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The Invisible Hand of Innovation showing in the General Purpose Technology of Electricity

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Abstract

The unintended economic effect on society as result of individual behaviour —Adam Smith's 'Invisible Hand' of economic progress in the eighteenth century — had its equivalent in technological progress. In the nineteenth century, again individual behaviour with its Acts of Innovation and Acts of Business had an unintended effect. It changed not only the economy, but also the world we are living in. The Communication Revolution, initiated by the 'Engines of Growth' of the GPT-E that are described, was the result of human curiosity, ingenuity and entrepreneurship. It were the General Purpose Engines of the Telegraph, the Telephone and the Wireless —developed by Morse and Cooke/Wheatstone, Bell and Marconi— that created its milestones. With all those other contributors, large and small, their basic innovations constituted the 'Invisible Hand' of technical progress.

Keywords
Adam Smith, General Purpose Technology, technological innovation, cluster of innovation, invention, history of technology.

JEL: N1, N7, O31, O33, O49

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Introduction

We live in the Era of Change. Obvious, as one observes the Communication Revolution and the Information Revolution, and its exponents of the smartphone and the Internet. Disruptive technologies like the Information & Communication Technologies (aka ICT), changed the world we are living in. Today, the magic word is 'innovation'. A word that covers quite a broad range of interpretations. From marketeer to management, from layman to scholar, each has its own interpretation.

When one studies the phenomenon of 'change', one continues on a long path of scholarly exploration. Following the path of the natural philosophers who studied *motion* and the 'Nature of Matter' leading to the Scientific Revolution, and the social philosophers who studied *Human Being* and the 'Nature of Society' leading to the Enlightenment, the innovation scholars of our time are studying *change* and the 'Nature of Innovation'.

In our contribution, first we will paint in some rough brushstrokes the Context for Innovation in the western world as it emerged over the last centuries. Next, we will pay attention to the Economic philosophers looking at economic change and economic progress. Then we zoom in on the innovation scholars who developed their views, theories, models and definitions. Based on our separate case studies, we will then explore the individual contributions of the inventors of the Communication Revolution: Morse, Cooke/Wheatstone, Bell and Marconi.

The Context for Innovation

Change is life. In biology, Change is the way a species adapts genetically to its environment to survive. We know that since Charles Darwin's *On the origin of the Species* (1859). That environment changes constantly. We humans know change from centuries-old experience. Not only the climatic changes that appear with some regularity, disrupting the natural equilibrium, causing peoples to migrate trying to find new means of subsistence. Also changes in societies that occur as people progress along the path of societal evolution. Change that disrupts the equilibrium of its existing power structure: creating new ruling classes. Change that is about the struggle for existence that dominates life. Change accompanied by turmoil and conflict: from food riots when harvests failed, to military confrontation in wars of succession and geographic expansion. Originally, landownership was the base for social power, worth fighting for. Then, based on new wealth and/or power over earthly resources, new social classes came to power: the merchants, the citizens. Followed by the new class of industrial entrepreneurs in the times of the Industrial Revolutions. Change that was creative in the Spirit of Times, destructive in the Madness of Times. Change that saw both its winners and losers. To cut it short:

"There is an ebb and tide in the affairs of Man, which taken at the flood leads on to fortune; Omitted, all the voyage of their life is bound in shallows and in miseries." (Shakespeare; Julius Caesar Act 4, scene 3, 218–224)

Change has many dimensions. Such as *Technical Change* that accompanied human life after they developed their first tools. *Social Chan*ge in the order and structures of societies small and big when Feudalism became replaced by Capitalism and Socialism. *Political Change* when the fortunes of times gave raise to other dominators as consequence of Colonialism and Imperialism. *Economic Change* that resulted from Trade and Industrialisation. All these forms of Change were accompanied with 'creative destruction'; the creation of novelty and the destruction of the old in an (r)evolutionary process.

Take the *Scientific Revolution*. Emerging from the Dark Ages — with Copernicus *On the Revolutions of the Heavenly Spheres* (1543) and Galileo's *Dialogue Concerning the Two Chief World Systems* (1632)—, it created the foundations of modern science. An evolution that was replacing the old intuitive understanding by the new scientific understanding of the 'Nature of Matter'. It paved the way to its social equivalent; the *Enlightenment* —with philosophies like John Locke's *Two Treatises of Civil Government* (1689). Now it was about the understanding of the 'Nature of Society' that, undermining the authority of Monarchy and the Church, was initiating political revolutions. Then came social revolutions destroying the old societal order and creating the new order: the *American Revolution*, the *French Revolution,* and the *European 1848-Revolutions*. Over time, these revolutions were accompanied by economic revolutions: the *Industrial Revolution* and the *Enlightened Economy*. It was about the consequence of technical evolutionary changes that disrupted the equilibrium of economies.

