries that produce these services (computer and electronic products manufacturing, the entire information sector, and computer systems design and related services) would have growth by over 190 percent between 2004 and 2015, more than triple the observed rate. To put it one other way, "these digital-technology industries accounted for only 7.7 percent of GDP in 2004. A full accounting of the productivity slowdown by the mismeasurement hypothesis requires this modest share of economic activity to account for lost incremental output that in 2015 is about 17 percent of GDP–over twice the 2004 size of the entire sector" (Syverson, 2017, pg. 180). The point we would make is that this disconnect between purported technological change and living standards is not something unique to today. Today it is an "underpricing" with regards to the free services available online. In the First Industrial Revolution, it was an "overpricing" of the gains from the shift to the factory system by not considering the pitiful working conditions.

If mismeasurement does not explain this disconnect, what does? Brynjolfsson et al. (2017) lay out three possible explanations for this paradox: false hopes, redistribution, and implementation lags. They highlight a number of impressive achievement in artificial intelligence involving what we usually think of as very human tasks. Algorithms trained using neural networks can now in many cases attain error rates as good as humans when it comes to translating words or labeling images. Google's AlphaGo summarily beat the best human player in Go just recently. These achievements make these authors doubtful that these are "false hopes." As for the distribution explanation, it argues that the benefits of these new technologies accrue to a very small fraction of the economy. This is true when it comes to who reaps the financial returns and who enjoys the products. For example, revenue generated per worker at Apple is nearly double than that at Ford. It also seems true if we think about the consumers that benefit from these products. There is a clear digital divide in access to broadband. In 2016, almost 40% of rural areas lacked access to broadband as defined by the FCC, compared to only 4% for urban areas (West and Karsten, 2016). In addition, many of the problems apps are designed to solve hardly seem like problems or seem to benefit a limited slice of the population (Arieff, 2016). Being able to get a reservation at the push of the button is not of major to concern in people in rural areas. Or as famously summed up by Peter Thiel, "We wanted flying cars, instead we got 140 characters."

