WHAT WORKS IN INNOVATION POLICY?

New Insights for Regions and Cities: Developing Strategies for Industrial Transition

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Broadening innovation policy: New insights for cities and regions

What Works in Innovation Policy? New Insights for Regions and Cities: Developing Strategies for Industrial Transition

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A consensus has emerged about an incipient fourth industrial transition, which is being ushered in by pervasive technologies such as artificial intelligence (AI) and machine learning. This paper considers whether a new industrial transition needs a new innovation policy to guide the economic performance of cities and regions. In particular, the paper analyzes which innovation policies proved to be effective during the previous three industrial transitions and draws out insights that might suggest approaches likely to be effective in Industry 4.0. After introducing a framework identifying the forces or pillars underlying innovation and economic performance, policy strategies for industrial transition are considered, such as the diffusion of innovation and productivity, the external and internal factors influencing the efficacy of innovation policies, and the relative effectiveness of prioritizing specific or broad-based target.

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Background information

This paper was prepared as a background document for an OECD/EC high-level expert workshop on "Developing strategies for industrial transition" held on 15 October 2018 at the OECD Headquarters in Paris, France. It sets a basis for reflection and discussion. The opinions expressed and arguments employed herein do not necessarily reflect the official views of the OECD or of its member countries, or of the European Union. The opinions expressed and arguments employed are those of the authors.

Broadening innovation policy: New insights for regions and cities

The workshop is part of a five-part workshop series in the context of an OECD/EC project on "Broadening innovation policy: New insights for regions and cities". The remaining workshops cover "Fostering innovation in less-developed/low-institutional capacity regions", "Building, embedding and reshaping global value chains", "Managing disruptive technologies", and "Experimental governance". The outcome of the workshops supports the work of the OECD Regional Development Policy Committee and its mandate to promote the design and implementation of policies that are adapted to the relevant territorial scales or geographies, and that focus on the main factors that sustain the competitive advantages of regions and cities. The seminars also support the Directorate-General for Regional and Urban Policy (DG REGIO) of the European Commission in their work in extending the tool of Research and Innovation Strategies for Smart Specialisation and innovation policy work for the post-2020 period, as well as to support broader discussion with stakeholders on the future direction of innovation policy in regions and cities.

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1. Introduction

1. In 1960, at the zenith of the era of mass production manufacturing, the wealthiest city in the United States was Detroit. [1] The city was unable to sustain the transition to the next industrial era revolving around computers, and the result has been a steady decline to what now has become the sixth poorest city in the United States, measured in terms of 2017 median income.[2] The 2017 unemployment rate was 17 percent. Not only did the city declare bankruptcy, but nearly two-thirds of children in Detroit are classified as living below the poverty line. The rate of illiteracy is estimated to be around one-half of the population. About one-third of the 140 square miles comprising the city is classified as vacant or derelict.[3]

2. Similarly, the city of Wuppertal ranked not only among the wealthiest regions in Germany during the industrial era but in all of Europe. It served as one of the major industrial cities during the era of heavy manufacturing, producing textiles, metals, chemicals, pharmaceuticals, electronics, automobiles, electronics, automobiles, rubber and printing equipment. However, like Detroit, Wuppertal was unable to adjust to the next industrial transition, computers, and suffered a long and persistent decline.

3. On the other hand, Singapore ranked among the poorest places in the world during the industrial era. However, unlike Wuppertal and Detroit, it was able to harness the opportunities afforded by the transition to the computer era and has emerged as one of the economically most successful regions in the world.[4]

4. The havoc but also the opportunities confronting cities and regions imposed by industrial transitions are not restricted to these poignant examples but rather are more the rule than the exception. Why one region is able to harness the innovative opportunities accruing from industrial transition while others succumb as a victim is attributable to, at least partially, innovation policy. Innovation policy has proven to make a considerable difference in the resilience and sustainability of cities and regions during industrial transition. Examples such as Detroit suggest that sticking with the status quo policy approaches that may have been very effective in one industrial era may prove to be ineffective or even counterproductive in the next industrial transition.

5. By contrast, other examples highlight policies enabling cities or regions to leverage the opportunities emanating from industrial transition. For example, at the zenith of the era

[1] Rich Mathews, "Detroit Bankrupt: To See Detroit's Decline, Look at 40 Years of Federal Policy," *Mic Network*, July 18, 2013, accessed on August 20, 2018 at https://mic.com/articles/45563/detroit-bankrupt-to-see-detroit-s-decline-look-at-40-years-of-federal-policy#.kxF0zrtCw.

[2] "See Richest, Poorest U.S. Cities and Counties Based on New Census Data," accessed on August 22, 2018 at https://www.mlive.com/news/index.ssf/2017/09/see_richest_poorest_us_cities.html.

[3] Rich Mathews, "Detroit Bankrupt: To See Detroit's Decline, Look at 40 Years of Federal Policy," *Mic Network*, July 18, 2013, accessed on August 20, 2018 at https://mic.com/articles/45563/detroit-bankrupt-to-see-detroit-s-decline-look-at-40-years-of-federal-policy#.kxF0zrtCw.

[4] "Why Singapore Became an Economic Success," The Economist, 26 March 2015, accessed on August 22 at https://www.economist.com/the-economist-explains/2015/03/26/why-singapore-became-an-economic-success.

of mass-production manufacturing during the second industrial transition, North Carolina ranked as the poorest state in the United States. The main industries consisted of tobacco, small-scale agriculture and textiles, which combined unskilled labor with a modicum of machinery and technology. However, during the third industrial transition to the computer era, an innovation policy creating Research Triangle was implemented, resulting in one of the most innovative and prosperous regions in the world (Link, 1995). Similarly, Bavaria ranked as one of the poorer *Länder* in the Federal Republic of Germany during the second industrial transition of mass-production manufacturing (Audretsch and Lehmann, 2016). In its famous policy of *Laptops and Lederhosen* (Audretsch and Lehmann, 2016), the region was able to leverage the opportunities presented by the industrial transition to computers and subsequently emerged as the most innovative region in Europe today, at least as measured by applications to the European Patent Office in 2017.[5]

6. At the cusp of the fourth industrial transition, or what has been termed as Industry 4.0, innovation policy needs to be re-considered for the new economic paradigm. The purpose of this paper is to consider what worked in innovation policy for cities and regions during the previous industrial transitions and what is likely to work in the fourth industrial transition. The following section explains how and why Industry 4.0 is similar to its three predecessors in some ways, while it is unique in others. Because the policy focus is on cities and regions, the third section analyzes the spatial dimension of industrial transitions. The fourth section considers the societal impacts and the fifth section identifies the forces underlying innovation and industrial transition, including resources and factors of production, spatial structure and organization, and spatial culture and institutions. These underlying forces form the basis for the sixth section, which rethinks policy strategies for industrial transition, including the diffusion of innovation and productivity, the external and internal factors influencing the efficacy of innovation policies, and the relative effectiveness of prioritizing specific or broad-based targets. The final section of the paper provides a summary and conclusions. While it is not possible to predict the future, particularly where new technologies are involved, an important lesson from the first three industrial transitions is that policy approaches which proved to be successful in a previous industrial era may be either ineffective or even counterproductive in the subsequent industrial transition. Each industrial transition seems to require its own approach to innovation policy that is congruent with both the emerging technologies as well as the underlying forces driving innovation.

[5] European Patent Office, accessed on August 21, 2018 at https://www.epo.org/news-issues/press/releases/archive/2017/20170307.html.

2. What Makes this Industrial Transition Unique?

7. The concept of "industrial transition" generally refers to fundamental and disruptive economic and social change. Klaus Schwab, Founder and Executive Chairman of the World Economic Forum, goes so far as to refer to "industrial revolutions," in that they denote "abrupt and radical change. Revolutions have occurred throughout history when new technologies and novel ways of perceiving the world trigger a profound change in economic systems and social structures" (Schwab, 2016, p. 6).

8. There is a general consensus that not only is the global economy undergoing such a type of industrial transition or revolution, but this is also not the first time in history when such a transition has occurred. Economists and other thought leaders have generally identified three previous distinct industrial transformations.

9. No one disputes or asserts that there were no societal or economic transformations prior to the mid-1700s. However, in order to have an industrial transformation, there must be industry. The great historical transformation from gathering and hunting to agriculture was indeed a disruptive revolution with a transformative impact on society and economic relations. As profound as that revolution was, it had little to do with industry. In fact, the general consensus dates the first industrial transformation as beginning roughly around the middle of the eighteenth century and lasting through the middle of the nineteen century. The first industrial revolution started in Britain with the mechanization of the textile industry and the introduction and diffusion of the steam engine, which in turn facilitated the development of manufacturing in factories. In the following decades the use of machines to make things, instead of crafting them by hand, spread around the world (Rifkin, 2011). The second industrial revolution began in America in the early 20th century with the assembly line, which ushered in the era of mass production.

10. The first industrial transition was triggered by a wave of inventions, such as the "flying shuttle", which greatly enhanced the time required to weave cloth and reduced the amount of raw materials and labor needed in the weaving process. Subsequent inventions, such as the "spinning jenny" and "water frame" raised productivity and efficiency to unprecedented levels. While one worker had devoted his entire effort to a single garment for its entire production, the new inventions enabled a specialization of tasks and division of labor. New inventions enabling the development of water power, steam and coal, thanks to the inventions by James Watt, significantly reduced the energy required in weaving.

11. The first industrial revolution changed the way that goods are produced and gave birth to specialization, by the division of labor and the increasing prevalence of machines in factories. People and society were changed as an impact of the advent of specialization and the division of labor and the evolvement of factories.

12. By the mid-1800s this first industrial revolution gave way to its successor. Prior to the 1860s in the United States, production, albeit manufacturing or agricultural, was typically at a small scale, reflecting the limited markets inherent in geographically isolated communities (Kolko, 1963). As Chandler (1977) documents, the minimum efficient scale (MES) level of production was typically at low levels of output. New transportation networks, principally the railroads, created regional and even national markets. New technologies ushered in large-scale production using assembly lines.

13. The technological revolution facilitating the emergence of large-scale production also required new managerial techniques, most predominantly "command and control of effort." A broad range of technological inventions ushered in large-scale production which gave rise to assembly line manufacturing. Along with the inventions spurring the emergence of mass production in factories came equally significant managerial inventions, which were characterized as "command and control of effort" Taylor (1911). In *The Principles of Scientific Management*, Taylor (1911) provided an approach to management rendering workers like any other factor of production or input into the manufacturing process, "The science of handling pig iron is so great and amounts to so much that it is impossible for the man who is best suited to this type of work to understand the principles of the science, or even to work in accordance with the principles without the aid of a man better educated than he is"[6]

14. Along with the emergence of large-scale manufacturing came a deskilling of labor, as tasks became routinized and simplified (Goldin and Katz, 1998; Atack, Bateman and Margo, 2004). The enhanced specialization made possible a greater extent of division-of-labor and greater focus of each specific task on the assembly line. For example, the introduction of the assembly line by Ford Motor Company in 1913 enabled 29 unskilled workers to outperform the tasks which had previously been done by a sole skilled labor, leading to a gain in efficiency of nearly one-third (Acemoglu, 2002). As Atack,, Bateman and Margo (2004) conclude, the second industrial transition led to the substitution of physical capital for skilled labor but unskilled labor was complementary to physical capital. According to Acemoglu (2002, p. 7), "The idea that technological advances favour more skilled workers is a twentieth century phenomenon."

15. The third industrial transition came with the introduction, development and diffusion of the computer. The key inventions, beginning around 1960 and continuing through the remainder of the century, were not just the computer, but also the personal computer, semiconductor, internet and social media. According to Frey and Osborne, (2017, p. 257), "What is commonly referred to as the Computer Revolution began with the first commercial uses of computers around 1960 and continued through the development of the Internet and e-commerce in the 199os" It was the invention of the microprocessor, which facilitated the computational capacity of the semiconductor, that enabled the shift from mainframe to personal computers. While expensive circuit boards were needed for mainframe computers, the advent of integrated circuits and solid state memory dramatically reduced the size and cost of computers.

16. There have been five critical inventions driving separate phases and developments of the third industrial transition.[7] The first was the mainframe computer. The second was the mini-computer, which refers to smaller computers which were introduced during the mid-1960s at considerably more advantageous prices, thus increasing their diffusion and adoption. The third was the personal computer, which became widely used in the 1980s and laptop computer, which became prevalent in the 1990s. The fourth was the development of the internet and the fifth was the smart phone, which started around the turn of the century.

17. Like its two earlier predecessors, the third industrial transition had a seismic impact on virtually all aspects of society. Not only did a massive shift in the occupational structure

[6] Matthew Stewart, "The Management Myth," *Atlantic*, June 2006, p. 81.

[7] Interview with Jack Harding, Co-Founder, President and Chief Executive Officer (CEO) of eSilicon.

of the labor force take place, resulting in individual winners and losers based on occupational choice, but the prosperity of cities and regions also were transformed. For example, computational power displaced to a considerable extent workers in occupations such as bank tellers, telephone operators, and typists. By contrast, occupations needed by and complementary to computational power, such as programmers, engineers and data analysts, ascended.

18. The ten occupations accounting for the greatest share of new jobs in the United States in 1980 were agricultural engineers, nuclear engineers, supervisors (guards), management analysts, law enforcement officers, marine and naval architects, welfare service aides, construction workers, carpenters (supervisors) and personal service (supervisors) (Berger and Frey, 2017).[8] By 1990 the leading occupations accounting for the largest share of new jobs had shifted to computer systems analysts and scientists, radiologic technicians, pharmacists, tool programmers (numerical control), parking lot attendants, nuclear engineers, peripheral equipment operators, health record technologists and technicians, urban planners, and archivists and curators (Berger and Frey, 2017). By the turn of the century, the occupations generating the greatest share of new job growth had shifted again to network systems and data communication analysts, computer support specialists, network and computer systems administrators, computer software engineers, database administrators, computer and information systems managers, radiation therapists, computer programmers, logisticians, and computer hardware engineers (Berger and Frey, 2017).

19. According to Berger and Frey (2017), there was "virtually no relationship" between abstract skills and jobs before the computer, at least in the context of the United States. However, starting in 1980, a sharp positive relationship emerged between abstract skill levels and the share of new jobs. The relationship between abstract skills and jobs maps on to the geographic dimension. According to Berger and Frey (2017), there was actually a negative relationship between abstract skills and job growth at the city level between 1970-1980, after controlling for factors including the size of the city, level of education, and industry composition. However, this trend reversed for the 1980-1990 and 1990-2000 periods, suggesting a positive relationship between abstract skills and jobs at the city level for the context of the United States.