Take the British Isles. From feudal times, British wealth was based on land creating agricultural wealth that was transferred up in the feudal hierachy to the aristocracy. As a result the wealth of the nation was the quite unevenly distributed. Next, as a result form trade and early colonialism, the richess from the American colonies flowed to England. It were the times of the merchants and traders, creating Mecantilism. This economic nationalism favoured the State (equal to the king ruling on the basis of his divine rights and the landowning aristocracy) with high importation tariffs, low exportation tariffs, creating a positive balance of trade and monopolyzing trade. It had suited the Monarchy, alsways short on financial funds paying for their 'private purse', financing 'the influence of the crown' and their subsequent wars. It also created mercantile wealth and mercantile capitalism: the Tobacco Lords, the Sugar Barons and the Nabobs returning from their spell with the East India Compagny. Then came the changes due to early mechanization; the early textile machines created by people like Arkwright, Hargreaves, Crompton and Cartwright. They disrupted the economic equilibrium as factorization and

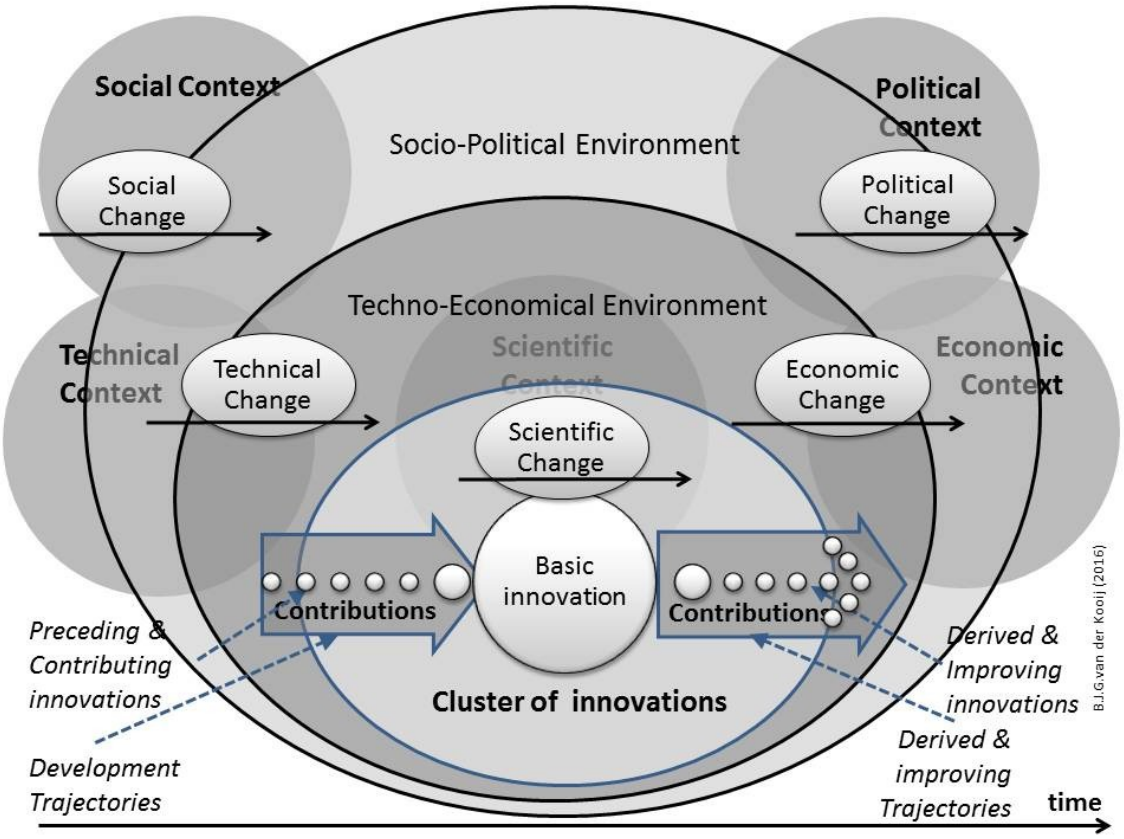

Figure 1: The separate contextual elements of the Context for Innovation.

The figure shows the components of our perspective and our unit of investigation; the cluster of innovations.

industrialization emerged, with its own 'nouveau riches': the Textile Barons and the Industrialists. The increasing influence of the state followed suite. In terms of the resulting industrial policy, the aim was at generating new wealth from manufacturing, supported by the state military and political power. Britain became the 'Workshop of the World' while the 'Royal Navy was ruling the waves' (Kooij, 2016).

The totality of these Changes created the environment in which innovation took place (Figure 1): the social-political envrionment and the techno-economic environment influenced by its seperate Change-elements.

About economic philosophy

Early economic philosphers (such as the eighteenth ccentury French Physiocrats, who called themselves the 'économistes') did built their early economic theories: the theories of wealth. They considered that the wealth of a nation resulted from the productive work of land agriculture. This became later known as the 'production function[1]' that relates economic production to land and labour. Over time, it became clear that the 'Nature of Wealth' was not only agricultural wealth based on landwonership. Trade and Colonialism had brought new mercantile wealth to social classes not owning land: the traders, the merchant and the early industrialist. Now the wealth of a nation resulted from productive work related to membership of social classes: labor from the working class, land from the aristocracy, and capital from the merchant class.

