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María Ortiz Polanía

University of Essex

EC203 Technological Change: Past, Present, and Future Prospects

Contribution of Technological Innovation in the Last Third of the 19th to Economic Growth in the 20th Century

Introduction

After World War II, between the late 1940s and the early 1970s, the United States, various countries in Western Europe, and Japan experienced a golden age of economic growth. Some countries in Western Europe had a growth rate high enough to reduce the real GDP per capita gap they had with the United States partly because of the war (Broadberry and O'Rourke, 2010). Evidence shows that, between 1820 and 1950, Western Europe went from having a real GDP per capita of around 96 percent of the American one to having one of around 48 percent of the American one. Fortunately for them, during this golden age, they returned to having a real GDP per capita of around 68 percent of the American one (Broadberry and O'Rourke, 2010).

The golden age was a phenomenon in which all regions (except for Asia) reached their highest growth rate till the moment (Crafts and O'Rourke, 2014). This makes it an era of high interest for economists, leading many to investigate its causes. For example, Gordon (2017) and Crafts (2014) used Solow's model of long-run growth as their main tool to try to explain it. This model parts from a Cobb-Douglas aggregate production function rewritten in terms of labour productivity and expressed as rates of change. It shows how economic growth is explained by changes in labour, capital, or something else that is unobserved and estimated as the residual of the function. Consequently, this residual, called the Total Factor Productivity (TFP) or technology, captures all that explains economic growth different from labour and capital (Solow, 1956).

Solow's model allowed Gordon (2016 & 2017) to empirically argue that the main boost to the high economic growth observed during the Golden Age was a very high increase in technology caused by the elevated levels of innovation present in the United States during the first years of the 20th century. He states that a 99 percent increase in output per hour witnessed in the United States between 1928 and 1950 can be largely attributed to a wave of innovations primarily spurred by the impact of wartime conditions. Consequently, he refers to this period as the great leap forward of the United States (Gordon, 2016) (Gordon, 2017).

It is crucial to note that Gordon's claim has been critiqued by other economists, like Crafts (2018), who found his estimations on the TFP growth to be exaggerated and questioned his emphasis on the effects of the war as the principal driver of increased innovations. Crafts (2018) presented other causes, like previous improvements in education and tendencies toward urbanization, as additional explanations for the rise in innovation. He coincided with the ideas of Mokyr (1990) that assure a series of optimal conditions (not only war) are the determinants of the level of innovation in a society. Mokyr (1990) includes factors like institutions, nutrition, religion, geography, and more.

Nonetheless, Gordon (2017) and Crafts (2018) both coincide in the idea that various innovations at the beginning of the 20th century are responsible for a relevant part of the economic growth observed after World War II. They also agree in attributing this increase in innovation mainly to the doors opened by some General Purpose Technologies (GPTs) invented during the last years of the 19th century (Gordon, 2017). General Purpose Technologies are all those innovations from which a series of sub-inventions are derived.

Still, when comparing Crafts' (2018) evidence, focused on Britain, to Godson's (2017) evidence, focused on the United States, it can be noticed that this innovation era was nonhomogeneous around the world (not even between these two strong economies). Contrasting the periods from 1924 to 1937 for Britain and from 1919 to 1941 for the United States reveals that various sectors of Britain's economy, such as manufacturing and electrical engineering, experienced lower growth in Total Factor Productivity (TFP) compared to their equivalents in the American economy (Crafts, 2018).

Given the previous context, the present article explains the three main GPTs from the late 19th century that, by permitting sub-inventions at the beginning of the 20th century, gave birth to the golden era of growth observed between the late 1940s and 1973. The first section describes this process for electricity, the second for internal combustion engines, and the third for organic chemicals (mainly hydrocarbons). Each section defines its respective GPT, as well as the sectoral changes it caused, its link to economic growth, and the divergencies between countries it presented.

Electricity

In the first place, Gordon (2017) presents electricity as one of the most defining GPTs of all time. According to Devine's (1983) statements, it represented the superiorly swift and complete energy use transition ever registered. From 1890 to 1920, when steam engines accounted for 80 percent of mechanical drive capacity, electricity emerged as the primary replacement for steam power, becoming the dominant source of motive power. This swift transition is also exemplified by the fact that within 45 years of the initial introduction of electric motors in factories, they managed to account for over 70 percent of the total capacity of driving machinery (Devine, 1983).

Furthermore, in addition to the elevated direct impact electricity had on Total Factor Productivity, Gordon (2017) presents its role as a General-Purpose Technology as pivotal for the inventions of the early 20th century, which also had a high effect on economic growth. Gordon (2017) highlights several sub-inventions derived from electricity that he classifies as fundamental drivers of productivity. These inventions include elevators, electric hand and machine tools, electric streetcars, elevated trains, and underground subways (Gordon, 2017). He also points to the importance of these sub-inventions for the simplification of daily domestic tasks of consumers. He exemplifies this by listing the following inventions that surged from electricity and facilitated this kind of duties: the electric iron, the vacuum cleaner, the refrigerator, the washing machine, the clothes dryer, and the dishwasher (Gordon, 2017). Additionally, Gordon (2017) points to the arrival of air conditioning in different spaces (movie theatres in the 1920s, some office buildings in the 1930s, and the American home in the 1950s and 1960s) as a major innovation permitted only by the role of electricity a General-Purpose Technology (Gordon, 2017).