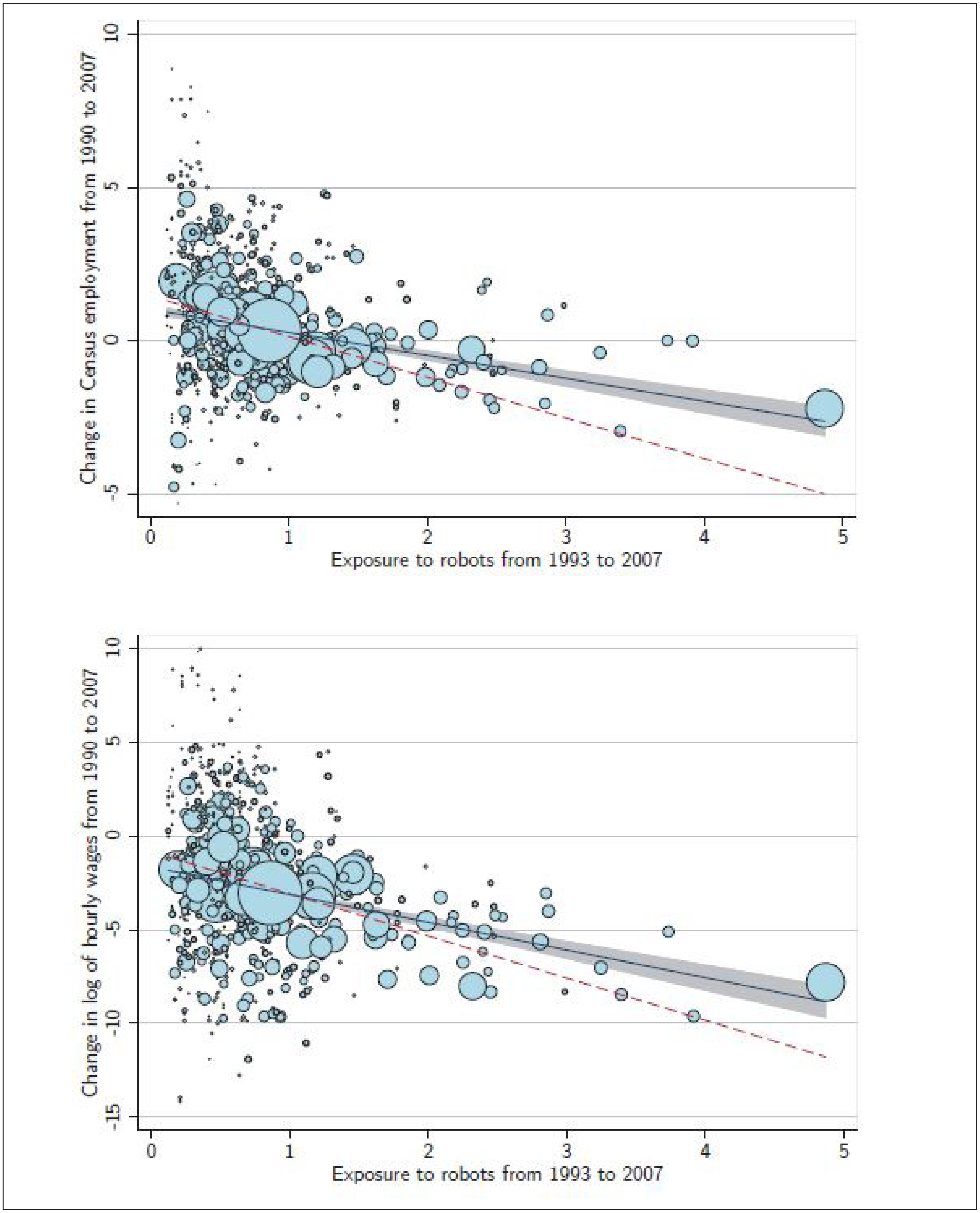
A distributional explanation undoubtedly could go far in explaining the sharp rise in inequality in western countries over the last 30 years. It would also be a promising explanation for the worldwide decline in the labor share of income (Karabarbounis and Neiman, 2013). However, that fact alone would not explain the productivity paradox. Instead this explanation is paired with a claim that many of these frontier technologies are close to zero sum activities. For example, even if we think about the advances in the trading of equities through in the form of high frequency trading, this seems like an activity with very little social return while the individual returns might be enormous. In this case with fixed costs to enter and a winner take all structure, there can be inefficiently high levels of entry (Mankiw and Whinston, 1986). We are a bit more sympathetic to this explanation of recent experience than Brynjolfsson et al., though this does not mean it will still be true going forward. It is always dangerous to simply extrapolate from current trends, but unlike past periods of technological innovation, it does seem frighteningly plausible that this time will be different when it comes to the distributional consequences of these technologies. We could imagine an economy in the not too distant future (20 years?) with large sections of the labor market "hollowed out," in the Katz and Margo (2013) terminology. A common pattern in recent years is that routine tasks with little unpredictable variability are more likely to be mechanized, while jobs that require continuous adjustment to new information and new physical settings along with fine sensory motor-coordination have not been. Many middle-skill jobs, both in manufacturing plants and in offices, have tended to fit into this former category. In this way, we are already seeing some of this labor-saving technology affecting the supply-side of the lower-skilled labor force (Jaimovich and Siu, 2014; Charles et al., 2017). More recently, Acemoglu and Restrepo (2017b) have provided evidence as shown in Figure 4 that at the local labor market level that increases in the use of production robots lead to declines in employment and wages. Some scholars, such as Beaudry et al. (2013), have gone even further and already called a peak in demand for high-skilled workers and cognitive tasks around the year 2000.

These changes in the labor market have had distributional effects on the time use of individuals affected by technological change. Using United States data, Aguiar and Hurst (2007) show that people with less than a high school education increased their leisure by almost 10 hours per week from 1965 to 2003 (dominated by an increase in television watching) while college graduates increased by less than one hour per week (with an increase in television watching offset by a large decline in socializing.) Aguiar et al. (2017) argue that at least part of the decline in hours worked for those with less than a high school degree is due to "leisure luxuries" in the form of video games. At least part of this widening inequality in leisure is driven by the highest-skilled workers increasing their work effort, but it is also driven by outright declines in work for lower skill workers. This is reflected not just in relatively high unemployment rates for those with just a high school degree (5.2% vs. 2.7% for those with a bachelor's degree as of 2016). It is also reflected in the 17 percentage point difference in labor participation rates between these groups. As a 2014 article in *The Economist* noted, "the workers who are now working the longest hours also happen to be among the most educated and best paid. The so-called leisure class has never been more harried."