It was the pioneer of political economy Adam Smith (1723-1790) who —after exploring the History of Astronomy, Ancient Physics and the Ancient Logis and Methaphysics (Smith, 1880)— wrote *An Inquiry into the Nature and Causes of the Wealth of Nations* (1776). In contrast to the protectionist policies of Mercantilism—according to Adam Smith—free trade created competition, cheaper goods and higher profits. Smith's views emerged in the times of colonial trade creating mercantile wealth and merchant capitalism, and in the time of early industrialisation, where the division of labour in the factory system created industrial wealth and industrial capitalism. It was the view of Smithian growth of economy that the production function included, next to labour and land, also capital. However, there was more, as he observed the 'Invisible Hand of Economy':

> *"As every individual, therefore, endeavors as much as he can both to employ his capital in the support of domestic industry, and so to direct that industry that its produce may be of the greatest value; every individual necessarily labors to render the annual revenue of the society as great as he can. He generally, indeed, neither intends to promote the public interest, nor knows how much he is promoting it. By preferring the support of domestic to that of foreign industry, he intends only his own security; and by directing that industry in such a manner as its produce may be of the greatest value, he intends only his own gain, and he is in this, as in many other cases, led by an invisible hand to promote an end which was no part of his intention*." (Smith, 1817, pp. Book IV, Chapter II.9).

Smith's 'Invisible Hand' was about individual actions that created unintended social benefits for the society. His view resulted in the 'laissez faire' economic policies that contrasted with protectionism in the

[1] The macro-economic 'production function' relates the output of the economic system to the inputs; eg Y=f(L,N,K) (ie labour, land and capital), Y= f (L,N,K,T) (ie labour, land, capital, technology).

privileged society of that time eighteenth century. Privileges with which the few had obtained riches at the expense of the masses. It was the dawn of the development of economic theories. Theories that tried to encapsule the rules that are governing economic progress after the First Industrial Revolution.

Jumping ahead in time, economists again looked at the effects of the Second Industrial Revolution. It was the Era of Industrialization, and economies went through cycles of growth and decline. Scholarly effort —by economist as Nicolai Kondratieff, Simon Kuznets, Clement Juglar, Joseph Kitchin and others— created theories about those economic cycles, but failed to get a grip on its origins as much of economic growth was left unexplained. By the 1950s economist —such as Robert Solow, Paul Romer — were trying to explain the so-called 'residual factor' of production function: the part that could not be explained by capital accumulation and increased productivity. Robert Solow's growth theory recognized that Ricardian factors —more workers, more capital, or more capital per worker— could not wholly explain economic growth. Innovation mattered, so Solow's economic theory of growth included, next to land, labour and capital, technical progress. Solovian growth added technological development that created new wealth to the production function. But, in what way did that technical progress influence economic cycles? Gerhard Mensch (1937), in his *Stalemate in Technology: Innovations Overcome the Depression* (1975/1979) related the emergence of basis innovations to new upswing of the economic cycle:

> *"The changing tides, the ebb and flow of the stream of basic innovations explain economic change, that is, the difference in growth and stagnation periods. [...] The lack of basic innovations seems to have caused the slide into past technological stalemates, and innovative surges finally brought the stalemate to an end."* (Mensch, 1979, p. 135).

He was not the only scholar who judged it was about basic innovations: *"The basic notion in all these theories is the same. Innovations are important drivers of economic growth and of economic cycles."* (de Groot & Franses, 2005, p. 6). That brings us to our present times where it is all about 'innovation', that gives rise to the question: what is 'innovation'?

About Invention and Innovation: technical and economic progress

Scholars look at the real world, developing their views, theories, models and definitions. In 1906, the economist Henry L. Moore (1869-1958) wrote:

> *"Economic terms seem to pass in their historical development through a series of stages which, without pretension to rigidness, may be described as follows: first, no definition is given, but it is assumed that everyone has a sufficiently clear idea of the subject to make a formal definition unnecessary; second, a definition is attempted and a number of exceptional forms are noted; third,*

with the further increase of data, the relative importance of the various forms changes, confusion in discussion is introduced, logomachy[2] *takes the place of constructive investigation; fourth, a complete classification of the forms embraced under the original term is made, and problems are investigated with reference to these classes. The bewildering vagueness of economic theory is largely due to the fact that the terms used are in all of these stages of development*." (Moore, 1906, p. 212)

Already in the early twentieth century, we find scholars thinking about the combination of technical progress and economic progress. The economic historian Abott Payson Usher (1883-1965) published his *A History of Mechanical Inventions* (Usher, 1929), an analysis about technical progress resulting from inventions. Inventions from early times up to the Industrial Revolution that had shaped the world by then. Mixing the notions of discovery and invention, from that analysis of the real world he developed his theory of *cumulative synthesis*. In that theory the 'Act of Insight' (unlearned activities) and the 'Act of Skill' (learned activities) creates –in a succession of phases— novelty labelled as invention. In addition, the emergence of inventions created technical progress. In the same period of time, the economist Alois Schumpeter (1883-1950) published *The Analysis of Economic Change* (Schumpeter, 1935), soon to be followed by his ground-breaking *Business Cycles* (Schumpeter, 1939). His theory of economic development was based on three elements: the process of innovation, the entrepreneur as innovator, and credit/capital. Innovation, clearly distinguished from invention, was a 'new combination'. As an economist, he was using again their favourite 'production function':

"We will simply define innovation as the setting up of a new production function. This covers the case of a new commodity, as well as those of a new form of organization such as a merger, of the opening up of new markets, and so on. [...] Innovation combines factors in a new way, or that it consists in carrying out New Combinations." (Schumpeter, 1939, p. 84).