20. The empirical evidence highlights the importance of having the critical labor component needed for the computer driven economy. Prior to the computer, manual and routine occupations were more prevalent. After the advent of the computer, those occupations relying on abstract skills became more important. Thus, there is at least some empirical evidence suggesting that the third industrial transition triggered a divergence in incomes and standard of living, as incomes between occupations relying on abstract skills and the more traditional manual and routine occupations diverged. According to Berger, "Much of this divergence stems from how successful cities have been in transitioning into modern, knowledge-intensive industries. The spread of computers contributed to growing wages at the top of the income distribution at the same time as computer-controlled

[8] Eric Jaffe, "The Computer Revolution and the Fates of U.S. Cities," *CITYLAB*, December 28, 2015, accessed on 23 July, 2018 at https://www.citylab.com/life/2015/12/how-the-computer-revolution-changed-us-cities/422010/.

equipment led to the automation of a wide range of work previously held by the middle class."[9]

21. According to Berger, the policy conclusion emanating from his study is, *"If that's the case, then struggling cities might catch up by investing in their labor force—training routine workers on abstract skills, or luring the knowledge class with urban amenities. Closing the skills gap [...] should ultimately help reduce the income inequality plaguing metropolitan America."*[10]

22. The fourth industrial transition, or what was announced as *Industrie 4.0* at the Hannover Messe, is being ushered in by a dramatic and revolutionary new wave of innovations and technological advances. At the heart of this new wave of technological change is artificial intelligence and connectivity. According to *The Economist*, *"Everything in the factories of the future will be run by smarter software. Digitization in manufacturing will have a disruptive effect every bit as big as in other industries that have gone digital, such as office equipment, telecoms, photography, music, publishing and films. And the effects will not be confined to large manufacturers; indeed, they will need to watch out because much of what is coming will empower small and medium-sized firms and individual entrepreneurs. Launching novel products will become easier and cheaper. Communities offering 3D printing and other production services that are a bit like Facebook are already forming online—a new phenomenon which might be called social manufacturing."*[11]

23. The contemporary industry transition has been referred to at times as Industry 4.0, or the fourth industrial revolution. What is triggering the claim that the fundamental economic paradigm is changing is the fusing together of the cyber and digital world to forge more efficient industries. The digitalization of manufacturing transforms conventional manufacturing into "smart factories". The most salient feature of Industry 4.0 Machines is machine communication, not just between humans and machines but between, or among, machines.

24. A second fundamental aspect of the contemporary industry transition involves the internet of things. The miniaturization of computers enables them to be attached to individual machines and then connected to the internet. Sensors detect and report information via the computer and over the internet about the machine operations. One example involves farm production, where sensors for temperature, water content, and soil quality relay instantaneous information and feedback to the tractor operator about how to optimally adjust the planting procedure. Each sensor would communicate not just with each other but also larger systems in what constitutes the internet of things. Similar connectivity can enhance productivity in factories by minimizing interfaces with humans and relying on the feedback and reactions from autonomous machine learning. More data from sensors and systems based on the internet of things systems enhances the ability to make smarter

[9] Cited in Eric Jaffe, "The Computer Revolution and the Fates of U.S. Cities," *CITYLAB*, December 28, 2015, accessed on 23 July, 2018 at https://www.citylab.com/life/2015/12/how-the-computer-revolution-changed-us-cities/422010/.

[10] Cited in Eric Jaffe, "The Computer Revolution and the Fates of U.S. Cities," *CITYLAB*, December 28, 2015, accessed on 23 July, 2018 at https://www.citylab.com/life/2015/12/how-the-computer-revolution-changed-us-cities/422010/.

[11] "Special Report: A Third Industrial Revolution," *The Economist*, April 21, 2012, accessed on 15 July 2018 at https://www.economist.com/special-report/2012/04/21/a-third-industrial-revolution.

decisions and ultimately boosts both machine and system efficiency. The data driven decision making involves a continuous cycle of improvement making data driven decisions, so that machine learning is conducive to system optimization. Data driven decision-making plays a key role in artificial intelligence (AI), which refers to machines making complex decisions without human input.

25. The advent of big data enables tasks which are not routine to be accomplished using computers. Campbell-Kelly (2009) points out that compared to human labor, computers have a very high upside for scalability. In addition, while human decision-making is vulnerable to distraction, moods and contextual influences, artificial intelligence remains undistracted and considers only the relevant information in decision-making algorithms.

26. Machine learning and connectivity is characterized by interoperability, information transparency, technical assistance, and decentralized decisions. The first characteristic, interoperability, refers to the ability for machines to exchange information across a broad range of systems. The second, information transparency, refers to the capacity for digital systems to use sensors and data as a basis for modeling real world phenomena in order to enhance the efficacy of decisions. This enables a machine to calculate and predict the likelihood of a system having problems or even failing. The third, technical assistance refers to the ability of machines to make autonomous decisions in response to data and situational information. The fourth, decentralized decision-making, refers to the ability to decentralize the locus of decisions to the individual machine in coordination with the overall system decisions. This decision-making needs to incorporate all of the relevant information and then act in an informed, intelligent but also autonomous manner to preserve the integrity and viability of the overall system.

27. What Brynjolfsson and McAfee’s (2014) refer to as the “second machine age”, emphasizes the connectivity and integration of computational capabilities that drive the Fourth Industrial Transition. While Brynjolfsson and McAfee (2014) conclude that the very speed of technological change exacerbates and even precludes technological forecasting and prediction, they make a compelling case for fundamental industrial transition, “Artificial intelligence (AI) is all around us, from self-driving cars and drones to virtual assistants and translation software. This is transforming our lives. AI has made impressive progress, driven by exponential increases in computing power and by the availability of vast amounts of data, from software used to discover new drugs to algorithms that predict our cultural interests. Many of these algorithms learn from the ‘bread crumb’ trails of data that we leave in the digital world. This results in new types of ‘machine learning’ and automated discovery that enable ‘intelligent’ robots and computers to self-program and find optimal solutions from first principles” (Schwab, 2016, p. 11).

28. At first glance, it might appear that the four industrial transitions have little in common. The catalyst for each transition was a decidedly different and unique set of technologies, ranging from steam and textiles in the first industrial transition, to transportation and electricity in the second industrial transition, computers, semiconductors and the internet in the third industrial transition, and finally to artificial intelligence and machine learning in the fourth industrial transition.

29. In line with the vastly different technologies, triggering each historical industrial transition has also been a distinct type of firm and industry context. For example, the second industrial transition is generally associated with the manufacturing of goods at a large scale of production. The great industrial stalwarts around the globe in manufacturing industries such as General Motors, Volkswagen and Toyota in automobile production and U.S. Steel and Nippon Steel in the steel industry come to mind. These were typically large, vertically

integrated companies operating in a highly concentrated market with considerable market power. The dominant industries of the second industrial transition, such as steel, automobiles, aluminum, and metalworking were characterized by a market structure of just a handful of large companies, typically possessing a high market share. Comparing studies across national contexts resulted in the observation that the extent of industry concentration tended to be specific to a particular industry and not necessarily a particular country. For example, the steel industry tended to exhibit a high level of concentration not just in a single country but also in every country where steel was manufactured. The same held for other manufacturing industries, such as automobiles, iron, steel, petroleum refining and shipbuilding. For example, the 1950 four-firm concentration ratio in automobiles, or share of sales accounted for by the largest four firms, was 90 in the United States, 88 in Canada (three-firm in 1948) and 69 in Great Britain (three-firm in 1951). (Scherer, 1970; Shepherd, 1966; Yamamura, 1966; and Rosenbluth, 1957). Similarly, in the iron industry, the concentration ratio was 55 in the United States, 76 in Canada and 40 in Great Britain. In petroleum refining the concentration ratio 39 percent in the United States, 80 in Canada and 84 in Great Britain (Scherer, 1970; Shepherd, 1966; Yamamura, 1966; and Rosenbluth, 1957).

30. An entire field of economics, industrial organization, dedicated its primary focus on analyzing the determinants, impacts and trends in industry and market concentration (Scherer, 1970). In fact, a long-term trend towards increased concentration during the second industrial paradigm could clearly be identified. This trend existed both for the entire economy or what was termed as aggregate concentration, as well as at the level of industries. For example, in the United States, the share of manufacturing assets accounted for by the largest one hundred firms was just over one-third in 1924. By the conclusion of the Second World War, it had risen to 39 percent, and by the end of the 1960s the largest firms accounted for one-half of the economy, measured in assets. One of the leading scholars in the field of industrial organization at that time, Scherer (1970, p. 44) observed, “Despite the uncertainties, one thing is clear. The increasing domestic dominance of the 100 largest manufacturing firms since 1947 is not a statistical illusion.”

31. The long-term shift during the era of mass-production manufacturing towards concentration and larger-scale production resulted in a decrease in the share of manufacturing employment accounted for small and medium-sized enterprises (SMEs) of 8.1 percent, from 37.1 percent in 1958 to 29.0 percent in 1977. However, this shift towards larger scale production and increased concentration occurred not just in manufacturing but was prevalent throughout the economy. For example, the share of employment accounted for by small and medium-sized enterprises (SMEs) fell by 17.9 percent in minerals, 3.6 percent in construction, 11.0 percent in wholesale trade, 10.2 percent in retail trade and 8.4 percent in services (Acs and Audretsch, 1993).

32. .By contrast, the third industrial paradigm, the computer age, is more commonly associated with a very different type of firm operating in a very different industry context. Entrepreneurial startups, created by bold founders with a daring vision, did more than galvanize the imagination of thought leaders and the public throughout the OECD and across the globe. They also transformed the structure of OECD economies, reversing the decades old trend towards greater concentration associated with the second industrial paradigm, mass-production manufacturing. Just as the semiconductor industry was spearheaded by a plethora of startups, including Intel, entrepreneurship played a big role in the personal computer and internet industries. The ubiquity of entrepreneurship led *The Economist* to observe in 1989 in an article titled, “The Rise and Rise of America’s Small Firms,” “Despite ever-larger and noisier mergers, the biggest change coming over the world

of business is that firms are getting smaller. The trend of a century is being reversed. Until the mid-1970s, the size of firms everywhere grew; the numbers of self-employed fell. Ford and General Motors replaced the carriage-maker's atelier; McDonald's, Safeway and W.H. Smith supplanted the corner shop. No longer. Now it is the big firms that are shrinking and small ones that are on the rise. The trend is unmistakable – and businessmen and policy-makers will ignore it at their peril."[12]

33. The empirical evidence identified a pervasive shift away from concentrated industries dominated by large industrial giants towards entrepreneurial startups and small firms. In the United States manufacturing sector, the share of sales accounted for by firms with fewer than one hundred employees increased from 11.6 percent in 1976 to 14.8 percent in 1986. Similarly, the share of sales accounted for by firms with fewer than 500 employees rose from 20.4 percent in 1976 to 25.8 percent in 1986. The shift towards an increased role in the economy played by small and medium-sized enterprises (SMEs) in the transition to the computer era was not restricted to any single country but was rather pervasive throughout the OECD. For example, the share of employment accounted for by SMEs increased between the 1970s to the mid-1980s by 9.8 percent points in the United Kingdom, 3.1 percentage points in the Federal Republic of Germany, 3.8 percentage points in the Netherlands, 3.5 percentage points in Portugal, 10.9 percentage points in the north of Italy, and 7.0 percentage points in the south of Italy (Hughes, 1993; Fritsch, 1993; Thurik, 1993; Mata, 1993; and Ivernizzi and Revelli, 1993).

34. However, such static comparisons across different historical points of time within the contexts of different technological paradigms may actually blur a dynamic process that could be common among each of the three previous episodes of industrial transition. A robust body of research has identified the propensity for industries to evolve through a similar life cycle over time that is common across the distinct technological paradigms (Klepper, 1996; Abernathy and Utterback, 1978; Gort and Klepper, 1982; Jovanovic and MacDonald, 1994; Klepper and Graddy, 1990; and Schmookler, 1966). The empirical evidence covers a broad range of industries over a wide spectrum of time periods, spanning several industrial paradigms and transitions, such as automobiles, tires, aircraft, petroleum, steel, semiconductors, computers, robots, scanners, textiles, tires, televisions, transistors, lasers and plastic molds, among others (Klepper, 2015).

35. The industry life cycle exhibits three or sometimes four distinct phases – birth, growth, maturity and decline. The birth phase consists of the initial stage of the life cycle. The expansion of the industry is the greatest in the growth phase. The mature phase characterizes the slowdown in industry growth. The final stage, decline, refers to the cessation of industry growth or even negative growth.

36. As Gort and Klepper (1982) and Abernathy and Utterback (1978) show, technological change and innovations tend to fuel the emergence of new industries. According to Klepper (1996), the industry life cycle exhibits several salient characteristics. The first involves the extent of product standardization versus variety and experimentation. As Abernathy and Utterback (1978) suggest, innovations and technological change are the catalyst for the creation of new industries. The high degree of uncertainty concerning the new technology and consumer demand generates a plethora of product types in the first stage of the industry life cycle. During the growth stage, a more distinct and exact product focus emerges. The mature stage of the industry life cycle is characterized by relatively standardized products. For example, the early automobiles, or "horseless carriages" during

[12]"The Rise and Rise of America's Small Firms," *The Economist*, January 21, 1989, 73-74,

the birth stage of the automobile industry exhibited remarkable variety from the perspective of today, including products with characteristics such as three wheels, a sail, and a chimney for steam. However, by the growth stage the product had converged and become considerably more standardized, which is one of the key characteristics of the growth phase.

37. The second characteristic involves entrepreneurship and the number of firms in the industry. Entrepreneurship plays a large role in the early stages of the industry with high rates of new-firm startups and entry. Startup activity tends to be high, so that the number of firms in the industry tends to rise over time. As the industry evolves towards maturity, entrepreneurship plays less of an important role. The startup rates decrease as the industry matures, and entry becomes less frequent. Thus, the number of firms in the industry tends to rise in the birth and growth stages but then declines steadily once maturity is attained.

38. The third characteristic involves the role of capital intensity and scale economies over the industry life cycle. As a dominant product design emerges in the industry, the importance of large-scale production with a high degree of capital intensity increases. Competition revolves more around price and less around novelty and design. There tends to be not just fewer firms in the industry but they also tend to be larger, resulting in more highly concentrated industries. Thus, in the early life cycle stages, the industry is characterized by considerable turbulence. However, as the industry evolves towards maturity, the industry tends to be characterized by considerably more stability.

39. Studies identifying the evolution of firms and industries over the life cycle generally find a common development over time across a broad spectrum of industries and time contexts, suggesting that the model holds for the earlier technological eras. Each technological era, or industrial transition, triggers the birth of a wave of new industries (Klepper, 2015).

40. Static comparisons across technological paradigms can be misleading because they may be comparing industrial transitions at different points in the life cycles of industries. The most prevalent comparison between the second and third industrial paradigms, or the era of mass-production manufacturing and the computer era typically characterizes the former as being in the later life cycle stages of maturity and decline and the latter as being in the earlier stages of the life cycle of birth and growth. The stalwarts of the mass-production manufacturing era, such as steel and automobiles, are viewed as consisting of large, dominant companies in capital-intensive and highly concentrated industries. By contrast, the prototype industries of the computer era, such as personal computers, semiconductors and software, are characterized as consisting of small, dynamic startups in highly turbulent and competitive industries. Such static characterizations may oversimplify differences between technological paradigms which are better characterized by a dynamic life cycle, where both firms and market conditions tend to evolve and develop over time.

41. For example, in the early years of the second industrial transition, Karl Benz started a new iron foundry and mechanical workshop in the 1870s in Mannheim, Germany. His inventions resulted in patents that provided the basis for the production of the two-stroke engine in automobile manufacturing, such as the speed regulation system, spark-based ignition using a battery, the spark plug, carburetor, clutch, gear shift and the water radiator. By the 1920s, Benz merged with another incipient automobile manufacturer to form Daimler-Benz. During this early stage of the life cycle, there was a plethora of small, startup companies attempting to manufacture automobiles.

42. The early stage of the automobile industry was similar in North America. Klepper (2015) identifies 725 entrants, most of them new-firm startups, in the United States automobile industry during the birth and growth phases. Henry Ford was among the early entrepreneurs in the automobile industry and founded Ford Motor Company in 1903. The introduction of his model T in 1908 marked the transition from the birth stage to the growth stage of the industry, as prices fell drastically and sales grew equally dramatically. By the 1920s, Ford had developed the key mechanism of mass production manufacturing, the assembly line, as automobiles becoming increasingly a standardized product. As Ford noted, "Any customer can have a car painted any color that he wants so long as it is black."