The previous list of inventions may have affected the Total Factor Productivity by reducing workers' levels of stress and exhaustion through the simplification of various of their daily duties and through the improvement of their regular environments. Nonetheless, plenty of electricity's sub-inventions from the beginning of the 20th century can be more directly connected to an increase in Total Factor Productivity. To exemplify this Gordon (2017) lists various sub-inventions of electricity that transformed the manufacturing and transportation sectors in the United States. For example, he points to electric-powered tools that work together with the assembly line as responsible for an increase in productivity. He argues that this innovation facilitated a shift from the traditional manufacturing structure prevalent before

1913, where craftsmen individually assembled goods at separate stations powered by steam engines and leather or rubber belts, to a new structure, where each worker had control over electric-powered machine tools and hand tools, with production organized along the principles of the Ford assembly line. Ford's assembly-line principle, introduced in 1913, aimed to enhance production efficiency by dividing the manufacturing process into sequential stages, with different workers and machines performing distinct tasks to create the final product (Gordon, 2017).

Additionally, Gordon (2017) states that the significant increase in electricity production during the 1930s and 1940s was permitted by economies of scale and their advantages. He affirms that larger electric-generating boilers allowed for the creation of electricity at a reduced unit cost. As a result, he finds that throughout this period, technological advancements permitted boilers to be constructed with increasing size, temperatures, and pressures, resulting in more tightly sealed and reliable systems (Gordon, 2017). Gordon (2017) uses this progression towards higher thermal efficiency and productivity in the electric utility sector to point at the incremental refinements of electric power to the growth in Total Factor Productivity (TFP) as being the result of a continuous process of improvement characterized by both the arrival of new sub-inventions of electricity and the incremental upgrades of the already existing electric power (Gordon, 2017).

Finally, when comparing Gordon’s (2017) conclusions, focused on the United States, with Crafts’ (2018) conclusions, it can be seen how electrical development was one of the sectors in which Britain was still falling behind America. Contrasting the periods from 1924 to 1937 for Britain and from 1919 to 1941 for the United States it can be evidenced how in electrical engineering/electric machinery, the United Kingdom saw a growth of 2.0 percent compared to the United States' 5.0 percent growth (Mowery and Rosenberg, 1998). These led the United States manufacturing productivity, with over 20 percent of TFP growth in the 1920s, to be significantly higher than that of Britain. The contrast in electricity consumption per employee between the two nations further highlights this discrepancy. In 1930, the United States had over three times the electricity consumption per employee that Britain had. Also, the British price for electricity was around 50 percent higher than the American price (Crafts, 2018).

Internal Combustion Engine

In second place, Gordon (2017) points to the transformative impact of the internal combustion engine as a General-Purpose Technology (GPT). The invention of the Internal combustion engine goes back to 1864 when Nicolaus Otto patented the first atmospheric gas engine. Subsequently, in 1872, American George Brayton invented the first commercially viable liquid-fueled internal combustion engine (Mowery and Rosenberg, 1998). It's important to emphasize that while the internal combustion engine is frequently celebrated as a pivotal American technology from the first half of the 20th century, its early development, particularly the gasoline-powered engine in the late 19th century, was largely an achievement of European origin. Notable contributors are Carl Benz, Gottlieb Daimler, Nikolaus Otto, Alphonse Beau de Rochas, Peugeot, Renault, and others (Mowery and Rosenberg, 1998).

The evolution and widespread adoption of the internal combustion engine highlights several of its roles as a GPT in the United States during the first years of the 20th century. The influences of the war in this process can be evidenced, for example, because the abundant domestic supply of low-cost petroleum-based fuels and the significant demand for affordable automotive and air transportation across the United States facilitated the internal combustion engine's rapid advancement and integration within the country's economy (Mowery and Rosenberg, 1998). Also, beyond transportation, the internal combustion engine helped increase productivity in sectors like agriculture with the mechanization of farm implements like tractors (Mowery and Rosenberg, 1998). This advancement had a pivotal role in farming by shaping new methods for the distribution of food and consumer goods. Ultimately, this led to the substantial restructuring of the retail industry alongside other innovations (Mowery and Rosenberg, 1998).

Gordon (2017) highlights how, as a General-Purpose Technology, the internal combustion engine can be seen as a close second when comparing its overall impact to that of electricity. He also points to how it enabled a multitude of sub-inventions and advancements across various sectors and states that it allowed for the transformation of personal travel and commercial transportation. Sub-inventions of the engine listed by Gordon (2017) include automobiles, trucks, buses, and taxis, which reshaped urban landscapes and facilitated the rise of suburbs and associated infrastructures such as supermarkets, motels, and roadside restaurants. This is relevant because, as explained by Mokyr (1990), demographical characteristics and urbanization are two crucial determinants of the level of productivity achieved in an economy.