In the end, Brynjolfsson et al. (2017) fall back on the claim that it takes time for new technologies to be implemented as the explanation for the disconnect between technological and economic advances. This surely seems right. For example, the basic idea of a neural network can be traced all the way back to the father of artificial intelligence, Marvin Minsky, in the 1960s, and the key innovation in implementing these, the back-propagation algorithm, goes back to the mid 1980s. However, it has only been recently that these breakthroughs have been implemented through developments of complementary technologies, particularly cloud based computing and cheap GPUs as well as the availability of large datasets that these algorithms can be trained on. The same development of complementary technologies happened for other GPTs such as electricity which required developments in technologies to transmit power, for example. Even by 1919, over half of US manufacturing establishments did not use electricity (David, 1991) and the biggest gains from electricity did not necessarily come from the direct cost savings from switching to electricity but rather the reorganization of production that is possible with electricity. Using a frictionless neoclassical model, Atkeson and Kehoe (1997) find that it can take 5 to 7 years following a major reform or productivity breakthrough for output to actually increase. Perhaps then we need to just wait.

Unfortunately, economic theory does not provide much guidance as to the long-run effects of these technological changes, particularly the effect of automation on labor demand. Going back to the early 20th century, Wicksell (1901) argued, in a pure neoclassical model, that technological progress could either lower or raise the marginal product of labor, and thus wages, depending on whether the technology was labor saving or

Figure 3
Effects of Robot Exposure on Wages and Employment



Notes: This figure is taken from Acemoglu and Restrepo (2017b).

augmenting. Wicksell concluded, “the capitalist saver is thus, fundamentally, the friend of labour, though the technical inventor is not infrequently its enemy.” However, he was careful to distinguish possible short-run deleterious effects from long-run outcomes. In a historical reflection, Wicksell (p. 164) wrote, “[T]he great inventions by which industry had from time to time been revolutionized at first reduced a number of workers to beggary...but then as accumulation continues these evils must disappear...and wages will rise.”

Whereas work from the 19th century such as Wicksell was, in the end, optimistic, about the economic consequences of technological changes, new theoretical work on this question is not quite so sure. For example, Acemoglu and Restrepo (2017a) develop a model where new “tasks” are constantly being created. Initially, humans can do these tasks more cheaply than machines, but depending on the wage, the tasks will eventually be automated. In certain parameterizations, there is a balanced growth path where new tasks for workers are created at the same rate as ones are being destroyed. In other cases, if labor is sufficiently expensive, all tasks become automated. The point though is that there is nothing that assures that human labor will be employed in the long-run. Korinek (2018) makes a similar point that a “good” outcome for humans is not assured by putting humans and, in his term, “artificially intelligent agents” on equal footing. More optimistic papers in this literature include Sachs et al. (2015) and Aghion et al. (2017). The former finds that a rise in “robotic productivity”, which substitutes completely for labor, can result in declines in consumption, in at least the short term, similar to Wicksell’s result. The latter shows how technological progress can lead to a “singularity” where productivity grows arbitrarily quickly.

One drawback of these works is that they use a representative agent (or equivalently assume perfect financial markets). So the distributional effects of technological change are of no consequence. Korinek and Stiglitz (2017) is one notable exception. They carefully lay out the conditions under which everyone will be made better off by technological change (perhaps through *ex post* transfers). The takeaway here like these other works is that while a case for optimism can be constructed, it is by no means assured. In particular, the cost of redistribution may be sufficiently large as to make compensating the losers from technological progress unfeasible. Summers (2013) in his Feldstein Lecture comes to a similar conclusion, conjecturing that continuing advances in computational power will allow for historically unprecedented substitution of capital for labor, with a possibility that “some categories of labor will not be able to earn a subsistence income.”

Are We Ready?

Assuming that Brynjolfsson et al. (2017) are right that the productivity paradox is more apparent than real and so rapid technological change is coming, the crucial question is whether we as a society are ready. If not, what can societies and governments do to prepare? Before discussing this question, we want to emphasize that while we have discussed the role of government responses in earlier technological revolutions, overall relative today, the level of involvement was small, and the transitions ended up being managed through mainly private action. Now could earlier transitions been achieved quicker with less pain through a more robust intervention government? Perhaps. Will predominantly private action be enough in the current technological revolution? Perhaps not. Still, we think it is important to keep in mind the role private action has played in previous transitions.