43. The mature phase of the industry life cycle is also associated with a shift in innovative activity away from more radical innovations, which change most crucial features defining the product, to more incremental innovation, with a focus on cosmetic changes. Advertising and product differentiation play an increased role in the mature stage of the industry. For example, the head of styling at Ford Motor during the 1950s shared, *"The 1957 Ford was great, but right away we had to bury it and start another. We design a car, and the minute it's done, we hate it – we've got to do another one. We design a car to make a man unhappy with his 1957 Ford 'long about the end of 1958.'"*[13]

44. Most thought leaders in policy, business and research think of the steel industry as a highly concentrated market consisting of a handful of large companies with considerable market power. That was not the case, however, in the early stages of the industry. During the birth and growth phases of the industry life cycle, the industry consisted of hundreds of independent firms in the United States (Kolko, 1963). The Bessemer Steel Association consisted of over 700 blast furnace, steel work and rolling mill companies in the 1880s (Nelson, 1959).

45. However, as the industry evolved towards the mature stage of the life cycle, not only did the products become standardized, but the industry consolidated through mergers and acquisitions, resulting in the emergence of a single dominant company, U.S. Steel, in a highly concentrated industry (Nelson, 1959).

46. The characterization of the third industrial paradigm as being driven by small, entrepreneurial startups fueled by transformational radical innovative activity may better reflect the earlier stages of the industry life cycle, when companies such as Apple, Microsoft and Google were being founded and their industries were in the formative stages of development. Not only have these companies subsequently evolved to becoming among the largest and most dominant, not just in their industries, but in the world, but recent evidence documents a diminished role of entrepreneurship, at least measured by startup activity and the share of employment accounted for by young and small firms (Willis, Haltiwanger and Cooper, 2017; and Decker, Haltiwanger, Jarmin and Miranda, 2014)

47. Thus, what may appear to be differences across industrial transitions might in fact reveal differences over different stages of the industry life cycle but actually mask similar tendencies and trends. Such similar tendencies and trends might suggest that in the beginning of the fourth industrial transition there will be a plethora of entrepreneurial opportunities as the new technologies present new directions and applications that are not easy for the incumbent firms and organizations to implement.

48. However, there are also compelling reasons to highlight three features characterizing the fourth industrial transformation that may make it distinct from its three

[13] Quoted from Halberstam (1993, p. 127).

predecessors. The first involves the pervasiveness of its impact on not just industry or the economy but rather on all of society. For example, in pointing out that economic growth in the third industrial revolution "has been simultaneously dazzling and disappointing," Gordon (2016, p. 2) offers a resolution to the paradox, "when we recognize that advances since 1970 have tended to be channeled into a narrow sphere of human activity having to do with entertainment, communications, and the collection and processing of information." By contrast, *"For the rest of what humans care about – food, clothing, shelter, transportation, health, and working conditions both inside and outside the home –progress slowed down"* (Gordon, 2017, p. 2).

49. The first three industrial transitions generally involved inventions that impacted a narrow range of technologies and industries. Supply chains were isolated within a particular industry or product. By contrast, the fourth industrial transition is predicated upon integration across different technologies and industries. The earlier industrial transitions involved vertical integration within an industry. The fourth industrial transition, by contrast, involves horizontal integration of technologies across industries. The concept of a "low-tech" industry is likely to become dated.[14]

50. In this sense, the fourth industrial transition could be better characterized as a societal transformation in its holistic and ubiquitous impact. The advent of Industry 4.0 involves a broad spectrum of specific technologies which are radically changing and new ones which are being introduced. While the earlier industrial transformations were predicated on just a handful of new technologies, the fourth industrial transition involves a broad spectrum of new technologies spanning a wide range of industries and contexts. A third distinctive characteristic involves the speed with which this change is happening. While it took the span of multiple generations for the previous industrial transitions to transpire, thanks to globalized communications, markets and other linkages, the fourth industrial transformation is happening at a much more rapid pace. Because of the rapid diffusion and adaption linkages and processes, the fourth industrial transition will allow for considerably little time to adjust and react to what are in many cases unprecedented changes.

[14] Interview with Jack Harding, Co-Founder, President and Chief Executive Officer (CEO) of eSilicon.

3. The Geography of Industrial Transitions

51. Industrial transitions have left their imprint on economic geography. As Krugman (1991) describes, *"The long shade cast by history over location"* (Krugman, 1991). Prior to the first industrial transition, most of the population in the developed countries resided in rural regions and small towns. Since production was at a small, craft scale and transportation limited and costly, markets were typically local in nature. For example, in 1800 industrialization had not yet come to the United States. Nine out of ten people lived in rural regions and small towns. Only ten percent of the population lived in a city. Thus, the division of labor and specialization was limited, "Most families were very self-sufficient and a trip to town was about buying staples, not groceries. In fact, the first grocery store would not open until 1916 – when Piggly Wiggly opened its first store in Memphis. The idea of living in an urban setting was not a standard way of life in 1800 and it was a lifestyle that would be slow to change. Homesteads and farms had everything that a family needed and people were self-reliant. Even senior care was provided by the family."[15]

52. Cities were limited in scale. For example, in 1800 New York City had around 60,515 inhabitants, Philadelphia had 41,220 and Boston had an estimated population of 24,937. The inventions of the first industrial transition had a massive impact on where and how people lived. The first industrial transition originated even earlier in Great Britain. As White points out, "London in particular was flooded with thousands of young people every year, many of whom worked as apprentices to the capital's numerous tradesmen. Other new arrivals gained employment as domestic servants to the dozens of aristocratic families that began spending much of their time in elegantly built town houses. Though death rates remained relatively high, by the end of the 18th century London's population had reached nearly one million people, fed by a ceaseless flow of newcomers. By 1800 almost one in ten of the entire British population lived in the capital city. Elsewhere, thousands of people moved to the rapidly growing industrial cities of northern England, such as Manchester and Leeds, in order to work in the new factories and textile mills that sprang up there from the 1750s onwards."[16]

53. The first industrial transition not only rendered small family owned manufacturing businesses as no longer competitive vis-à-vis their larger rivals but it also meant that many of the small, rural communities were at a competitive advantage. The development of electricity, transportation networks and large-scale production shifted the geographic scope of markets away from local towards the regional and national. The inventions of that era also facilitated the development or urban density and cities.

54. The new technologies enabled large-scale production, and new management techniques to facilitate an unprecedented extent of the division of labor, which increased the level of the minimum efficient scale of production. Large-scale production emerged with a marked competitive advantage vis-à-vis the small-scale, family owned businesses, which were traditionally rooted in their communities. The result was not just the rise of large, dominant companies in concentrated markets in the second half of the nineteenth

[15] "1800-1990: Changes in Urban/Rural U.S. Population," accessed on 29 July, 2018 at https://www.seniorliving.org/history/1800-1990-changes-urbanrural-us-population/.

[16] Matthew White, "The Rise of Cities in the Eighteenth Century," *Georgian Britain*, accessed on 30 July, 2018 at https://www.bl.uk/georgian-britain/articles/the-rise-of-cities-in-the-18th-century.

century but also the demise of small, family businesses that had previously been viable and thriving for generations.

55. Thus, by 1900 the inventions driving the first industrial transition had enabled the growth of density and emergence of cities on an unprecedented scale. Four out of ten American resided in cities, and by 1920, one-half of the population in the United States lived in a city. For example, the population of New York had exploded to 3,437,202 residents, Philadelphia with a population of 1,293,697, and Boston as having 560,892 residents.[17] As Gordon (2016, p. 4) points out, *"When the electric elevator allowed buildings to extend vertically instead of horizontally, the very nature of land use was changed."*

56. The second industrial transition also led to an increased concentration of economic activity in manufacturing centers. In the United Kingdom, economic activity, particularly in manufacturing, was concentrated in the Northwest of England, and in particular in the Manchester-Liverpool region, which had been one of the wealthiest regions of the world until the 1930s (Götting, 2014). Similarly, the industrial center of Glasgow expanded rapidly in the first half of the twentieth centuries until it began a steep decline in the 1970s. In the United States, the industrial center was in Midwestern cities such as Detroit, Pittsburgh and Akron, Ohio. Geographic proximity to the manufacturing location was important to benefit from the location-specific assets, resulting in a shift in the income distribution that was considerably skewed towards industrial manufacturing centers. In the United States, Detroit was the wealthiest city in 1950 and Pittsburgh was not far behind.

57. The third industrial transition also uprooted economic geography. Many of the industrial centers that had thrived in the second industrial transition experienced a deterioration in the standard of living, including the Ruhr Valley in Germany, Northwest of England, and the Midwest in the United States, and in particular Detroit and Pittsburgh. Rather, a new set of locations emerged as the most prosperous regions in the OECD, such as the San Francisco, Seattle, Austin and San Jose in the United States and Munich in Europe.

58. In fact, the advent of the third industrial transition, particularly the later developments such as the internet and smart phone, had been predicted to mitigate disadvantages associated with economic geography and locations within peripheral regions (Cairncross, 1997). The inventions of the third industrial transition greatly reduced the marginal cost of transmitting information across geographic space. During the previous industrial eras, geographic proximity was typically a prerequisite to accessing the requisite information. However, with the advent of the internet and smart phone, information could be transmitted across geographic space at virtually no cost. As *The Economist* observed, the advent of the internet would also usher in "The Death of Distance."[18] According to *The Economist, "What will happen when the cost of communications comes down to next to nothing, as seems likely some time in the first decade of the next century? The death of distance will mean that any activity that relies on a screen or a telephone can be carried out anywhere in the world."*[19]

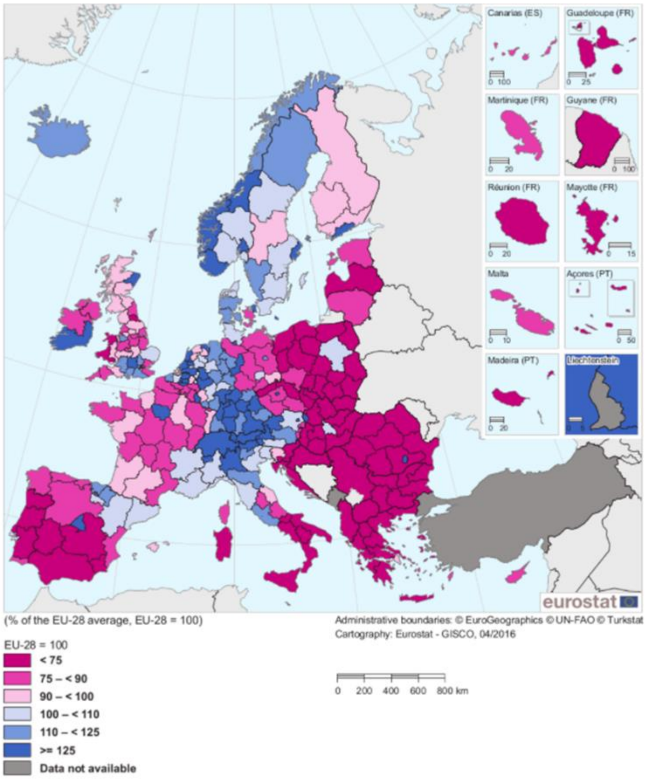
[17] "1800-1990: Changes in Urban/Rural U.S. Population," accessed on 29 July, 2018 at https://www.seniorliving.org/history/1800-1990-changes-urbanrural-us-population/.

[18] "The Death of Distance," *The Economist,* September 30, 1995.

[19] "The Death of Distance," *The Economist*, September 30, 1995, p. 27.

59. However, rather than geographically dispersing, the spatial concentration of economic activity increased during the third industrial transition. Innovative clusters tend to spatially concentrate in places such as Randstad (the Rotterdam-Amsterdam region) in the Netherlands, Stockholm in Sweden, Barcelona in Spain, Cambridge in the United Kingdom, Toronto in Canada, Munich and Silicon Valley in the United States. The explanation is that the cost of transmitting a crucial economic resource – knowledge and ideas – remains less affected by the internet and smart phone. In particular, the transmission of tacit knowledge, which involves ideas and thoughts that are too complex to be codified, typically requires face-to-face proximity or repeated and in-depth interaction among people (Audretsch and Feldman, 1996; Audretsch and Stephan, 1996).

Figure 1. GDP per inhabitant

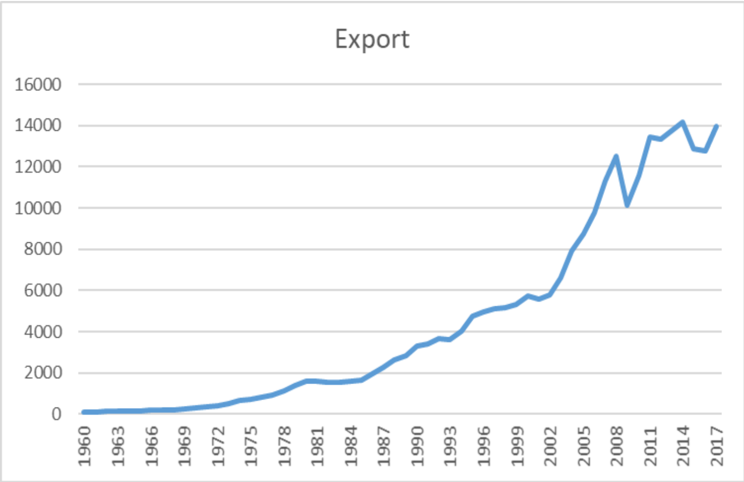


Note: Gross Domestic Product per inhabitant in Purchasing Power Standard (PPS) in relation to the EU-28 average, by NUTS 2 regions, 2014
Source: Eurostat.

60. In particular, ideas, which can be agreed upon and articulated, are characterized as being codified, in that they can be formulated in writing. Codified information lends itself to being communicated over the internet. Ideas which are difficult to articulate and do not lend themselves to codification are characterized as being tacit in nature. Thus, as Figure 1 shows, rather than converging, the standard of living and levels of economic well-being are highly skewed and unevenly distributed across a relatively integrated economic area, such as the European Union. Along with the advent of large-scale manufacturing came an explosion of international trade during the first two industrial eras. By the zenith of the second industrial era, this was referred to as “internationalization”, which generally referred to a high degree of trade with other countries.

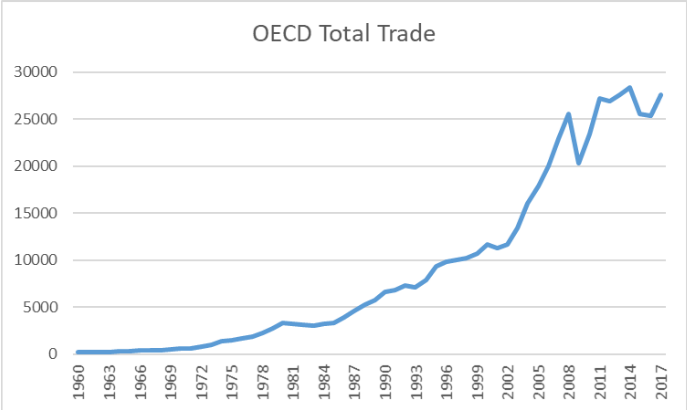
61. As Figure 2 shows, global international trade, measured by exports and imports accelerated considerably during the third industrial era. However, the concept of globalization, which became prevalent in the 1990s, is more nuanced and involves integration that is more pervasive across borders (Leamer, 2007). The fourth industrial transition is also likely to impact economic geography. Rifkin (2011) predicts a shift from globalization to continentalization, which echoes Rugman and Verbeke's (2005) regionalization. On the one hand, digitalization provides a platform for geographic where the disadvantages of location in the periphery are mitigated. Due to the integration of technologies and platforms, there are opportunities to participate in supply chains even in remote and peripheral regions. However, Rifkin (2011) argues that such supply chains are likely to be more continental in focus rather than extend across the globe. In any case, there is no reason to think that they will be constrained by national borders.