As it was about economy, in the view of Schumpeterian economic growth the entrepreneur dominated more than the inventor: the entrepreneur was the innovator. This brought the human element in the equation. It was the dawn of the development of a different kind of innovation theories developed by economists, sociologists and psychologists and managerial scholars.

The historian Usher and economist Schumpeter were not the only scholars observing invention and innovation. The sociologist Seabury Colum Gilfillan (1889-1987), after a historic analysis of the invention

[2] Logomachy: a meaningless verbal battle of words.

of ships (S.C. Gilfillan, 1935), wrote *The Sociology of Invention* (Gilfillan, 1935). However, there was quite some confusion notable:

> *"The definitions given to inventions vary considerably, even if not so greatly as in the case of the steam engine, and there is no way out of the arbitrary assumption of one definition. The best we can do, if we seek accuracy, is to try to make clear what definition we are using*." (S. C. Gilfillan, 1945, p. 77).

Moreover, the economist Vernon Ruttan (1924-2008), studying the contributions of Usher and Schumpeter, observed not much later:

> *"The distinction between exactly what is meant by invention in contrast with innovation, and innovation in contrast with technological change, is usually less clear.' This absence of any clear-cut analytical distinction among concepts which have been assigned such important places in current economic discussion is particularly disturbing."* (Ruttan, 1959, p. 596).

Not withholding this confusion, innovation rose in the attention of the innovation scholars, resulting in stark rise in publications by economist, sociologists and psychologists, and the management scholars. From the late nineteenth century interest in discovery, followed by interest in invention, we came to the increasing interest in technological induced innovation after World War II (Figure 2).

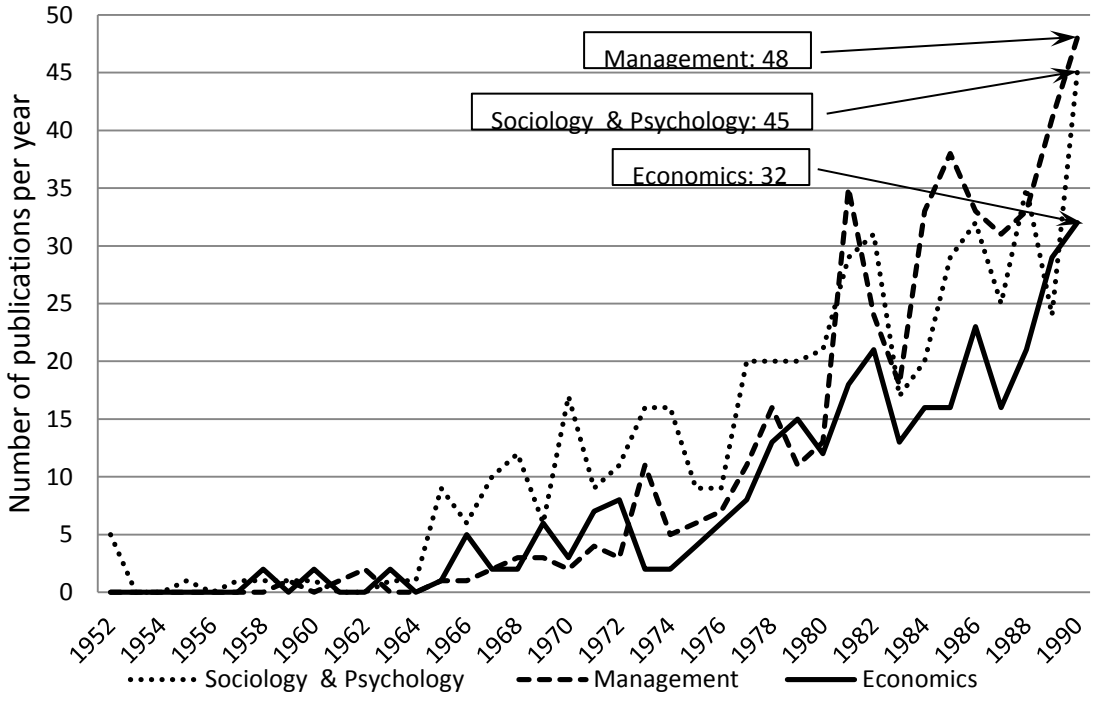

Figure 2: Number of publications on innovation (articles, 1952-1990).