In this paper, we have stressed several broad themes. As argued in the previous section, the delay between the invention of revolutionary technologies and an increase in measured living standards is nothing new. We now turn to considering, assuming there will be changes in the aggregate economy, what policy responses should be. As we have stressed, the most successful responses to revolutions are improvisational. It is not just that the institutional responses are ad hoc, but also that many of the most important of them were designed in response to previous periods of technological change. The GI Bill was crucial for expanding access higher education. However, this bill was not some very forward looking piece of legislation that saw the rise of information technology and the relative decline in manufacturing. Because of the necessity of improvisation, we will not offer a bullet-point plan that, if enacted, will insure a smooth transition in the face of rapid economic change. Instead, we want to emphasize broad goals for developed and developing countries. In many ways, the message here is the same as when economists are asked to opine on how a country can develop. The answer is that it depends, and will depend on the particulars of the situation (Rodrik, 2015). We can maybe point to some useful metrics for how well the process is occurring, but the mapping between those outcomes and clear policy prescriptions is muddled, and given each country's unique history and development pattern, we would be sorely misguided in providing this "one size fits all" set of policy ideas. Dincecco (2015) emphasizes precisely this point for developing countries today. The historical record shows the role of chance and contingency in all of these transitions.

We do think there are broad differences in how developing versus developed countries should think about making this transition. For both types of countries, we worry about the least advantaged in society and to what extent technological change will affect their situation, and it surely seems that the trajectory is a continuation of this hollowing out. For developed countries, while there is certainly material depravation, we see the larger potential problem of this hollowing out as how to live a life without the organizing feature of work. For developing countries, where material depravation for the least advantaged is a pressing concern, we see the potential problem as ensuring that the gains from technological innovations are shared widely.

Developed Countries: Cautious Experimentation

Developed countries should in principle be in a position to respond. As compared to the eve of the Industrial Revolution when famous economists such as Thomas Malthus were arguing against an early form of welfare for the unemployed, today western countries consider government intervention to provide some aid to the unemployed and destitute as legitimate, broadly speaking. That said, there are many reasons to doubt whether political systems can rise to the challenge of rapid technological progress. We are skeptical that a fair observer would look at the U.S. currently and think that it is in a position to respond to a new Industrial Revolution. It has failed in many ways to respond to the major changes caused by globalization and, in many ways, the economic, political, and demographic environment has gotten worse. That said, as we have emphasized throughout, no society is ever really ready for an economic revolution.

On the face of it, it seems rather strange to worry about the end of the work. For one, as noted earlier, average hours worked over the last few decades in the U.S. have not really fallen, and even if in this case the past is not a good guide to the future, why should we worry about greater opportunities for leisure? In fact, some economists and other social theorists have suggested that a reduced work week is not an unalloyed good because of underlying preferences for accomplishment and labor for its own sake (Freeman, 2008; Phelps, 2008). However, these preferences must surely be at least partially cultural, as the attitudes of elites towards work has varied widely across societies. *If* a major reduction in work does occur, the "little platoons" of civil society, to use Edmund Burke's phrase, must find a way to provide structure and support for people without work. Even setting aside issues of the distribution of material goods, there will have to a change in how society views the value or work. Keynes viewed the old Adamite adage of "in the sweat of thy brow" as quite dispensable. All this reshaping of preferences would take time, so "For many ages to come the old Adam will be so strong in us that everybody will need to do some work if he is to be contented" (Keynes, 1930). Those ages are likely to be difficult.

Turning to explicit government policies, we emphasize to start that this world of scarce work is not here yet. It makes little sense to develop a welfare system for a technological transition which has not happened. At the same time, we are skeptical to what extent these past periods have particularly clear implications for what types of policy responses are recommended for today. It might be tempting to suggest that a major public employment program to reemploy people who have lost their jobs because of automation is necessary. Such a program of sufficient size to absorb all of these displaced workers would never be politically feasible, particularly in the U.S. The only time such public employment programs have ever been attempted on a wide scale were in the face of the most severe downturn in economic history with programs, such as the Public Works Administration under the New Deal, and during world wars with mass conscription. Even if such work-creation programs could theoretically be created, the problem with many of them is that they "lock" people into the place they are currently living, when moving is sometimes necessary for upward mobility. In the same way, tying relief to being located in a certain area is a good way to keep people immobile and entrench poverty. Like governments, people need to be able to respond flexibly to economic changes like they did in moving from the farm to the city in the Second Industrial Revolution, for example. Perhaps something like the policy *du jour*, the universal basic income, would be useful in promoting flexibility. We would strongly encourage additional experimentation with this policy to understand its effects.