Figure 2. Total World Export



Source: Calculations based on World Bank data.

Figure 3. Total Trade in the OECD



Source: Calculations based on World Bank data.

4. The Societal Impacts of Industrial Transitions

62. Industrial transitions have had a profound impact on society. The (first) industrial revolution unequivocally uprooted society by shifting economic activity from rural communities and small towns to manufacturing in urban areas. Family farms and businesses which had been viable for generations proved to no longer be competitive against the emerging competition from large-scale competition with an increased reach due to a rapidly burgeoning transportation network. The wave of bankruptcies and foreclosures in rural communities combined with the growing manufacturing factories in the urban regions triggered a massive shift in population. As the population followed the opportunities to the cities, life fundamentally changed, both in the rural communities as well as in the cities.

63. The first industrial transition uprooted society and people. Prior to the first industrial transition four out of five people lived in rural regions and worked in agriculture. After the first industrial transition, four out of five people lived in cities. Overall, the population of Britain increased by four hundred percent. The composition of the work force also changed, "Women and children now went to work and didn't stay at home as there was an easy way to earn an income. And as more businesses sprang up, more and more jobs were created which meant that more people could earn an income and this spurred population growth. The impact of the Industrial Revolution dramatically changed society and the world."[20]

64. For example, the impact of the first industrial transition on London was depicted as "Life was frequently confusing and chaotic. The network of narrow allies and lanes, that had remained largely unchanged in many towns since medieval times, proved increasingly inconvenient to horse-drawn vehicles, and, like today, many cities were prone to traffic congestion. In 1749, for example, hundreds of people were stuck in a traffic jam on London Bridge that took nearly three hours to clear."[21]

65. It was not just life in London that was uprooted but rather the impact on society was pervasive throughout urban areas, "Many 18th-century towns were grimy, overcrowded and generally insanitary places. London in particular suffered badly from dirt and pollution, so much so that candles were sometimes required at midday in busy shops owing to the smoggy conditions outside. Many travellers noted the 'smell' of London as they approached from far away, and letters received from the capital city were often said to have a 'sooty' odour. Alongside the stinking rivers and choking pollution of cities, open sewers ran through the centre of numerous streets. Gutters carried away human waste, the offal from butchers' stalls and the tonnes of horse manure that were left daily on the streets. The roads of most towns and cities were unpleasantly dusty in the hot summer months, and

[20] Cited from https://historygeographyassignmenthelp.weebly.com/mass-production-in-the-industrial-revolution.html, accessed on 10 August, 2018.

[21] Matthew White, "The Rise of Cities in the Eighteenth Century," *Georgian Britain*, accessed on 30 July, 2018 at https://www.bl.uk/georgian-britain/articles/the-rise-of-cities-in-the-18th-century.

many became virtually impassable in the winter owing to their muddy and flooded condition."[22]

66. There was also vehement resistance to the technological change driving the first industrial transition. While the infamous Luddite riots between 1811 and 1816 have earned global notoriety, there were similar large-scale riots in both the years preceding and following the Luddites (Mantoux, 2006). The Lancaster riots, some three decades earlier were triggered by jobs displaced from cotton machines, *"The sole cause of great riots was the new machines employed in cotton manufacture; the country notwithstanding has greatly benefited from their erection and destroying them in this country would only be the means of transferring them to another…to the deteriment of the trade of Britain"* (Mantoux, 2006, p. 403).

67. The fundamental shift in society was not restricted to one continent. On the other side of the Atlantic, Boorstin (1973) explained the prevalent shift in society triggered by the first industrial transition, *"The century after the Civil War was to be an Age of Revolution – of countless, little-noticed revolutions, which occurred not in the halls of legislatures or on battlefields or on the barricades but in homes and farms and factories and schools and stores, across the landscape and in the air – so little noticed because they came so swiftly, because they touched Americans everywhere and every day. Not merely the continent but human experience itself, the very meaning of community, of time and space, of present and future, was being revised again and again, a new democratic world was being invented and was being discovered by Americans wherever they lived."*[23]

68. According to Gordon (2016, p. 1), who refers to the "the special century" spanning the first and second industrial transitions, *"The century of revolution in the United States after the Civil War was economic, not political, freeing households from an unremitting daily grind of painful manual labor, household drudgery, darkness, isolation, and early death. Only one hundred years later, daily life had changed beyond recognition. Manual outdoor jobs were replaced by work in air-conditioned environments, housework was increasingly performed by electric appliances, darkness was replaced by light, and isolation was replaced not just by travel, but also by color television images bringing the world into the living room. Most important, a newborn infant could expect to live not to age forty-five, but to age seventy-two. The economic revolution of 1870 to 1970 was unique in human history, unrepeatable because so many of its achievements could happen only once."*

69. The change in economic geography triggered by the second industrial transition also left its imprint on society. On the one hand, the absolute isolation of rural life mitigated, as the key inventions of electricity and the telephone provided connectivity. As Gordon (2016, p. 5) observes, *"The 1870 house was isolated from the rest of the world, but 1940 houses were networked, most having the five connections of electricity, gas, telephone, water, and sewer."* Thus, *"the overarching transition in the half century after the Civil War was from an agrarian society of loosely linked small towns to an increasingly urban and industrial society with stronger private and governmental institutions and an increasingly diverse population"* (Gordon, 2016, p. 6). The shift from small, isolated

[22] Matthew White, "The Rise of Cities in the Eighteenth Century," *Georgian Britain*, accessed on 30 July, 2018 at https://www.bl.uk/georgian-britain/articles/the-rise-of-cities-in-the-18th-century.

[23] Quoted from Gordon (2016, p.1).

communities to cities is reflected by the increase in the share of the populated living in cities to nearly three-quarters by 1970 from one-quarter a century earlier.

70. On the other hand, the economic disparities between urban and rural populations increased, as the productivity levels accruing from large-scale manufacturing generated unprecedented wealth in cities such as Manchester in the United Kingdom, Trollhäten in Sweden, and Detroit in the United States (Lochbiler, 1973). Those countries with large-scale manufacturing generally enjoyed a surge in incomes, while those with a paucity of manufacturing tended to fall behind.

71. Still, the overall distribution of income remained relatively even during the second industrial divide, at least in terms of human capital and education. According to Goldin and Katz (2009), the wage gap between the educated and less educated actually declined between the first eight decades of the twentieth century.

72. As Gordon (2016), Stiglitz (2012) and Piketty (2013) point out, an important societal impact of the third industrial transition has been a dramatic increase in income inequality. Stiglitz (2017, p. xvii) colorfully describes the social upheaval in the OECD country exhibiting one of the greatest degrees of income inequality, the United States, *"The data describing what has been happening in the United States are sobering: for nearly a third of a century the incomes of most Americans have been essentially stagnant. A middle-class life – a decent job with decent wages and a modicum of security, the ability to own a home and to send one's kids to college, with the hope of a reasonably comfortable retirement – has been moving increasingly out of reach for a large proportion of the country. The numbers in poverty have been increasing, as the middle is being eviscerated. The one group doing well has been the top – especially the top 1 percent and even more, the top .1 percent, the richest several hundred thousand Americans."*

73. The increased income inequality has generally occurred over two important dimensions. The first has been at the geographic level. Increases in incomes and the standard of living have tended to spatially cluster in specific locations, while other cities and regions have suffered a decline in living standards, which has increased the income gap across regions within individual countries. At the same time, many countries outside of the OECD have been able to leverage the technological opportunities generated in the third industrial transition to actually grow more rapidly and narrow the income gap, or what had been referred to as the "North-South Divide".

74. The second dimension involves human capital and education, or more broadly labor skills. Workers with high levels of human capital and labor skills have benefitted in terms of higher income levels, while their counterparts with low levels of human capital, education and labor skills have experienced a decrease in incomes and standard of living (Autor and Dorn, 2013; and Autor, Levy and Murnane, 2003). This trend has happened within countries and throughout the OECD (Atkinson, 2008; Goldin and Katz, 2009). For example, compelling empirical evidence found that computers were substituted for labor in occupations such as telephone operators, accountants and telephone operators (McKinsey Global Institute, 2013; Bresnahan, Brynjoholfsson and Hitt, 2002; and Bresnahan, 1999). At the same time, human capital and skilled labor shifted from being a substitute for physical capital to a being a complement for technology. Thus, the wages of high human capital workers tended to rise, while those of their less skilled counterparts fell. According to Frey and Osborne (2017, p. 258), *"The Computer Revolution can go some way in explaining the growing inequality of the past decades."* They highlight Krueger's (1993) empirical evidence that those workers using a computer enjoy a wage premium between ten to fifteen percent greater than their counterparts not using a computer do.

75. Taken together, these two dimensions of income and wealth disparities have been attributed with fueling a growing hostility against globalization and the emergence of a populist movement favoring anti-globalization measures, such as Brexit in the United Kingdom, the National Front in France, AfD in Germany and the Five Star Movement in Italy (Rifkin, 2011; Stiglitz, 2017). According to Galston, *"The rise of populism, mostly right-leaning, is the most important European political development of the 21st century. It has eaten into support for traditional center-right parties while dealing a knock-out blow to the center-left. The result is the end of the center-left/center-right duopoly that has dominated European politics since the end of World War II. Party systems throughout Europe have fragmented, and most have shifted toward the right. And the rise of populism has opened the door to increased Russian influence throughout Europe."*[24]

76. All of the three previous industry transitions experienced massive employment dislocations. The fourth industrial transition is also predicated to trigger substantial employment dislocations.[25] Gartner estimates that 1.8 jobs will be eliminated by 2020 as a result of artificial intelligence.[26] Frey and Osborne (2017) have attempted to quantify future employment displacement from the technologies associated with the fourth industrial transition. While the impact of computerization could be measured for the third industrial transition by distinguishing between cognitive and manual tasks and between routine and non-routine tasks, Frey and Osborne (2017) instead argue that, in fact, all of those tasks can be displaced by technology drawing on artificial intelligence. By classifying occupations as either routine or non-routine, they are able to estimate the impact of computerization on employment. The conclude that nearly one-half of employment in the United States is exposed to a high risk of displacement, which they define as *"jobs we expect could be automated relatively soon, perhaps over the next decade or two"* (Frey and Osborne, 2017, p. 268). They also find that a large share of jobs in the services are similarly exposed and vulnerable to the fourth industrial transition. The transportation and logistics are projected to be similarly adversely affected by the fourth industrial transition. The model used by Frey and Osborne (2017) finds that engineering and science jobs are not vulnerable to machine learning and artificial intelligence. They also find a continuation of the positive relationship between wages and educational attainment.

77. A key distinction between the impact of the fourth industrial transition and its three predecessors is that while the latter focused on substituting technology and capital for what Autor, Levy and Munane (2003) characterize as routine tasks, the fourth industrial transition may involve substituting technology and capital for non-routine tasks. The analysis of big data combined with continual feedback enables algorithms that can actually perform non-routine tasks more efficiently than can highly skilled and high human capital workers. As Brynjolfsson and McAfree (2011) make clear, the boundary between the third industrial transition and the fourth industrial transition is when computer applications shifted from a sole focus on routine tasks to non-routine tasks.

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[24] William A. Galston, "The rise of European Populism and the Collapse of the Center-Left," *Brookings*, March 8, 2018, Accessed on 2 August, 2018 at https://www.brookings.edu/blog/order-from-chaos/2018/03/08/the-rise-of-european-populism-and-the-collapse-of-the-center-left/.

[25] Ryan Browne, "Five of the scariest predictions about artificial intelligence," *CNBC*, August 1, 2018, accessed on 2 August, 2018 at https://www.cnbc.com/2018/08/01/five-of-the-scariest-predictions-for-ai.html.

[26] "Gartner Says by 2020, Artificial Intelligence Will Create More Jobs than it Eliminates," accessed on 2 August, 2018 at https://www.gartner.com/newsroom/id/3837763.

5. Innovation & Industrial Transition

78. Each industrial transition has had its own key forces underlying innovation specifically and economic performance more generally. This section classifies the underlying forces driving innovation and economic performance into three dimensions or pillars. The first involves ingredients or inputs, which are generally referred to as factors and resources in the production process. The second refers to the manner in which those ingredients in the production process, or factors and resources, are organized and structured within a specific spatial or geographic context, typically a city, state or region but perhaps even an entire nation. The third refers to spatial culture and institutions and the way that they influence innovation and economic performance.

5.1. Factors & Resources

79. Not only do factors and resources play a key role in shaping innovative activity and economic performance across all units of economic analysis, ranging from individuals to firms and organizations, industries, regions and countries, but they also have played a key role in industrial transitions. The catalyst for the first two industrial transitions was fundamental developments enabling physical capital to be combined with natural resources that drove unprecedented levels of efficiency and productivity. The locational advantage of physical capital was typically linked to an abundance of key natural resources. The great industrial regions, such as Manchester and Birmingham in the United Kingdom, the Ruhr Valley in Germany and Detroit and Pittsburgh in the United States provided access to the key natural resources that drove the large-scale manufacturing production. Most of the important innovations also tended to be in industrial production.

80. Systematic econometric evidence supported the view that physical capital was the key factor of production driving economic performance. Those places enjoying the greatest investments in physical capital tended to exhibit the strongest economic performance. As Chandler (1990) found, this held at the level of the firm, as well as for the industry (Scherer, 1970). The Solow (1956 and 1957) model with its focus on two factors of production – physical capital and labor – confirmed the primacy of physical capital, along with the subsequent wave of studies applying the production function model to a broad range of country contexts, . After reviewing the literature, Nelson (1981, p. 1032) summarized, *"Since the mid-1950s, considerable research has proceeded closely guided by the neoclassical formulation. Some of this work has been theoretical. Various forms of the production function have been invented. Models have been developed which assume that technological advance must be embodied in new capital […] Much of the work has been empirical and guided by the growth accounting framework implicit in the neoclassical model."*

81. In the third industrial transition, the computer era, the key factor and resource shifted from physical capital to knowledge, ideas, creativity and human capital. This was partly due to the high component of human capital in the production, or development of computers within the industry. The computer industry ranks among the most intensive users of human capital and research and development.