Source: Scopus query (TITLE(Innovation) AND DOCTYPE(ar) AND SUBJAREA(MULT OR ARTS OR BUSI OR DECI OR ECON OR PSYC OR SOCI) AND (LIMIT-TO(SUBJAREA,"SOCI") OR LIMIT-TO(SUBJAREA,"PSYC"))) (Accessed 2014)

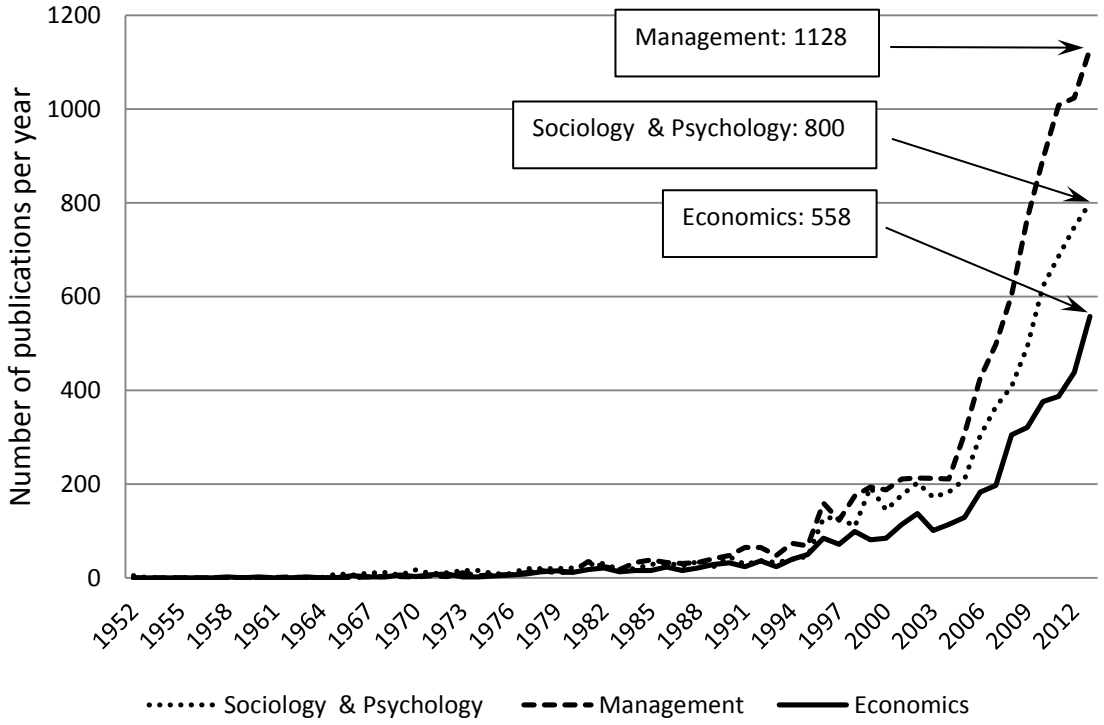

Figure 3: Number of publications on innovation (articles, 1952-2012).

Source: Scopus query (TITLE(Innovation) AND DOCTYPE(ar) AND SUBJAREA(MULT OR ARTS OR BUSI OR DECI OR ECON OR PSYC OR SOCI) AND (LIMIT-TO(SUBJAREA,"SOCI") OR LIMIT-TO(SUBJAREA,"PSYC"))) (Accessed 2014)

Jumping ahead in time, around the turn of the twenty-first century one can observe an explosion in scholarly work on innovation (Figure 3). In 1988, we found in the numerous publications, both of a scholarly nature as well as a more general nature, some 76 definitions of the notion of innovation (Kooij, 2013). In 2014, we found in the largely increased number of publications, some 250 definitions, numerous theories and models. Innovation was seen a product innovation and production-process innovation. It was also observed as the process of idea to marketable product. The Concept of Innovation was even broadened into 'social innovation' and 'open innovation'. Scholarly interest was culminating in a peak in the 2010s, but still resulting in a state of confusion: *[...] there is no one commonly accepted definition of innovation''* was observed, and *"...Researchers within each discipline conceptualize innovation differently and have quite different views...."* (Gopalakrishnan & Damanpour, 1997, pp. 15, 19). That was not only the situation in the technical and economic disciplines:

> *"Despite this understanding, explicit definitions of innovation are rare among sociologists. The early few definitions that exist differ considerably. Certainly, they all refer to the idea of novelty,*

but they differ in the sense that some include the act itself (combination), others the impacts of innovation, still others the subjective perception of it." (Godin, 2008, p. 31).

Thus, in innovation research, one could conclude: 'it is a mess out there'. This bold statement is to say that the confusing use of theories/concepts origination from totally different perspectives, having different levels of analysis, based on different definitions (if any), indicates that the studies in innovation theories are just in its early phase of maturing. Clearly, in the present Body of Knowledge of Innovation, the answer seems to be well hidden in an entangled web of Innovation Paradigms. The result is the similar confusion as already observed a century ago by Henry Moore (Moore, 1906).

The Invisible Hand of Innovation

As already observed in our earlier publication (Kooij, 1989) (in the Dutch language), the mainstream of all those scholarly efforts seemed underexposing one specific dimension. That dimension was *human behaviour* in its social setting, as the driving force of innovation. True, psychologist had payed attention to individual behaviour (eg the theory of heroes of innovation, the entrepreneurial creativity, the creative act), and sociologist to the collective innovative behaviour (eg theories on organizational innovation, on the diffusion of innovation). But the perspective of the individual person, with his fears and hopes, his capabilities and his limitations, his nativity and his perseverance —all those element that create the personality of human beings— had been underexposed. Just as the private environment in which the innovator was operating: his educational and parental background, his family and profession, his living circumstances dominated by the spirit and madness of his times.