One concrete policy area that is worth reconsidering in this new economy, broadly put, is the scope of property rights. We have seen throughout history the importance of redefining property rights in response to technological changes. In the First Industrial Revolution, this involved not only the creation of private property rights in the form of enclosure but also the circumvention of others. For the Second Industrial Revolution, these changes came in the form of antitrust policy in response to changes in the scale of industry due to the presence of new technologies. For the ICT revolution, one example was the fight over the legality of Google's effort to digitize and make searchable libraries of books, many of them still under copyright. While Google did not make these copyrighted books freely available, the Authors' Guild in the 2013 U.S. case of *Authors Guild v. Google* argued that this still violated the doctrine of "fair use." In the 2nd Circuit Court of Appeals' opinion in Google's favor, the court ruled that the "purpose of the copying is highly transformative...and the revelations do not provide a significant market substitute for the protected aspects of the originals." Whether or not this was the correct decision legally, it is clear that this case and many others involving file sharing services such as Napster dramatically redefined what could or could not be done with copyrighted material in the digital age.

Given these examples from earlier revolutions, we think it is important that the regulatory regime be nimble enough to respond effectively to the changes. New technologies may be associated with increasing returns to scale in consumption, or network externalities, as is often argued for firms such as Facebook. Posner (2000) argues that, while the current antitrust regime in the United States is theoretically flexible enough to respond to respond to these challenges, the limited technical resources of the government may make it difficult in practice to craft remedies. How to respond to these challenges, when market dominant firms are perhaps inevitable and will often be located outside the jurisdiction of the nation, will be a crucial challenge for the next decades, from relatively unimportant industries such as social networking to more substantial ones, as in the role of Facebook in journalism.

These considerations should also extend to property rights in the form of intellectual property. Overly developed property rights in the presence of high transaction costs can be an impediment to responding to a new environment. This may be particularly pressing in the future, as the "intangible economy", including most prominently intellectual property, becomes more of the economy (Haskel and Westlake, 2017). Some researchers, such as Heller (2008), have argued that overly dispersed and strong intellectual property rights have resulted in a "tragedy of the anti-commons", with rights holders unable to reorganize them in a productive way or to be used for subsequent innovation. For example, Williams (2013) finds that genes sequenced by the private firm Celera versus those put in the public domain by the Human Genome Project were 20-30 percent less likely to have future product development. Shapiro (2000), while remaining "agnostic (but suspicious)" about whether too many patents are granted, suggests antitrust authorities should be accepting of market mechanisms, such as patent pools, intended to avoid these patent thickets. At the same, we caution that historical evidence on the efficacy of patent pools has not shown overwhelmingly positive effects. Lampe and Moser (2014) finds that a 19th century sewing machine patent pool diverted innovation towards an inferior substitute. Lampe and Moser (2016) using a period during the New Deal when such pools were tolerated find that each additional patent included in the pool reduced patenting by 14%.

But what if the end of work does come? We would argue that in considering such a "dystopic" state of the world, it is important to keep in mind how we would get there. That is, an end of work would imply that capital due to advanced AI has become so productive and hence, goods have become so cheap. This seems to us like a world where the political question of how to allocate material goods should be relatively easy (since they are so cheap). As we noted in our 2015 paper with Mokyr, in this new world, "the connection between measures of output [or income] and human well-being...will become even more tenuous." It is still the case that this will require a political response to expand the social safety net and perhaps that will be made that much more difficult to achieve because of the concentration of financial wealth brought on by this revolution and resulting corruption in the democratic process. On this basis, it might be prudent to consider mechanisms for attempting to limit the concentration of wealth as a way to safeguard broad political participation. These policies need not necessarily involve large increases in the size of government; Lindsey and Teles (2017), for example, proposes decreasing inequality through liberalizing land use, occupational licensing, and intellectual property rules.

Developing Countries: Developing Credibility

For developing countries, the problems that this "end of work" could bring on are much different. For one, we worry much more about the transition path in these countries, as it may be disruptively painful for some workers and industries. While along many measures of development, America or Britain of the 19th century look like India or China today (Ziebarth, 2010), it is hard to know what this transition will look like. For western countries, the usual path of development has involved a transition from agriculture to manufacturing and now onto services. In many developing countries, with perhaps China the leading example, the first transition has occurred, at least in part. For others, this remains somewhere off in the distance. The question is what will happen if in the not too distant future manufacturing has become totally automated, as discussed by Rodrik (2016). Will these countries simply be able to jump all the way to a service economy? Or will these countries be permanently stuck in a state of underdevelopment with an unlimited surplus of labor like the original Lewis (1954) dual-sector model?