82. However, the shift to human capital was also largely attributable to the complementarities between human capital and computerized technologies. While the first two industrial transitions shifted the demand for an increase in less skilled labor, the

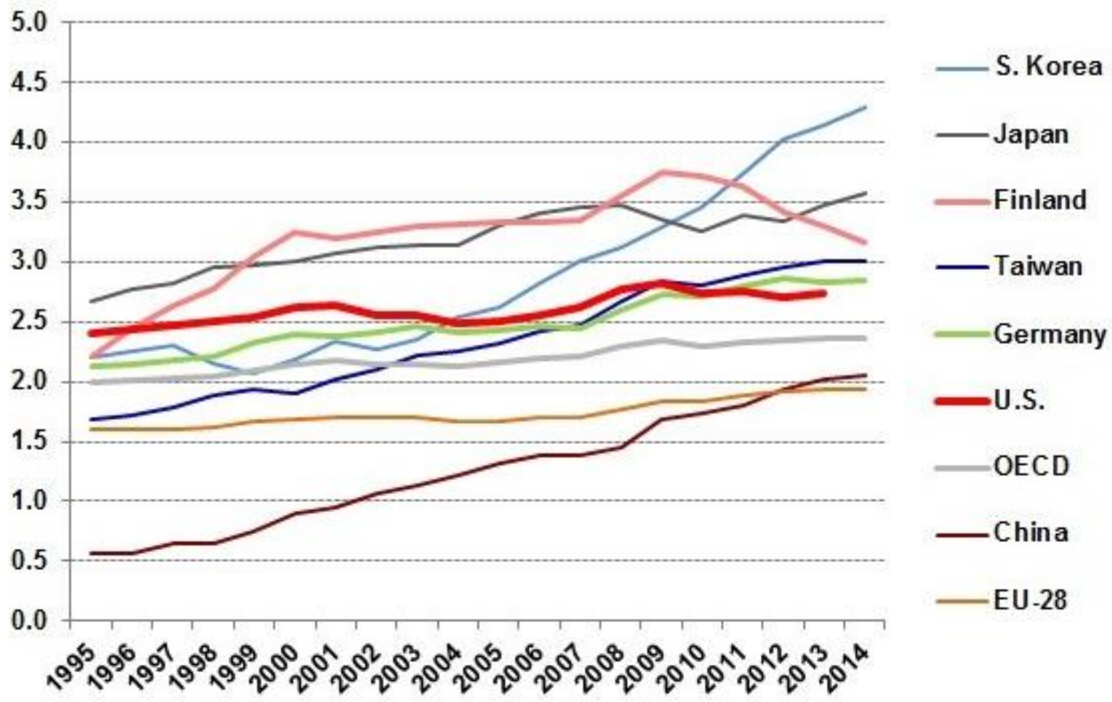
complementarities between computers and human capital resulted in an increased demand for human capital (Acemoglu, 2003; Autor, Levy and Murnane, 2003; Autor, Katz and Krueger, 1998; Bresnahan, 1999; Bresnahan, Brynjolfsson and Hitt, 2002; and Levy and Murnane, 2004).

83. In addition, the advent of globalization, which is a salient characteristic of the third industrial transition, shifted the comparative advantage of many of the OECD countries away from the most successful industries driving competitiveness and economic performance during the second industrial transition, such as steel, textiles and shipbuilding to lower cost locations in less developed countries (Blinder, 2009; Stiglitz, 2018; and Blinder and Krueger, 2013). While the demand for manufactured goods and products was not falling in the OECD, the ability of companies to shift production to lower cost locations through outsourcing and offshoring was fundamentally altered in a globalized economy (Blinder, 2009; Blinder and Krueger, 2013). Thus, a wide range of companies, industries and regions within the OECD, such as Bilbao, Spain and Kiel, Germany in shipbuilding, and Windsor, Canada, Trollhättan, Sweden, Detroit and Holden, Australia in automobile production, suffered a deterioration in economic performance and standard of living as a consequence of the shift in comparative advantage away from physical capital in the OECD.

84. However, a new comparative advantage emerged in OECD countries in industries with a high component of knowledge and human capital. While this shift was first detected by econometric studies in the late 1980s (Bowen, Leamer and Sveikauskas, 1987; and Bowen and Sveikauskas, 1989), it became increasingly evident through the turn of the century (Leamer, 2007 and Spence, 2011). Knowledge is generally considered to be created by investments in research and development. A strong and compelling relationship has been found to exist between R&D and innovative output for firms, industries, regions and countries (Mohnen and Hall, 2013; Mairesse, Mohnen and Kremp, 2005; Audretsch and Feldman, 1996; Cohen, 2010; and Hall, 2011). The increase in R&D in OECD countries over time, as Figure 4 shows, reflects the shift in the key factor of production towards knowledge. Because it is complementary to physical capital, the wages of less skilled and lower human capital tended to fall (Autor, Katz and Kruger, 1998; and Goldin and Katz, 2009). Combined with the increased demand for high human capital labor, the third industrial transition has witnessed a pronounced and pervasive widening of the distributions of income and wealth throughout the OECD (Spence, 2011; Goldin and Katz, 1998; Atkinson, 2008; Stiglitz,2012; and Piketty, 2013).

Figure 4. National R&D investment

Gross R&D as a percentage of GDP



Source: OECD Main Science and Technology Indicators 2016.

85. While the focus of human capital is generally on education, there is also compelling evidence that formal education fails to fully capture all aspects of talent and skills that have proven to be highly valued in the third industrial transition. For example, based on the content of occupations that involves creativity, Florida (2002) expanded the concept of human capital to the creative class and found a positive relationship between those regions with a high share of the labor force accounted for by the creative class and economic performance. In particular, Florida suggested a more expansive approach to measuring what has traditionally been thought to constitute human capital. Rather than measuring educational attainment or number of years in school, Florida instead used the classifications of occupations to distinguish those workers in the creative class from those in the working class or the service class. In particular, the creative class consists of the supercreative core, which includes scientists, academics and artists, and the creative professionals include management, finance, law, healthcare and sophisticated sales (Florida, 2002).

86. Germany does not seem to have a high extent of what is commonly measured as reflecting human capital. For example, in 2013 an average of 39 percent of people aged between twenty-five and thirty-four had graduated from a college or university for the OECD, but in Germany it was only 28 percent. Yet, Germany ranks among those OECD countries that have proven to be the most resilient at achieving and maintaining global competitive and achieving a strong economic performance in manufacturing in the third industrial transition. Most of the OECD has struggled to maintain competitiveness and a strong performance in manufacturing. For example, the share of the labor force was cut in half in France since 1970, from 28 percent to less than 14 percent, as has been the case

throughout much of the OECD. Similarly, the share of gross domestic product (GDP) accounted for by manufacturing of 22 percent is nearly twice as high in Germany as the 13 percent of GDP in the United States and the 12 percent of GDP in Great Britain (Audretsch and Lehmann, 2016). The strong manufacturing performance in Germany is attributable to the strong investments in labor skills that enable workers to master craft skills that contribute to both higher quality products and innovation. These labor skills are typically developed not at a university or college but rather through the apprentice system. Thus, there is a strong link between labor skills, innovation and economic performance.

87. According to Frey and Osborne (2017), the fourth industrial transition is likely to continue to be driven by similar factors and resources as the third industrial transition – knowledge, human capital and creativity. In terms of policy instruments, this would mean university research, private and public R&D and education. However, successful investments in R&D and human capital will prioritize the technological areas underlying the fourth industrial transition – informatics, computer science, data science and engineering.

5.2. Spatial Structure & Organization

88. The insight of Porter (1990) in *The Competitive Advantage of Nations* was that economic performance, the standard of living and competitiveness were not solely determined by factors and resources. Rather, how those factors and resources, along with the ensuing economic activity, are structured and organized in geographic space can make a great difference. In particular, Porter (1990) provided compelling theoretical reasons and case studies suggesting that economic activity organized in clusters enhances economic performance and competitiveness across all levels of economic analysis, ranging from individuals to firms and organizations, to industries and to regions and countries. Clusters and industrial districts (Becattini, 2004) generally refer to a spatial concentration of interconnected businesses in both a horizontal and vertical sense, in that they encompass suppliers as well as other firms in the same or related business. The same factors and resources will generate a better economic performance and degree of competitiveness if they constitute a cluster than they would if they are not in a cluster. Examples included automobile production in Gothenburg in Sweden and Stuttgart in Germany, high-quality textiles and apparel in Emilia-Romagna in Italy, and steel in the Ruhr Valley in Germany.

89. As Marshall observed, clusters, or what was termed as an industrial district (Becattini, 2004), were also an effective form of spatial organization and structure in the first industrial transition as well as the second industrial transition. The textile mills of Manchester, England constituted a cluster or an industrial district, as did their counterparts in New England in the United States.

90. Porter's thinking and examples clearly drew mainly on the second industrial transition. However, clusters have also proven to be an effective spatial structure and organization in the third industrial transition. The most prominent examples of clusters based on computer technology are Silicon Valley in California, Cambridge in the United Kingdom, Singapore, Munich, Stockholm, Austin, Texas and Research Triangle, North Carolina. Thus, clusters, along with their success, have been a highly visible feature of the third industrial transition.

91. However, a cluster represents just one type of spatial structure and organization which enhances the effectiveness of the factors and resources used. A very different form of spatial structure and organization involves the extent to which economic activity is

specialized in one industry or sector, or diversified across a broad range of different, but complementary industries. The argument for specialization focuses on the gains from scale economies (Arrow, 1962) and reduction in transactions costs (Williamson, 1975). The first two industrial transitions provide compelling cases for a geographic organization and structure of spatial specialization. One study estimates that two million people in the United States were employed in "company towns", where a sole firm provided the bulk of employment, which is the extreme case of spatial specialization (Borges and Torres, 2012).

92. There are also poignant examples where spatial specialization is correlated with a strong economic performance during the third industrial transition. The automobile industry accounts for 59 percent of the economic activity measured in tax revenues, in Wolfsburg, Germany.[27] Similarly, Siemens accounts for 62 percent of the economic activity in Erlangen, Germany.[28] The aerospace industry dominates economic activity in Huntsville, Alabama, in the United States, as do pharmaceuticals in Leverkusen, Germany, and automobile production in Turin, Italy.

93. By contrast, Jacobs (1969), drawing largely on a case study of Toronto in Canada, argues that it exactly the opposite, spatial diversity, that is conducive to an enhanced economic performance and competitiveness. She argues that it is differences across complementary industries and types of economic activity that can stimulate knowledge spillovers. If workers and decision makers are engaged solely in a narrow line of homogeneous activity, then there are few differences among people to generate knowledge spillovers. Rather, according to Jacobs (1969), it is differences across workers employed in heterogeneous but complementary economic activity that creates a rich potential for knowledge spillovers.

94. A compelling body of empirical evidence (Glaeser and Gottlieb, 2009; Glaeser, Kallal, Scheinkman, and Shleifer, 1992; and Audretsch and Feldman, 1996) has found that spatial diversity tends to be more conducived to innovative activity and a strong economic performance than does spatial specialization. Those cities and regions characterized by spatial diversity tend to exhibit more innovative activity than do cities and regions characterized by spatial specialization (Audretsch and Fedlman, 1996). However, there are certainly compelling examples and cases studies linking both spatial specialization and spatial diversity to innovative activity, at least for the third industrial transition.

95. Another aspect of spatial structure and organization invovles whether economic activity is undertaken by several firms possessing market power, such as a monopoloy or oligopoly, or instead by firms characterized as operating under conditions of competition. Arrow (1962) argued that firms with monopoloy power are more conducive to innovative activivty for two reasons. The first involves the incentives to invest in new knowledge and other innovative activities. A high degree of monopoloy power facilitates the ability of firms to appropriate the returns accruing from their investments in research and development, human capital through employee training and new knowledge more generally. By contrast, under the conditions of competition, such the returns from such investments tended to be eroded and captured by other firms.

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[27] "Town and Company," *The Economist*, February 25, 2016, accessed on August 10, 2018 at https://www.economist.com/business/2016/02/25/town-and-company.

[28] "Town and Company," *The Economist*, February 25, 2016, accessed on August 10, 2018 at https://www.economist.com/business/2016/02/25/town-and-company.

96. The second reason involves the finacial resources available to fund investments in research and development and the creation of new knowledge that fuels innovation. The economic rents accruing to monopoloy power provide a source of funding for research and development, as a strategy to ensure subsequent economic returns in the future. By contrast, in the absence of monopology power, the high degree of uncertainty and knowledge asymmetries associated with innovative activity tend to result in financing constrats for innovation (Arrow, 1962).

97. However, there are also reasons that having firms operating under competition may be more conducive to innovation. Glaeser, Kallal, Scheinkman, and Shleifer (1992) argue and provide compelling econometric evidence that innovative activity is enhanced by cities where firms are in competitive markets. Their emphasis is on the input markets, and particularly on the factor markets for ideas and knowledge as inputs in the innovation process, rather than on product markets. They argue that competition for workers with knowledge and ideas that drives innovation not only raises their value but also provides an incentive for firms to seize innovative opportunities and new ideas before they are taken by other firms. Consistent and compelling empirical evidence has found that a spatial structure and organization of competition tends to exhibit a higher degree of innovative activity than does a spatial structure of market power and concentration of economic activity among a few firms (Glaeser, Kallal, Scheinkman, and Shleifer, 1992; and Audretsch and Feldman, 1996).

98. A different aspect of spatial structure and organization involves economic activity which is generated in entrepreneurial firms rather than in established incumbent enterprises. A rich body of literature has identified that entrepreneurship plays a key role in innovative activity by serving as a conduit for the spillover of knowledge from the firm in which it was created to the new firm in which it was actually transformed into innovation.

99. The knowledge production model of innovation links knowledge inputs, such as research and development (R&D) and human capital to innovative outputs (Griliches, 1979). There are compelling reasons why, however, the decision-making hierarchy of the incumbent organization may not place the same valuation of new ideas generated by those knowledge producing investments, such as R&D, that does the employee working on the new ideas. New ideas and knowledge are distinct from other economic goods because of the degree of inherent uncertainty, asymmetries and high transactions costs involved in explaining why the new idea may be potentially valuable. It may seem more obvious to the individual worker who developed the idea why it may actually enhance profitability if implemented and transformed into an innovation than it does to a broad spectrum of decision-makers with different backgrounds and experience sets, even though they are all in the same firm. Decision makers with diverse experience sets, backgrounds and perspectives will tend to value an inherently uncertain idea differently. Thus, the valuation placed on a given new idea and potential innovation, even if the firm made the investments to generate that idea, may be higher to the employee who created the idea and the decision-makers within the organizational hierarchy (Audretsch, 1995; Audretsch, Keilbach and Lehmann, 2006; and Klepper, 2007).

100. Differences between how an employee and the decision-making hierarchy within a firm value an idea can lead to the decision by the firm not to transform the idea into a new innovation by the firm. Such a decision generates an entrepreneurial opportunity if the employee or values the idea as being potentially profitable.

101. It is what has been termed as constituting the knowledge filter that impedes employees in a firm but being unable to transform new ideas into innovations. The

knowledge filter poses a barrier preventing new knowledge from being transformed into innovative activity in the firm that actually created the new ideas (Audretsch, Keilbach and Lehmann, 2006; Qian and Jung, 2017; Braunerhjelm, Ding and Thulin, 2017; and Link, 2017). However, it also creates the opportunity for knowledge spillover entrepreneurship, which is defined as entrepreneurship that occurs from new knowledge and ideas created in the context of an incumbent firm but actually is transformed into innovative activity in the context of a new entrepreneurial startup (Audretsch, Keilbach and Lehmann, 2017; Qian and Jung, 2017; Braunerhjelm, Ding and Thulin, 2017; and Link, 2017). Because the new ideas, which were generated by the incumbent firm's investment in research and development and human capital are not able to penetrate the firm's knowledge filter, they become the basis for an entrepreneur(s) to start and grow a new entrepreneurial firm (Audretsch, 1995; and Klepper, 2007).

102. An example of knowledge spillover entrepreneurship is provided in the context of Europe. Five IBM engineers were involved working on developing a new product, Scientific Data Systems (SDS)/SAPE software. The company, however, did not value the potential value of the product and decided to drop the project. Convinced of its potential value, the five engineers left IBM and instead started their own firm, *Systemanalyse und Programmentwicklung* (System Analysis and Program Development), or SAP, which became Europe's most prominent example of an entrepreneurial startup that achieved global dominance. The investment in the new knowledge was made in one firm, IBM, but the actual innovations were realized in the context of a new entrepreneurial startup, SAP (Audretsch and Lehmann, 2016).