This is not the place to try and realize such an effort, but we can try to find illustrative evidence of the importance of individual human behaviour to the Concept of Innovation. For such an analysis, we assume the following:

Our first assumption is that humans initiate, create and implement innovation. Their *Act of Innovation*, a process characterized by the stepwise evolution from an idea into an artefact, is the core of the early innovative efforts. Their subsequent *Act of Business* is the further development and commercialization of that innovation.

Our second assumption is the existence of certain innovations that, by the mere effect of their existence and their impact on society, became 'basic innovations'.

Our third assumption is that these basic innovations appear in a cluster of innovations of a different nature: the contributing and the improving innovations. Innovations that are identifiable by their patents.

The subject of our attention are three 'basis innovations' that are part of the swarming capabilities of the General Purpose Technology of Electricity: we call them the invention of the telegraph, telephone and the wireless. In rough brushstrokes, we will try and paint a picture of the people 'who did it' and 'how they did it'.

The invention of the Telegraph

Telegraphy was the result of two parallel developments: the work of Cooke & Wheatstone in England, and the work of Morse in America. Let us first consider the contextual aspects for their activities. England, part of the old world with its remnants of the feudal society (eg the State monopoly of the Post Office), America as the new world where the concept of freedoms dominated. It was the aftermath of the Napoleonic Wars. America had definitively severed the ties with Britain in the War of 1812 (1812-1815). England was in economic turmoil after Napoleon was defeated at Waterloo (1815). The Battery Mania that started with Volta's invention of the battery (1800) was getting on steam. That communication over distance was possible, was already proven by Chappe's Semaphore. Next, let us consider the individual aspects of the early contributors to the Communication Revolution:

William Fothergill Cooke (1806-1879), son of a surgeon, was, after his military career, a student in medical arts, lacking any knowledge of the new phenomenon of electricity. After a military spell in India, observing demonstrations of the experimental telegraphic systems (Schilling, Gauss & Weber) in Germany, he saw the opportunity for communication at a distance using electricity. Back in England, after creating a crude artifact, he developed a vison what could be done with that new device: its application in railway signaling. He saw the business opportunity it could have, and was realistic enough to realize that he needed expert help. That he found in the electrician[3] Charles Wheatstone (1802-1875), already embarking on the same development. Together —with the inevitable struggles between partners— they created their needle-telegraph and pointer-telegraphs, experimented with them along railroads, built the prototypes and got patents. To commercialize their invention, with the help of others, they created a company. They had to fight opposition in legal battles over priority. All in all, in little over a decade, they created the foundations of British telegraphy (Kooij, 2015, pp. 230-334).

[3] The expression 'electrician' is used to identify people with an actual knowledge of electricity at that time.

Samuel Finley Breese Morse (1791-1872), son of a pastor, was a painter. From a struggling artist he became a struggling inventor, lacking any knowledge of electricity. By then electricity was a new phenomenon that created the Battery Mania in which many experimented with electro-magnets (Henry, Sturgeon). Hearing about electro-magnets on board of the steamer Sully in 1832, Morse had an idea: the communication over distance with lightning speed with that new electro-magnet. It became the vision of his life, absorbing his intellectual powers and consuming his physical condition. Then followed some years of experimenting where Morse —assisted by the technician Alfred Vail— developed the hardware (the prototypes) and the software (the code for communication). It resulted in the creation in 1837 of his electro-magnet telegraph: the Morse Telegraph he was granted a patent for. Next, from a struggling inventor he became a struggling entrepreneur, stimulated by others in his entourage to create a company. After the first telegraph lines started operating successfully, soon others discovered the value of his invention. Morse had to fight for the protection of his patent rights in many controversies and legal battles over priority. Nevertheless, in the period of a decade, his drive had given existence to the new Morse Telegraph System penetrating society with lightning speed (Kooij, 2015, pp. 338-441).