What is clear from history is that the ability to act on the part of governments has been crucial for responding to technological change. We see no reason why this will be any different in the future and, if anything, if the speed of technological change increases, it will be even more important. Unfortunately, we have no concrete suggestions for how to go about developing this ability to act paired withe the credibility that these actions are done for the public good. This only developed over centuries in western countries and, in the current moment, seems like this credibility could just as easily be shattered. Moreover, what forms these actions should take have been quite varied. As we have seen, sometimes the government investment is directly in infrastructure as in roads, and other times in basic research. What complementary investments would be needed to take advantage of fourth Industrial Revolution technologies is difficult to predict today.

What does seem potentially new about this period of technological change for developing countries is the fact that it is basically impossible to hide from it. These technological changes developed in advanced countries are being "imposed" on developing countries. Earlier revolutions that centered on the production of goods made it so that, at least in principle, developing countries could put up trade barriers and keep foreign goods and technology out. How does a country do that when it comes to the internet and AI? There are just not that many countries that have the resources and political will of a China to censor and control citizens' access to the internet. This makes us skeptical about the ability of governments in developing countries to protect infant industries in these areas unless a country is willing to cut itself off totally from the world brought by the internet.

The fact that these technological changes are being imposed by developed countries does suggest that we need to carefully think about the effects on the global distribution of income. While the changes in the global economy over the last 30 years have benefited many poorer countries (Milanovic, 2016) with their large pools of cheap labor, AI might be changing this equation with coders and venture capitalists in Western countries now capturing the income generated by these breakthroughs. It is difficult for us to imagine outright income redistribution on the global scale to address this issue. That said, as we discuss now, weakening intellectual property rights might be one way for developing countries to share in the gains from these breakthroughs.

Like developed countries, one concrete area of government policy that developing countries should reconsider is intellectual property protection, particularly when it is under the guise of "free trade" agreements. As Rodrik (2017) recently argued, trade deals today are largely about domestic regulation and standards, most notably the extension of intellectual property rights, rather than the traditional lowering of tariff and non-tariff barriers at the border. Our point is not to argue for or against these deals. Intellectual property protection may indeed be an important contributor to growth. Rather, it is to suggest that developing countries should be cautious in constraining their flexibility in developing appropriate intellectual property regimes solely in the name of developing "strong property rights".

History provides numerous ways in which innovation has been encouraged in "non-standard" ways outside the normal patent system. For one, there are cases of compulsory licensing that have proven effective. For example, Moser and Voena (2012) examine the Trading with the Enemy Act following WWI and find that compulsory licensing increased chemical invention by at least 20%. Second, there are many famous cases of prizes being offered such as the British government's 1714 prize for a method of determining longitude at sea that resulted in the invention of the marine chronometer by John Harrison in 1761. Moser and Nicholas (2013) find that prize winning technologies at the 1851 Crystal Palace Exhibition saw a 40% increase in patenting after 1851 versus those that exhibited but did not win. The optimal level of protection may differ across time and space, and history suggests countries which take a flexible, yet credible, approach to reorganizing these property rights if necessary will reap large benefits. To be more explicit, intellectual property rules trade off granting monopoly rights for, theoretically, a bigger stock of ideas to use. If a developing country in the future can obtain cheap, high quality, robot-produced goods and services at the cost of no longer being a location where potential innovators want to push the technological frontier, they should consider doing so.

Concluding Thoughts

It is tempting to dismiss worries about the effects of technological innovation by saying that people have worried about these things for centuries. This is true, but sometimes it *is* different. Malthus's model of the economy was to a first approximation correct for all of human history up to that point. Unfortunately for his reputation, he was writing roughly when his eponymous model ceased to accurately describe the economy. So too may optimistic conclusions about living standards based on the previous Industrial Revolutions prove to be a mirage.

That said, we are relatively optimistic that at least the next several decades will not be characterized by widespread mass unemployment. While truly human-level or better artificial intelligence may indeed be such a game changer that history provides little guidance, this seems to be quite far off at the present. For now, past episodes of industrial revolutions provide useful parallels. As we discuss in Mokyr et al. (2015), the new jobs that developed using newly invented technologies were often literally inconceivable. Mill and Ricardo would have been baffled to hear about such jobs as "brand ambassador" or "video game designer." This is likely still true for the current process of automation. In this paper, we have attempted to draw out these comparisons, as well as lessons for how institutions can respond to changes. In short, we recommend flexibility, cautious experimentation, and the development of social institutions, most prominently but certainly not only governments, with sufficient credibility to guide adjustments to outdated structures when necessary.

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