103. By serving as the conduit for the spillover of costly knowledge in which firms and society have made substantial investments, entrepreneurship is conducive to innovative activity for two important reasons. The first is that as the factor and resource of knowledge becomes more important, entrepreneurship also becomes more important because those not able to penetrate the knowledge filter of firms create entrepreneurial opportunities. The second reason involves the link between investments in knowledge, such as human capital and R&D and innovative activity. Innovation is assumed to automatically benefit from knowledge spillovers in the models of endogenous growth (Romer, 1986, 1990 and 1994; and Lucas, 1988 and 1993). However, regions with strong investments in new knowledge may not necessarily experience robust innovative activity (Audretsch, Keilbach and Lehmann, 2006). Rather, the knowledge filter may impede the transformation of new knowledge into innovative activity.

104. There are compelling case studies identifying regions unable to transform rich investments in knowledge, principally research and development (R&D) and human capital into innovation. For example, what is commonly referred to as the "Swedish Paradox" and the "European Paradox", characterize two contexts where only a paucity of innovative output resulted from significant investments in knowledge (Audretsch and Lehmann, 2016). Other examples abound, such as the Baltimore region in the United States, where Feldman and Desrochers (2003) find that robust investments in research and development (R&D) and human capital failed to provide a catalyst for commercialization of that new knowledge in the form of innovative activity.

105. Thus, entrepreneurship is an important form of spatial organization and structure because it can serve as a crucial conduit facilitating new ideas and knowledge to spill over from the firm making the investments to create the knowledge to the entrepreneurial startup actually commercializing those ideas though innovative activity. Entrepreneurship

provides a missing link between the investments in new knowledge and innovation (Audretsch, Keilbach and Lehmann, 2006; and Qian and Jung, 2017).

106. The key role played by entrepreneurship in providing a conduit for the spillover of knowledge and innovative activity has been identified in a number of studies. In particular, one group of studies finds that the propensity for individuals to become an entrepreneur is higher in contexts characterized by large investments in new knowledge, typically measured in terms of research and development (R&D) and human capital. The positive relationship between investments in new knowledge and entrepreneurial activity spans all of the main units of observation in economic analysis, ranging from individuals to firms, industries, regions and entire countries (Audretsch, 1995; Zucker, Darby and Armstrong, 1998; and Klepper, 2001). High rates of entrepreneurship are generally associated with contexts exhibiting a high degree of investments in new knowledge. Studies similarly tend to find that contexts investing relatively little in R&D and human capital, or new knowledge, generally tend to experience less entrepreneurship (Audretsch, Keilbach and Lehmann, 2006; and Klepper, 2001 and 2007).

107. A different set of studies has found a positive impact of entrepreneurship on economic performance, typically measured in terms of economic growth or unemployment (Braunerhjelm, Ding and Thulin, 2017; Audretsch, Keilbach and Lehmann, 2006; and Qian and Jung, 2017). The positive relationship between entrepreneurship and economic growth is robust for multiple spatial units of analysis, including cities, regions and states or provinces within a particular country, to cities and regions within a cross-national context, and to countries spanning a broad range of economic development contexts. Thus, both theoretical arguments as well as systematic empirical evidence suggest that a spatial organization and structure consisting of entrepreneurship is conducive to both innovation and economic growth.

108. Several aspects of spatial structure and organization, notably entrepreneurship and spatial diversity, clearly served as a catalyst for innovation in the third industrial transition. In the first and second industrial transitions, different aspects of spatial organization and structure seemed to have been more important for innovation and economic performance, such as market power and spatial specialization.

109. However, as discussed earlier, in the earlier stages of the life cycle of each industrial transition, a spatial organization and structure characterized more by entrepreneurship and spatial diversity rather than by monopoly and spatial specialization may have been more conducive to innovation. Thus, there are several reasons to speculate or project that as the fourth industrial transition unfolds, several characteristics of spatial structure and organization emerge as being the most advantageous for innovative activity. The first is a clustering of economic activity in the new technologies. In fact, clusters have been shown to be linked to innovative activity across all of the first three industrial transitions, and because they draw heavily on knowledge and ideas, the economies accruing from cluster activity are also likely to emerge in the fourth industrial transition as well.

110. The second characteristic likely to prove advantageous in the fourth industrial transition is spatial diversity. The technologies underling the fourth industrial transition, such as artificial intelligence (AI) and machine learning facilitate integration across a broad range of industries and types of economic activity. Thus, the potential for rich knowledge spillovers across technologies and industries will be available only if a broad range of diverse activity is present. By contrast, spatial specialization will tend to limit the opportunity for knowledge spillovers and integration. The third characteristic is a high degree of competition to make the most out of costly investments in knowledge and ideas,

particularly with respect to the application and commercialization of artificial intelligence and machine learning. This will enhance the returns accruing to workers and firms investing in artificial intelligence (AI) and machine learning, as well as other knowledge capabilities.

111. The fourth characteristic of spatial structure and organization that is likely to be conducive to innovative activity in the fourth industrial transition is robust entrepreneurial activity. Not only does entrepreneurship play a key role in the early stages of industrial transitions, but it seems to gain in importance in contexts where knowledge and new ideas are a key resource and factor of production. At least the early stages of the fourth industrial transition are likely to be fraught with uncertainties and knowledge asymmetries, suggesting that a spatial structure and organization of entrepreneurship is likely to be conducive to innovative activity in the fourth industrial transition.

112. It is important to emphasize that the specific forms of spatial structure and organization identified here are not at all exhaustive and more illustrative of the types that have been to be important for innovative activity and economic performance. There are many additional aspects of spatial structure and organization that also exert considerable influence on innovation that need to be considered when formulating innovation policy.

5.3. Spatial Culture & Institutions

113. Spatial culture and institutions, or what has been referred to as the human dimension (Audretsch, 2015) manifests itself in a broad spectrum of geographically focused activities and characteristics, including linkages, networks, interactions, leadership, identity, image and emotional affinity. These are all particular aspects characterizing spatial culture or the human dimension. It remains a formidable challenge for public policy to provide precise measurement of what actually constitutes spatial culture and institutions.

114. In comparing two similar regions during the third industrial transition, the Boston greater region and Silicon Valley in California in the United States, Saxenien (1994) sought to explain why Silicon Valley exhibited a consistently stronger innovative performance than did Boston, despite having similar profiles in terms of the key knowledge resources and factors of production, such as research and development (R&D), human capital and universities. Her analysis suggested that the regional innovative advantage of Silicon Valley stemmed from a very different source – spatial culture. In particular, Saxenien (1994) found that the regional innovative advantage was not attributable to differences in investments in key factors and resources, such as research and development, but rather to the way that people interact with each other.

115. The human interactions Saxenien (1994) found to provide the catalyst for the regional innovative advantage consisted of linkages and networks. She found that while Silicon Valley was characterized by rich and vibrant networks and linkages, by contrast people in the Boston region tended to work in a disconnected, autonomous manner with a paucity of linkages and interactions, *"It is not simply the concentration of skilled labor, suppliers and information that distinguish the region. A variety of regional institutions – including Stanford University, several trade associations and local business organizations, and a myriad of specialized consulting, market research, public relations and venture capital firms – provide technical, financial, and networking services which the region's enterprises often cannot afford individually. These networks defy sectorial barriers; individuals move easily from semiconductor to disk drive firms or from computer to network makers. They move from established firms to startups (or vice versa) and even to*

market research or consulting firms, and from consulting firms back into startups. And they continue to meet at trade shows, industry conferences, and the scores of seminars, talks, and social activities organized by local business organizations and trade associations. In these forums, relationships are easily formed and maintained, technical and market information is exchanged, business contacts are established, and new enterprises are conceived. […] This decentralized and fluid environment also promotes the diffusion of intangible capabilities and understandings" (Saxenien, 1994). The importance of culture in driving the innovative performance was backed up by her finding that software engineers and others involved in the Silicon Valley networks use language and vocabulary is specific to the region, providing a common social regional bond.

116. As Acemoglu, Johnson and Robinson (2002) and Acemoglu and Robinson (2012) conclude, Saxenien's insight is not restricted to a single case study consisting of two regions in one OECD country. Rather, they provide compelling examples of other regions and contexts where culture and institutions provide the catalyst for innovation.

117. The Emilia-Romagna region in Italy's northeast is one of the most productive regions in Europe, resulting in one of the highest living standards in Europe and the OECD. For example, the per capita GDP of Emilia-Romagna is roughly 25 percent greater than the mean GDP per capita for Italy and over one-third greater than the mean GDP per capita for the European Union. Piore and Sabel (1984) found that the innovative advantage of the region lies in the unusual and exceptional networks, linkages and interactions among people. Particularly in the high-value specialized textile industry, people were linked by interacting through a rich web of organizations, institutions, and cultural traditions. According to Piore and Sabel (1984), such interactions facilitated a high flow of knowledge and best practices, as well as a complex combination of both competition and cooperation, across people, ultimately resulting vibrant innovations. According to a former President of Emilia-Romagna, Vasco Errani, *"The Emilia-Romagna Region is committed to ensuring socio-economic dynamism, innovation capacity and quality of development to foster the creation of new business, the growth of the existing ones and to create therefore new employment opportunities. In Emilia-Romagna innovation at all levels is the result of the initiative and creativity of our entrepreneurs and skilled manpower, in a very heterogeneous business system which is all the more robust (from very small to medium-small and large enterprises, from manufacturing and agricultural to co-operative enterprises). It is a continuous process, embedded in the widespread culture of the Emilia-Romagna society, and supported by politics and institutions."*[29] As the Emalia Romagna and Silicon Valley examples suggest, the key role played by the human dimension in the form of linkages, networks as a driver of innovation applies at least to the third industrial transition.

118. Another example of a region benefitting from networks to foster innovative activity is the Research Triangle Park regions of North Carolina. The successful transformation that resulted from Research Triangle Park was attributed by the former governor of North Carolina, Governor Hunt, to the interactions and linkages among key people, "The secret of the Park's success is the relationships between those people who teach, those people who do research, and the public and the private sector and those of us in government" (Link, 1995, p. 43)

[29] Aster Emilia-Romagna High Technology Network: Technopoles. Aster: Bologna. (2011, February). Available World Wide Web: http://www.diaprem.unife.it/materiale-teknehub/Tecnopoli.pdf

119. Cities and regions that have more social capital and these places tend to do better economically. More broadly, the concept of social capital has been used to reflect regions characterized by a strong human dimension (Malecki, 2012). Other regions seem to chronically suffer from a paucity of social capital, which impedes policy efforts to stimulate a transition away from a historically based type of economic activity that is no longer viable or function. Addressing factors and resources and spatial structure and organization may not compensate for a paucity of social capital.

120. A broad consensus exists that social capital is important for fostering innovative activity. At the same time, there is less agreement about what actually comprises social capital (Paldam, 2000). The World Bank defines social capital as, *"the norms and networks that enable collective action. It encompasses institutions, relationships, and customs that shape the quality and quantity of a society's social interactions. Increasing evidence shows that social capital is critical for societies to prosper economically and for development to be sustainable. Social capital, when enhanced in a positive manner, can improve project effectiveness and sustainability by building the community's capacity to work together to address their common needs, fostering greater inclusion and cohesion, and increasing transparency and accountability."*[30]

121. Social capital is important for innovative activity, especially in industrial transitions, because it facilitates complementarities and knowledge spillovers across both firms and people (Coleman, 1988). Innovation, particularly during an industrial transition, requires collective action. Social capital creates a platform for collective action that is conducive to innovative activity. This aspect of the human dimension generally focuses on social organizations and other groups that help people act collectively. In particular, social capital characterizes the interactions and relationships of people, and spans trust, norms, cooperation and coordination.

122. According to Putnam (2000), *"Whereas physical capital refers to physical objects and human capital refers to the properties of individuals, social capital refers to connections among individuals – social networks and the norms of reciprocity and trustworthiness that arise from them. In that sense social capital is closely related to what some have called 'civic virtue.' The difference is that 'social capital' calls attention to the fact that civic virtue is most powerful when embedded in a sense network of reciprocal social relations. A society of many virtues but isolated individuals is not necessarily rich in social capital."*

123. Empirical evidence confirms the hypothesis that social capital is conducive to innovation (Durlauf, 2002; and Sobel, 2001). Those regions exhibiting high levels of social capital tend to generate a high level of innovative activity. By contrast, low levels of regional social capital tend to be associated with a paucity of innovation.

124. Social capital in general, and network and linkages in particular, seem to have been particularly relevant in the third industrial transition. This is because the resource and factor of production, knowledge and ideas, played such a prominent role in the third industrial transition. However, a spatial culture of networks and rich interactions among people within the region is conducive to transforming ideas into innovative products, services and processes.

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[30] The World Bank Group, "Overview: Social Capital," Accessed on August 15, 2018 at http://go.worldbank.org/C0QTRW4QF0.

125. Empirical evidence suggests that social capital which was formed during an early industrial era can actually impede the transition to a new industrial era. For example, studies have found that both the extent of entrepreneurship as well as the underlying entrepreneurial culture is the lowest in those regions of the United Kingdom which had actually been the economic leaders during the industrial revolution and in the second industrial transition – particularly in the North of England (Stuetzer et al., 2016). By contrast, those regions which were not particularly developed in the industrial revolution and the second industrial transition, particularly in the south of England, tend to exhibit the highest degree of entrepreneurial culture as well as actual entrepreneurial activity. The interpretation is that the cultural imprint from the earlier industrial eras left a cultural imprint that developed social capital for workers to engage in large-scale production in factories but not think and behave entrepreneurially, where autonomy and creativity are key personality attributes (Stuetzer et al., 2016). The presence of large-scale industries during the Industrial Revolution in Great Britain seem to have left a long-term imprint that negatively affects different aspects of entrepreneurship, entrepreneurship culture and the actual entrepreneurial activities, even after the large-scale industries have lost their dominating role in the regional economy (Stuetzer et al., 2016).

126. This third aspect or pillar, spatial culture and institutions, shaping the innovative and economic performance of cities and regions will play an important role in the fourth industrial transition. This is because of the importance of human relationships and networks, particularly across different industry and regional contexts, in communications and decisions as well as coordinating economic activity. The role played by weak ties and informal linkages will be important in the fourth industrial transition because of the integration required across disparate technologies and industries. This will raise the value of people who understand a broad spectrum of technological and industry contexts and have the communication and "soft" skills required to communicate across those technological and industry contexts. (Lazear, 2004 and 2005).

6. Rethinking Policy Strategies for Industrial Transition

6.1. The Diffusion of Innovation and Productivity

127. As the previous sections make clear, industrial transitions can wreak havoc on society and the economy, but they also present new opportunities for innovation and an enhanced standard of living. The ability of a city or region to harness the opportunities afforded by an industrial transition rather than succumb as a victim may be shaped by the particular policy strategies. While each industrial transition is unique, several insights guiding policy strategies for industrial transitions, including the contemporary transition to Industry 4.0, can be gleamed. The first is that the efficacy of policies to facilitate the diffusion of innovation and productivity may influence whether a region is able to successfully navigate an industrial transition or rather is derailed by an industrial transition.