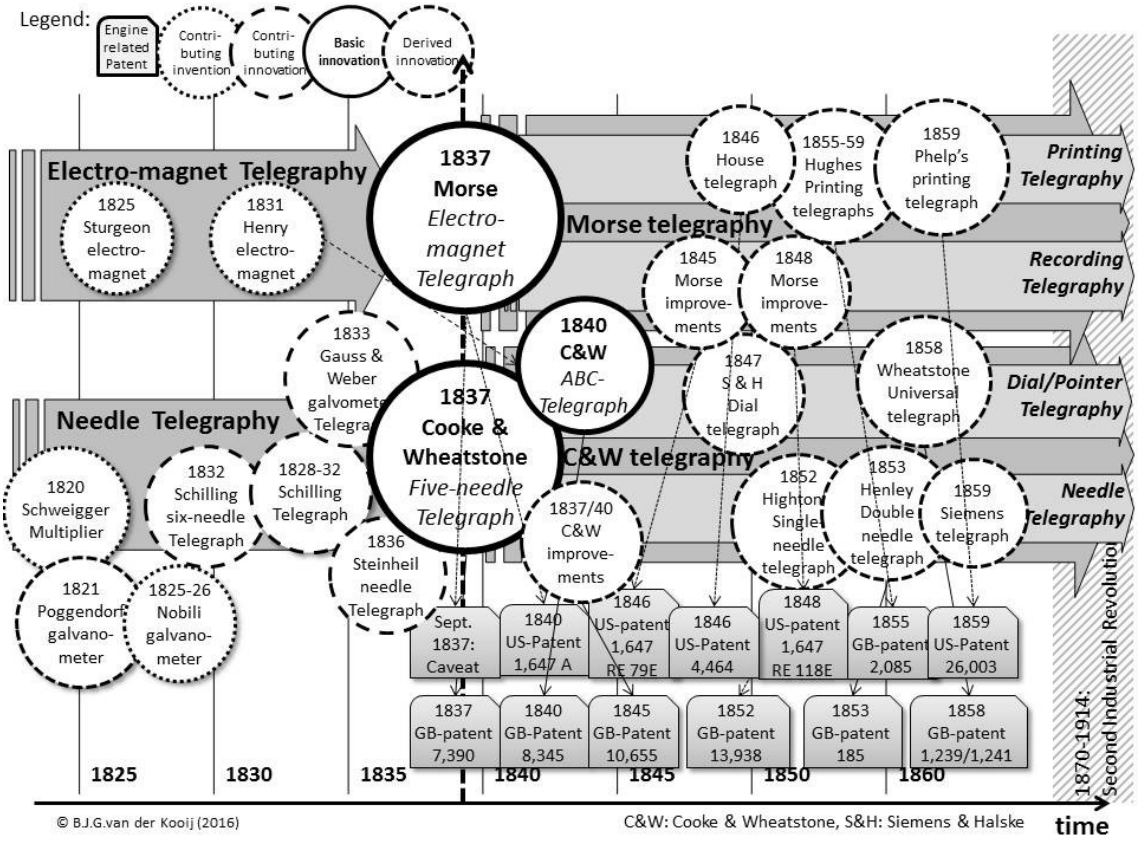

Figure 4: The Clusters of Innovations creating Telegraphy.

In both cases their work was preceded by the work of other's who contributed with their work. Samuel Morse was a painter, used to conceptual thinking and the creative act. Cooke was a former soldier, from a well to do family, studying medicine and looking for a focus in life. Wheatstone was a restless experimenting scientist, eager to build up knowledge in the new technologies of the GPT-E. What do these inventors have in common? Stimulated by a dissatisfaction with their current lives, challenged by the opportunity, they conceptualized their invention. They had a vison what they saw as its future. They had the guts and endurance, despite much opposition, to bring it to maturity, to confront the inevitable opposition and fight the priority battles. Their personal motivation was fuelled by the opportunity, their goal was to create, and their contribution to society was an unintended side effect. Their invention was followed by a range of improving innovations, created by themselves and by many others. Again, people with their own personalities, grabbing the opportunity to create novelty (Figure 4).

The Invention of the Telephone

Telephony was the result of the endeavours of Alexander Graham Bell, working in the context of his times in America. By the midst of the nineteenth century, telegraphy had started to conquer the world. Spreading on the American and European continent, it was on the brink of connecting the continents. On the European continent it was a governmental affair, in England the Post Office was to claim its monopoly. In America is had become a public/business affair, the nervous system of commerce, service providers sprouting everywhere. There, the Telegraph Mania had resulted in a Telegraph Boom of the late 1840s-early 1850s; creating the first tycoons and their empires. Among them, a monopolistic company called Western Union. The 1870s saw an increase in telegraphic communication creating a demand for higher capacity. Engineers were experimenting and trying to find a solution of sending simultaneously more messages over the same wire. There we find in the early 1870s a teacher of deaf, excited by the new phenomenon of 'electric speech'; electricity used to realize speech.

Alexander Graham Bell (1847-1922) —the son of professor Alexander Melville Bell who invented the Visible Speech system to learning deaf people to communicate—, emigrated in 1870 with his parents to Canada. Following in his father's footsteps, he became a teacher of deaf, soon having a private practice for deaf children in Boston, USA. Being fascinated by the possibilities of electricity, working during daytime at his practice, experimenting in the evening late into the night with electromagnets, coils, tuning forks and piano wires, he conceptualized the musical telegraph using AC-currents of different frequencies. Despite his enthusiasm for electric speech, pressed by Gardiner H.Hubbard, father of his pupil Mabel Hubbard, he focused on the capacity problem of