Like Mowery and Rosenberg (1998), Gordon (2017) gives special attention to the role of the internal combustion engine in the evolution of air travel and its connection to World War II. He focuses on the 1930s when piston-powered military and commercial aircraft saw significant advancements. He notes that this development, rather than a new General-Purpose Technology, was a culmination of the internal combustion engine's invention in 1879 and the aerodynamic design breakthroughs pioneered by the Wright Brothers in 1903 (Gordon, 2017).

Finally, when comparing the United States with Britain and other countries, it is evident how, even though the original version of this engine was brought to the market by a German inventor, the United States was the principal exploiter of its potential sub-inventions while Britain fell behind. These events show the importance of Germany as one of the most determinant countries in terms of its role during the Second Industrial Revolution of the late 19th century. They also show the leading position the United States had in the innovation of sub-inventions of the internal combustion engine during the 20th century (Crafts, 2018) (Mowery and Rosenberg, 1998).

Organic Chemicals: Dyestuffs, Pharmaceuticals and Hydrocarbons

In third and final place, the role of organic chemicals as a General Purpose Technology of the late 19th century that impulsed the growth in productivity during the early years of the 20th century must be underlined. Gordon (2017) underscores the importance of hydrocarbons, specifically oil and natural gas, and highlights the transformative role of plastics as intermediate goods in technological progress. Hydrocarbons, comprising carbon and hydrogen, form the basis of petroleum. This is significant because plastics, primarily derived from petroleum, are synthetic organic compounds with diverse applications that made them immensely valuable throughout the 20th century (Gordon, 2017).

Despite their intermediary nature, oil and plastics underwent substantial advancements during the 1930s, contributing to technological progress and societal change. Gordon (2017) exemplifies this by pointing to the discovery of the East Texas oil field in October 1930, which marked a monumental moment in the American petroleum industry, fueling innovations and discoveries in petroleum and related chemical industries. As a result, the United States saw a surge in plastics innovation with numerous types introduced, including polyvinylidene chloride, low-density polyethylene, acrylic methacrylate, polyurethanes, polystyrene, Teflon, nylon, and neoprene (Gordon, 2017).

These advancements are relevant for the increase in Total Factor Productivity during the first years of the 20th century because they drove sectoral developments in petroleum and plastics industries that made production more efficient. Gordon (2017) identifies this as highly beneficial for the outcomes of the transportation and distribution sectors. He points out the introduction of larger and more durable tires, coupled with improvements in rubber technology, as an example of the statement. This sub-invention, derived from organic chemicals, contributed to the increase in Total Factor Productivity by swiftly increasing agricultural efficiency and facilitating the transition of trucks to become competitors to rail in freight transportation (Gordon, 2017).

Lastly, when comparing the United States with other countries it can be observed again how, before the 1930s (from the Second Industrial Revolution till before the Great Depression), the chemical industry innovations were led by Germany. However, between the 1930s and the 1950s (alongside the Great Depression and World War II), this industry experienced its most significant growth in the United States (Gordon, 2017). More specifically, as signaled by Gordon (2017), various types of plastics had already been invented in Europe before the 1930s. These include celluloid (1863), polyvinyl chloride (1872), cellophane (1908), bakelite (1909), and vinyl (1927) (Gordon, 2017). Still, according to Gordon (2017), the United States emerged in the 1930s as the principal setting for further innovations within the industry. These innovations contain the invention of polyvinylidene chloride (1933), low-density polyethylene (1935), acrylic methacrylate (1936), polyurethanes (1937), polystyrene (1938), Teflon (1938), nylon (1939), and neoprene (1939) (Gordon, 2017).

Conclusion

To conclude, the technological advancements of the late 19th century, particularly electricity, internal combustion engines, and organic chemicals, acted as General Purpose Technologies by laying the groundwork for a series of sub-inventions to increase Total Factor Productivity throughout the first years of the 20th century. This eventually led to an increase in growth that marked the golden age of economic development between the late 1940s and the early 1970s. This information remains pertinent today as it contributes to guiding the analysis required for engaging in crucial discussions surrounding the role of Artificial Intelligence (AI) as a General

Purpose Technology and its ongoing and potential impacts on productivity and beyond. Drawing from the examination of the three General Purpose Technologies explained, it can be argued that the full impact of AI on Total Factor Productivity is unlikely to be immediately apparent. Similar to the GPTs of the late 19th century, it will likely take time for the sub-inventions of AI to begin transforming the economy. Also, as observed with the sub-inventions of the 20th century, disparities in the use of AI as a General-Purpose technology are likely to exist between countries, causing future differences in their levels of growth.

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