128. Experience from previous industrial transitions suggests that policies oriented not to adapt new technologies and innovations but rather to maintain the status quo technologies, or what was conducive to innovation and a strong economic performance during the previous industrial era may not work in the subsequent economic transition. For example, when the inventor of the stocking frame knitting machine, William Lee, petitioned Queen Elizabeth for patent protection in 1589, he was turned down on the grounds that it would displace existing labor, *"Thou aimest high, Master Lee. Consider thou what the invention could do to my poor subjects. It would assuredly bring to them ruin by depriving them of employment, thus making them beggars."*[31]

129. Some of the most innovative and prosperous regions in the second and third industrial eras, such as Detroit in the United States and the North of England remained committed to the status quo policy strategies that had proven conducive to innovation and a strong economic performance, floundered in the industrial transition to the computer era due to inability to adapt innovations that would have enhanced productivity. Policy in the second industrial transition had focused on resources and factors of production such as physical capital and access to relatively unskilled labor. For example, when the Chairman of General Motors declared, "What's good for General Motors is good for America"[32], it was widely interpreted as a confirmation of policies prioritizing investments in physical capital and a spatial structure and organization focusing on specialization in the status quo industry, which was characterized by considerable market power, automobiles.

130. By contrast, the third industrial transition was been based on very different factors of production and resources, such as high levels of human capital, and high knowledge investments in research and development (R&D) and universities. Similarly, the forms of spatial structure and organization that have been more conducive to innovation were clusters, spatial diversity rather than specialization and entrepreneurship, because they generally facilitate the spillover of knowledge. In addition, a very different cultural and institutional context, emphasizing independence and autonomy seemed to be more effective than the cultural and institutional contexts emphasizing obedience and conformity in the second industrial era.

[31] Cited from Acemoglu and Robinson (2012, p. 182).

[32] Cited in Halberstam (1993, p. 118).

131. Rather than sticking with the policy approach that worked effectively during the previous industrial era, a more successful strategy is to focus policy on the resources and factors of production, forms of spatial structure and organization, and spatial culture and institutions that are conducive to innovative activity and a strong economic performance in the new industrial transition. Typically, the sanguine policy strategy addresses all three dimensions underlying innovation and economic performance and strives to achieve policy coherence in addressing the challenges posed by industrial transition. For example, a study by the Centre for European Economic Research (ZEW) found that only five percent of firms in Germany use artificial intelligence (AI). To take advantages afforded by the growth industry of AI, the study argues a proactive policy to accelerate the rate of adaption.[33]

132. For example, an element of the spatial culture and institutions, leadership, played a key role in facilitating a positive shift from the second to the third industrial transition in the Basque region of Spain, involving the cities of Bilbao and San Sebastian. During the second industrial era, the Basque region, and in particular the city of Bilbao developed a policy strategy revolving around shipbuilding. The key resources and factors of production were physical capital combined with low skilled labor. The form of spatial organization and structure was a high degree of specialization in a single industry, shipbuilding, which was dominated by a handful of firms. However, by the 1980s, on the eve of the third industrial transition, the Basque region lost its competitive advantage in shipbuilding. Economic growth stagnated and unemployment was in the double digits (Basque Institute of Competitiveness, 2013).

133. According to Mendia, who worked in the Ministry of Industry for the Basque region at the time, the key challenge in adjusting to the (third) industrial transition was to transform the identity to people living there and the image to the outside world. The policy instrument deployed was a campaign to persuade the Guggenheim Museum in New York City to make Bilbao the location of its first museum outside of North America. The strategy revolved around shifting the identity and image of the region, through engaged and focused leadership, from manufacturing based on combining physical capital with low human capital to a region featuring culture, hospitality and innovation.

134. Regional leadership was important to overcome the inertia and resistance against the new policy approach. According to Alfonso Martinez Cearra, who served as the Director General of Bilbao Metropoli-30, a non-profit organization devoted to the strategic management of Bilbao, *"Originally 95% of Bilbao's politicians were against the Guggenheim Museum arguing that with the money they could build a new factory, but now they have changed their minds. They agree that a new image is needed to revitalize the city, resorting to art and culture. In France, the Mitterand era invested millions of francs in Paris. Paris is thus a key city to learn about image in the world."*[34]

135. Procuring the Guggenheim at Bilbao required a substantial investment. The agreement reached between the Solomon R. Guggenheim Foundation the Basque Government required an investment of around $100 million to construct the museum in Bilbao. The Guggenheim Foundation also required the Basque to pay a one-time fee of $20

[33] "Künstliche Intelligenz hat langfristig sehr gute Wachstumsaussichten," *ZEWNEWS*, July/August, 2018.

[34] Alfonso Martinez Cearra, "Bilbao: Revitalisation through Culture," Accessed on August 16, 2018 at http://www.rudi.net/books/10603.

million and an annual contribution of $12 million for the budget to run the museum, which would be managed by the Guggenheim Foundation.[35]

136. The opening of the Guggenheim Museum Bilbao in July 1997 by King Juan Carlos I of Spain marked the departure from the previous industrial era and the beginning of the new industrial transition. Not only did the spatial culture and institutions adjust to the new industrial transition, but the key resources and factors of production shifted from physical capital and unskilled labor to knowledge, research and human capital, "*The effect of the Guggenheim on Bilbao has been amazing in many ways. For example, with the influx of tourists to a small formerly industrial, inward-looking city, children have been exposed to seeing people from all over the world - Asians, blacks etc., people they had never seen before. The Guggenheim is an extraordinary building. You can't tell people how to be a modern city, you have to integrate what is there. Gehry (the architect) did this. The building integrates the city and while it is beautiful from the outside, from the inside it is even more stunning. The Guggenheim has become a symbol for Bilbao. 1.36 million people visited the museum in its first year and it generated 0.47% of the Basque Country's GDP.*"[36] The 2017 GDP per capita in the Basque region was about ten percent higher than the GDP per capita for the entire country.[37]

137. The strategy for policy for the Basque Region and Bilbao also involved shifting the locus of the spatial structure and organization from spatial specialization to spatial diversity. The successful policy enabling Bilbao to transition from a dismal economic performance with little innovative activity towards the end of the second industrial era to a vibrant economic performance with a high degree of innovative activity during the third industrial transition had to transform elements of the resources and factors of production, the spatial structure and organization, and the spatial culture and institutions. As Cearra points out, *"What has been achieved through cultural investments in Bilbao is that the exterior diffusion of Metropolitan Bilbao's image is now associated with leisure and culture - not industry. Cultural infrastructures have an important role to play in cities. They contribute to higher levels of competence, creativity and security, not to mention social cohesion. They promote a better understanding between different cultures and different generations of the society. Likewise, they encourage the citizens to participate more actively in collective development, thereby bringing about a greater awareness of identity and benefiting or creating local traditions."*[38]

138. Another example where policy has enabled a region to harness the opportunities afforded from an industrial transition rather than succumbing as a victim is San Diego in the United States. During the second industrial era, San Diego had served as a naval base

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[35] Pedro Gomez Damorena Gomez, Deputy Minister for the Press Office, Planning & Strategy, Department of Industry, Innovation, Trade & Tourism, Basque Government. "Perspectives on Basque Competitiveness." Presentation at the 15th TCI Annual Global Conference: Bilbao, Spain. 17 October 2012.

[36] Alfonso Martinez Cearra, "Bilbao: Revitalisation through Culture," Accessed on August 16, 2018 at http://www.rudi.net/books/10603.

[37] Accessed on August 16, 2018 at https://countryeconomy.com/countries/spain-autonomous-communities/basque-country.

[38] Alfonso Martinez Cearra, "Bilbao: Revitalisation through Culture," Accessed on August 16, 2018 at http://www.rudi.net/books/10603.

and other military facilities. However, in the transition to the third industrial era, the economic performance stagnated.

139. By formulating a strategy to refocus policy away from the strategies of the second industrial divide to a new approach that involved all three dimensions underlying innovation and economic performance, San Diego was able to reinvent itself. In terms of resources and factors of production, the region shifted away leveraging its coast to instead leveraging the research and development (R&D), particularly at the life science programs at the universities, along with the high levels of human capital. In terms of spatial structure and organization, the policy shifted away from prioritizing spatial specialization to entrepreneurship. The shift in spatial culture and institutions was to develop novel policy instruments to promote rich networks among people spanning the business, university and government communities.

140. New policy instruments to create networks, such as CONNECT, were implemented with the goal of linking and connecting life science entrepreneurs, scientists, innovators and the finance community, including venture capital and angel capital. According to Walshok and Schragge (2013, p. 27), *"The key purpose of University of California-San Diego CONNECT was to link academic researchers with entrepreneurs, and then to link both of these parties to venture capitalists and business service providers who could help grow new companies that would create high-wage jobs and regional prosperity at a time when a number of regional economic 'drivers' such as real estate, banking and defense contracting, were in disarray. CONNECT was truly a bottom up collaborative which developed after extensive consultation with university researchers, private-sector executives and professional business service providers."* The networks and linkages through the CONNECT program spawned some of the key firms and industries in the newly emerging third industrial transition in the life sciences

141. Walshok and Schragge (2013) emphasize that a strong social capital has been an enduring characteristic of the region, providing it with the resilience but also flexibility to change policy approaches and strategies that are specific to a particular strategy. According to Walshok and Schragge (2013), *"Second tier cities such as San Diego, Seattle and Phoenix often have distinguishing features that allow them to be more nimble and adaptable than first tier cities such as New York, Chicago or Miami. Many metropolitan areas whose citizens decry their lack of Fortune 500 companies, large employers, established multigenerational leadership and family wealth have developed out of necessity, high risk, innovative, entrepreneurial, and frequently collaborative approaches to economic growth, which today are the envy of many first tier cities. New York, Stockholm and Bogota have all launched CONNECT programs, originally created in San Diego. Chicago, Detroit and Atlanta have launched technology venture funds based on a model originally created in Austin, Texas. It could even be argued that in the absence of large scale established companies and powerful centers of civic leadership, second tier cities often, out of necessity, develop experimentation and risk taking that can end up paying off in big way for an innovation economy. That has certainly been the case in San Diego since the turn of the last century."*

142. Another example is provided by Link (1995), who also identifies the key role played by a shift in policy strategy to navigate North Carolina out of a dismal economic performance with little innovation during the second industrial era to ranking among the most innovative regions in the world during the third industrial transition. The successful strategy involved a policy congruence in re-focusing the priorities among the three key dimensions underlying innovation and economic performance. The priorities for resources

and factors of production shifted from physical capital and unskilled labor, chiefly in the tobacco, small-scale agriculture and textile industries in the second industrial era to human capital and knowledge based on research and development (R&D) and human capital to the third industrial transition. Regional leadership contributed to innovation by formulating and implementing both a vision and strategy for innovation, as well as in communicating that strategy and innovation with local decision makers. In addition, leadership can help transform the identity of a region to the rest of the world as well as the region's own self-image. In particular, leadership helps to generate and implement a vision, which is then linked to a strategy, to improve a place's economic performance. Leadership also must communicate this vision to others and persuade people to buy into their vision. Effective leadership is important in changing perceptions of a place, both for the people at the place as well as the perceptions of others everywhere else. Link (1995) explains how leadership provided the catalyst for an industrial transition, away from the mature and declining industries to new emerging industries by transforming the identity and image of the region.

143. To facilitate the diffusion of innovation and productivity in the fourth industrial transition, a policy congruence across all three pillars or dimensions influencing economic performance is required. Human capital, including skilled labor, and knowledge will be the most important resources and factors of production to diffuse innovation and productivity in the fourth industrial transition. Policy instruments, such as education at all levels, research and development (R&D) and universities and other research institutions will play an important role in the ability of a region to adapt new technologies and leverage them to enhance productivity. As Aghion and Howitt (1994) make clear, technological change has a much more pervasive impact beyond the displaced workers. The efficiency gain results in a real income effect, which in turn can raise demand for other goods and services. The demand for labor will increase in those markets. Goldin and Katz (2009) conclude that education has been the key to equipping the labor force with the flexibility to exit out of the industries where labor has been displaced by technology and capital and enter into industries where human skills are still needed. In fact, in their projections of the impact of the fourth industrial transition on specific occupations, Frey and Osborne (2017) find that the demand for jobs that are not vulnerable to artificial intelligence and machine learning will increase. In particular, they identify an increase in employment in occupations such as engineering and sciences, but also those with a large component of social intelligence and creativity. The future of education hinges on its ability to equip workers with the requisite skills for the fourth industrial revolution.

6.2. The Locus of Innovation Policy: External and Internal Factors

144. Innovation policies can have a broad institutional, spatial and political locus, ranging from local to regional, national and even supranational, such as the European Union. All are important and play an important role in industrial transitions. Rather than debate which policy level is more important and should take precedence, the more relevant and pragmatic approach is to analyze the policy congruence between the external and internal factors.

145. External factors at the regional level generally refer to the three pillars influencing innovation and economic performance discussed in the previous section – resources and factors of production, spatial structure and organization, and spatial culture and institutions. These pillars underlying regional innovation and economic performance can be either within the region, in which case they are internal factors, or external to the region, or a combination of both.

146. The variation in innovation and productivity within countries suggests that innovation policies at the national level cannot alone generate high levels of innovation and productivity. Conversely, without a congruent national innovation policy, the impact and success of local and regional innovation policies may also be limited. For example, OECD countries with a strong innovation performance, such as Canada, exhibit a large spatial variance in innovative example. The most innovative province, Ontario, had around 150 annual patent applications per capita between 2010 and 2012.[39] By contrast, the province of Atlantic Canada was only about one-fourth as innovative, with fewer than 40 annual patent applications per capita, and the province of Manitoba was just over one-half as innovative with 80 annual patent applications per capita.[40]

147. Similarly, in a different OECD country exhibiting considerably less innovative activity, Italy, there is also substantial variance. For example, as Figure 5 shows, the Lombardi region ranks as the European region with the eleventh highest number of patent applications at the European Patent Office in 2016. By contrast, regions in the south of Italy are considerably less innovative.[41] These examples are characteristic of the high degree of spatial variation of innovative activity exhibited within OECD countries. This suggests that factors external to the province, such as the national system of innovation (Lundvall, 1992; Nelson, 1993; and Edquist, 1997), along with national innovation policy more generally, is not a guarantee for a strong regional innovative performance.

148. Conversely, empirical evidence would seem to suggest that a weak external innovative context hinders the innovative capacity of regions. For example, the twenty most innovative regions in Europe in 2017 were concentrated in just ten countries – Germany, France, the Netherlands, Sweden, Great Britain, Italy, Belgium, Denmark, Switzerland and Austria. All of the regions are in countries with a strong innovative performance. Regions not having access to an external context with a strong innovative performance may be confronted with an innovative disadvantage.

[39] Jason Kirby, "And the Engine of Canadian Resourcefulness is…Memo to Trudeau: Canada's Resourcefulness Engine is in the Same Province as its Resource Engine,"*Macleans Canada*, accessed on August 20, 2018 at https://www.macleans.ca/economy/economicanalysis/and-the-engine-of-canadian-resourcefulness-is/.

[40] Jason Kirby, "And the Engine of Canadian Resourcefulness is…Memo to Trudeau: Canada's Resourcefulness Engine is in the Same Province as its Resource Engine,"*Macleans Canada*, accessed on August 20, 2018 at https://www.macleans.ca/economy/economicanalysis/and-the-engine-of-canadian-resourcefulness-is/.

[41] The statistics are from the European Patent Office, "Annual Results and Statistics 2017," accessed on August 20, 2018 at https://www.epo.org/news-issues/press/annual-results.html.

Figure 5. Leading European Regions for patent applications in 2016

Rank	Region	Country	Applications	Growth
1	Bayern	DE	7 240	4.0%
2	Île-de-France	FR	7 090	-4.1%
3	Nordrhein-Westfalen	DE	4 893	-1.5%
4	Baden Württemberg	DE	4 817	-4.5%
5	North Brabant	NL	3 524	4.6%
6	Hessen	DE	2 185	-0.1%
7	Stockholm	SE	1 943	-6.0%
8	Rheinland-Pfalz	DE	1 813	9.0%
9	Greater London	GB	1 551	-3.7%
10	South Finland	FI	1 534	-8.6%
11	Lombardia	IT	1 438	3.0%
12	Vlaanderen	BE	1 405	11.6%
13	Niedersachsen	DE	1 368	0.8%
14	Auvergne-Rhône-Alpes	FR	1 205	0.1%
15	Vaud	CH	1 143	13.8%
16	Zürich	CH	1 091	-5.6%
17	South Holland	NL	1 051	-9.6%
18	West Austria	AT	930	0.4%
19	Basel-Stadt	CH	889	-8.0%
20	Berlin	DE	855	9.6%

Source: European Patent Office

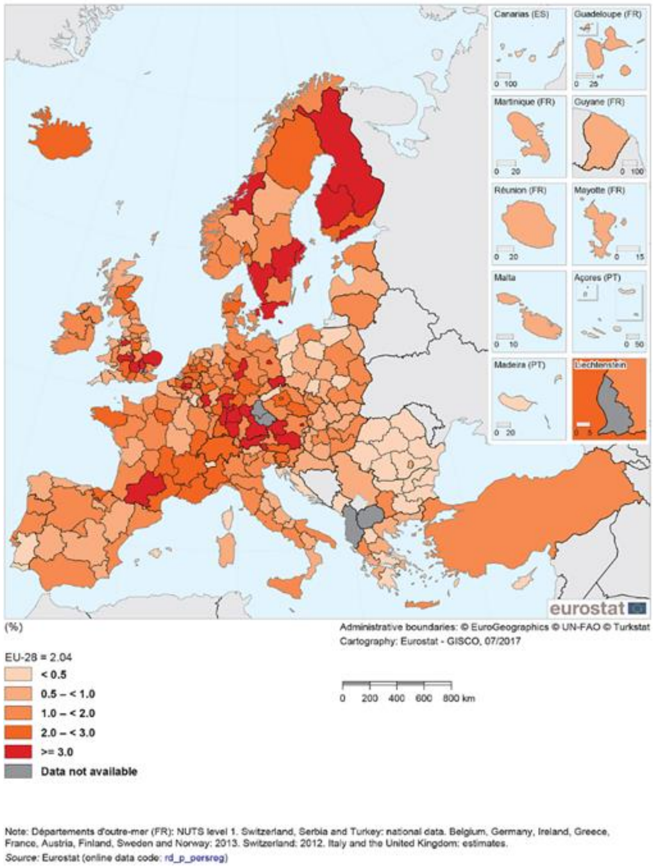
149. Innovation policy congruence suggests that the internal and external policies are complementary in a way that is conducive to regional innovative activity. For example, one-quarter of the twenty most innovative regions in Europe, as measured by patent applications at the European Patent Office in 2017 were located in Germany.[42] At the national level, Germany ranked third in the European Union in 2016 in terms of investment in research and development (R&D), measured as a share of gross domestic product.[43] In addition, there are a number of policies at the national level that create the opportunity for regional policy to leverage them for innovation. For example, research institutes such as the Max Planck Institutes and Fraunhofer Institutes are generally a partnership between funding at the national and Länder levels (Audretsch and Lehmann, 2016).

[42] The statistics are from the European Patent Office, "Annual Results and Statistics 2017," accessed on August 20, 2018 at https://www.epo.org/news-issues/press/annual-results.html.

[43] Eurostat, accessed on August 20, 2018 at http://ec.europa.eu/eurostat/statistics-explained/index.php?title=File:Gross_domestic_expenditure_on_R_%26_D,_2006_and_2016_(%25,_relative_to_GDP)_FP18.png.

Figure 6. R&D intensity

Gross Domestic Expenditure on R&D, relative to GDP, by NUTS 2 regions, 2014



Source: Eurostat.

150. Policy approaches that encourage an external and internal innovation policy congruence have proven to be particularly effective during previous industrial transitions, such as the smart specialization regional policy of the European Union (McCann and Ortega-Argilés, 2016). The smart specialization approach requires a region to focus internal policy on the types of economic activities where the region can develop and sustain a competitive advantage and strong economic performance. According to McCann and Ortega-Argilé (2016, p. 537), *"The basic argument of the smart specialization approach is that policy resources must be prioritized on those activities, technologies or sectors where a region has the most realistic chances to develop wide-ranging and large-scale impacts which also develop and build on many different local and interregional linkages and connections. Such an approach requires that many of these activities and technologies to be prioritized are already partly embedded in the region's existing industrial fabric and that as many local actors and institutions are engaged in the policy design and delivery process. Importantly, policies should be focused on stimulating and facilitating entrepreneurial actions, and with local SMEs being seen not only as the key priority in their own right but developing links between SMEs and other larger local actors is a critical agenda. The argument here is that such linkages can provide the platform and network effects which local entrepreneurial initiatives need in order to build requisite scale."*

151. Technologies associated with the fourth industrial transition, such as artificial intelligence and machine learning, may accentuate the importance of internal innovation policies relative to external policies for the regional innovative performance. This is because of the geography of opportunities in the fourth industrial transition, which will tend to be global. No region is excluded, at least on the basis of geography, from accessing and participating in a particular technological application using artificial intelligence and application. This means that in the fourth industrial transition there are three key elements to regional innovation policy:

1. Identifying global opportunities, which means not that they are globally ubiquitous but that their geographic location could potentially be located anywhere in the world. An important aspect of innovation policy will be to create the institutions and culture needed to develop the absorptive capacity to globally scan for opportunities;
2. Identify and developing regional assets and capabilities in the new technologies
3. Linking the regional assets and capabilities to the global opportunities.

152. Regions and the internal innovation policy community know and understand (2) and (3) better than does the external policy community in an industrial era characterized by rapidly changing new technologies. The knowledge asymmetries between the internal and external innovation policy institutions with respect to knowledge about the region and its assets and capabilities places the internal innovation policy institutions and community at a distinct advantage in being able to identify global opportunities and act on those global opportunities.

6.3. The Focus of Innovation Policy: Specific or Broad-Based Targets?

153. Both specific policy targets as well as broad-based targets play an important role in innovation policy and both contribute to regional innovation performance. However, the roles and the impacts of specific and broad-based policy targets are not symmetric and will evolve during the fourth industrial transition compared to the previous industrial transitions.

154. Specific policy targets were effective at the broader, national locus of policy during the second industrial transition. Examples abound of national policy targeting specific industries and firms to enhance their innovative and economic performance (Johnson, 1984; and Johnson, 1982). For example, the Ministry for Industry and International Trade (MITI) formulated and implemented innovation policy at the national level in Japan that targeted specific industries and firms in industries such as steel, automobiles and machine tools. Systematic empirical evidence found that the specific policy targets resulted in an enhanced economic performance. (Pugel, 1986 and Magaziner and Hout, 1980).

155. There are also examples of specific policy targets for Europe during the second industrial transition. Article 92 of the European Economic Commission Treaty granted the Commission the power to either approve or reject a proposal by a member state to implement a specific-based targeted policy. Most of the national specific targeted policies were in heavy manufacturing, such as hot-rolled steel and shipbuilding. In addition, individual countries such as the Federal Republic of Germany, France, Sweden, Italy and Belgium implemented specific targeted policies at the national level, mostly in heavy manufacturing or textiles (Dorges, 1980; and OECD, 1972).

156. Specific policy targets at the national level may have been effective during the second industrial transition because they revolved around economic activity where the key resource and factor of production was physical capital and moderately or low-skilled labor, typically involved in large-scale production. Innovation was incremental and less radical in such industries, and with relatively mature products, it was relatively straightforward to know or predict the technological trajectories of mature products and industries. Relative certainty about what should be produced, how it should be produced and who should produce it, in terms of firms and industries, is more conduce to specific policy targets at the national level.

157. However, in the third industrial transition, computers, the key resources and factors of production shifted more to knowledge and ideas, along with skilled labor and human capital. In addition, with the expanding extent of globalization, the comparative advantage in the higher cost OECD countries shifted towards economic activity and industries in the earlier stages of the life cycle. With a greater degree of uncertainty about the direction and nature of technological trajectories, asymmetries and greater costs of transacting ideas, specific policy targets proved to be less successful. For example, the CEO of Digital Equipment Corporation (DEC), Ken Olsen, forecast minimal demand for the emerging technology, the personal computer in 1977, *"There is no reason anyone would want a computer in their home"*[44] Similarly, even before the dawn of the computer era, the President of International Business Machines (IBM) had forecast, *"I think there is a world market for maybe five computers."*[45]

158. Thus, the specific innovation policies targeting Computers between 1972-1976, Very Large Scale Project (VLSI) between 1976-1979 and Development of Basic Software and Related Periphery between 1979-1983, which involved companies such as Fujitsu, Hitachi, Mitsubishi Electric, NEC and Toshiba, are not generally viewed as contributing to a successful innovation performance because of the difficulties inherent in selecting specific targets for policy in industries using technologies that are volatile, highly uncertain and rapidly evolving (Pugel, 1986).

159. With early stage technologies and industries, national policies targeting specific targets and industries are confronted with the challenges of a great degree of uncertainty, asymmetries and costs of transacting ideas, rendering such specific policy targets less effective. By contrast, policy targets that are at the earlier stages of the innovation process and closer to fundamental or basic research and development are more congruent with early stage technologies and industries. At the same time, specific targets and industries that encourage knowledge spillovers and commercialization of the more fundamental research and development may be effective if they are at a low-cost small scale. For example, the Fraunhofer Institutes in Germany proved to be highly effective in promoting commercialization of more basic research, such as the development of the MP3 player (Audretsch and Lehmann, 2016). Similarly, the Small Business Innovation Research (SBIR) program in the United States, which involves small and limited amounts of funding per project, has been found to make a valuable contribution in helping small companies

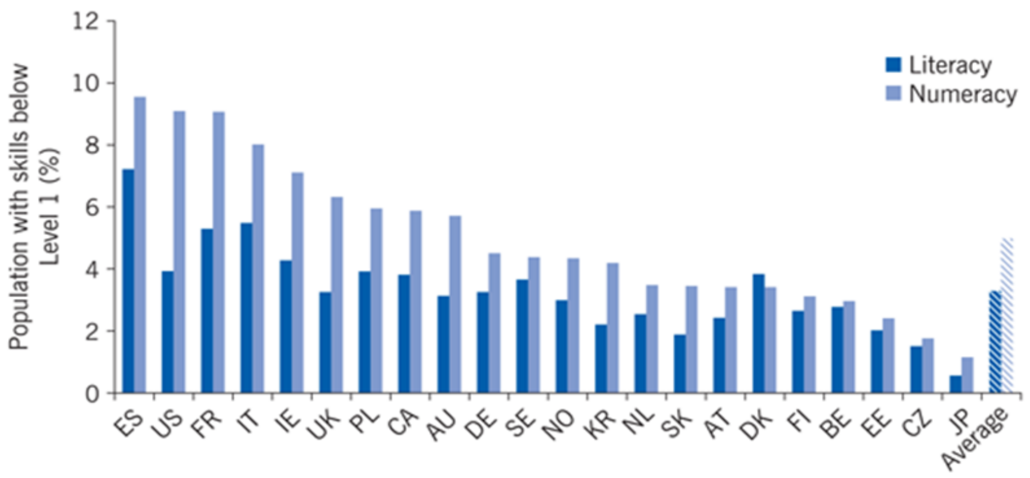
[44] Robert Strohmeyer, "The 7 Worst Tech Predictions of All Time," *PC World*, 31 December, 2008, accessed on August 22, 2018 at https://www.pcworld.com/article/155984/worst_tech_predictions.html.

[45] Robert Strohmeyer, "The 7 Worst Tech Predictions of All Time," *PC World*, 31 December, 2008, accessed on August 22, 2018 at https://www.pcworld.com/article/155984/worst_tech_predictions.html.

commercialize research. It should be emphasized that both of those examples involve national policies that are typically implemented at a regional level. With their regional-specific knowledge about the particular regional capabilities and strengths, specific-based policy targets may be more effective at the regional level.

160. Regional and city success in the fourth industrial transition is likely to require proactive innovation policies involving specific-based policy targets that build on the regional or local strengths and capacities but shift their direction and priorities towards the new technologies, such as artificial intelligence and machine learning. Broad-based policy targets, particularly at the national level in terms of investments in human capital, labor skills, and research and development will provide a platform for the more specific based policy targets formulated and implemented at the regional and local levels. As Figure 7 shows, skill levels clearly vary across the OECD.

Figure 7. The share of the workforce with low levels of skill



Note: Working age population (aged 25 to 64). Below level 1 skills in the PIAAC survey are defined as "very low level." UK refers to England and Northern Ireland. BE refers to Flanders.

Source: OECD. *OECD Skills Outlook 2013: First Results from the Survey of Adult Skills*. Paris: OECD Publishing, 2013.

161. However, it is important to emphasize that Mazzacuto (2013) argues and provides a number of compelling examples suggesting that innovation in the previous industrial transitions, most notably in the third industrial transition involving computer technologies, was facilitated by bold and visionary large-scale projects initiated by governments at the national level. According to Mazzacuto, *"We pretend that the government was at best just in the background creating the basic conditions (skills, infrastructure, basic science). But the truth is that the involvement required massive risk taking along the entire innovation chain: basic research, applied research and early stage financing of companies themselves."*[46] Her argument would suggest that, because supply chains will be increasingly interrelated and entwined, specific policy targets will be more important and effective in the fourth industrial transition.

[46] Rana Foroohar, "Why You Can Thank the Government for Your iPhone," *Time*, October 27, 2015, accessed on August 26, 2018 at http://time.com/4089171/mariana-mazzucato/.

6.4. Conclusions

162. This paper has attempted to garner insights from past experiences with innovation policy in industrial transitions to guide policy in the fourth industrial transition. While each of the previous industrial transitions has been unique, one common feature among them is that the policy response made a great difference in the subsequent innovative and economic performance of regions and cities. The resilience of cities and regions to either harness the opportunities afforded by the industrial transition or else succumb as a victim is highly dependent upon the policy response.

163. Each industrial transition has drawn on a unique mix of the fundamental forces shaping the innovative and economic performance of regions and cities – resources and factors of production, spatial structure and organization, and spatial culture and institutions. Each industrial transition has fundamentally altered the specific fundamental forces within each of these pillars generating a strong and sustainable innovative and economic performance. Policies ignoring or resisting the industrial transition have proven to be not just futile but result in an innovative disadvantage and weak economic performance.

164. Human capital and labor skills using the new technologies, along with scientific and engineering capabilities in artificial intelligence and machine learning are emerging as the key resources and factors of production in the fourth industrial transition. Investments not just in new knowledge and human capabilities but also in the relevant fields and areas, are a *prima fascia* condition for sustainable economic success in the fourth industrial transition. Without the requisite investments in human capital and knowledge, the capacity both to innovate and diffuse or adapt new technologies to the particular region or city will be lacking, dimming the innovative and economic prospects.

165. In the early phase of an industrial transition, when the focal industries and technologies are still in their early and formative stages, spatial diversity across complementary activities may be more conducive to subsequent innovative activity than focused specialization. Knowledge spillovers across different but related technologies and industries are conducive to unanticipated innovations and breakthroughs, as well as more generally creating new opportunities. Cities and regions with robust entrepreneurial ecosystems will be more adept at commercializing basic research and discovering which particular applications of artificial intelligence and machine learning are the most congruent with the particular strengths and assets of the particular city or regions.

166. Perhaps most importantly is that each industrial transition has required a new approach to innovation policy. Sticking with the status quo has generally not led to positive results during the previous three industrial transitions. Rather, *audentes Fortuna iuvat*, or fortune favors the bold.

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