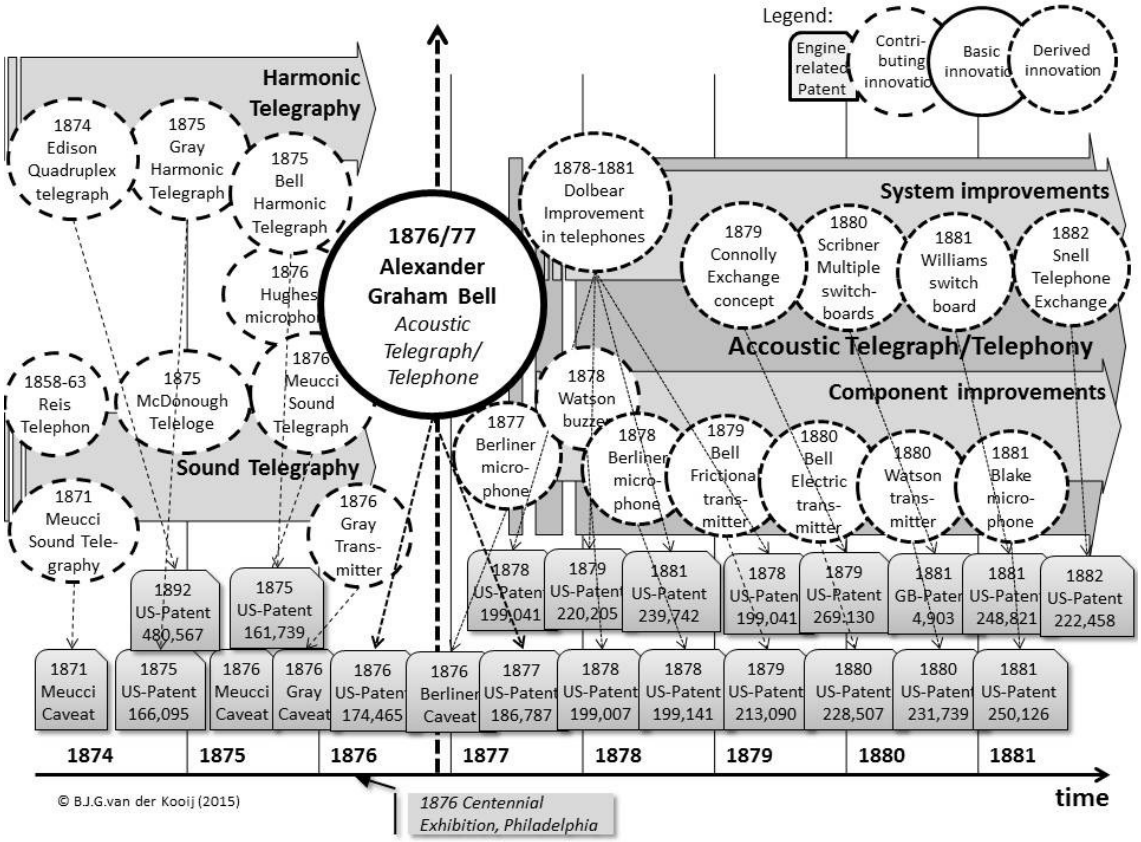

Figure 5: The Cluster of Innovations creating Telephony.

telegraphy. Based on his tuned reed relays, he created a multi-frequency system for simultaneous transmission. With the help of Hubbard and the father of another pupil, George Sanders, they entered into a Patent Association Agreement, financing his further experimenting. By 1875, Alexander had a solution for sending more telegraphic messages simultaneously and he obtained a patented for it. Extending that concept, after further experimenting with the technical expertise of his assistant Thomas Watson, he made his artefact.

However, he was not the only, active along this development trajectory. Bell did just beat Elisha Gray when he, after a race to the patent office, applied for another caveat that would contain the claim for telephony. By 1877, he had created the device and patented his invention of transmitting 'electric speech': it was to be his famous telephone-patent. Also in 1877, he created with help from his entourage, his first company to exploit his patents. After starting to construct the first apparatus, used on the existing infrastructure of telegraph lines, soon local telephone networks started to appear. Soon, he had to fight for his invention with the monopolist of telegraphy: Western Union. Bell managed to win this David-Goliath like confrontation, focusing on telephony,

and Western Union sticking to telegraphy. Later he was involved in some 600 legal battles over priority. Notwithstanding this life time nuisance, in a decade, his drive, ambition and stamina had given existence to the new Bell Telephone System penetrating rapidly society. (Kooij, 2016, pp. 150-336).

This, in short, is the story of the invention of the telephone. Clearly many tinkerers and thinkers had contributed with their innovations in harmonic telegraphy and sound telegraphy. In addition, many improvements in both the components as well as the system would follow (Figure 5). Bell had a vison what saw as the possibilities of his concept of 'electric speech'. He had the guts and endurance, despite much opposition and supported by his entourage, to bring it to maturity, to confront the inevitable opposition and fight the priority battles. His personal motivation was fuelled by the opportunity, his goal was to create, and his contribution to society was also an unintended side effect.

The Invention of the Wireless Telegraph

Wireless telegraphy was the result of the endeavours of Guglielmo Marconi, working in the context of his time in Italy and England. It started in Italy, which had just seen its Unification resulting in a monarchy, entering the Age of Electricity. After conceptualizing his invention in Italy, he brought it to England. There cabled telegraphy was the monopoly of the British Post Office, spreading its cables all over England, providing telegraphic services to the public. England was in the midst of the Second Industrial Revolution by the end of the twentieth century. Both the scientific community and the engineers of the Post Office were experimenting trying to improve telegraphy without wires, creating a controversy between them, when in Germany Heinrich Herz developed a new way to transmit information; the Herzian waves. As both telegraphy and telephony had one big drawback —they used copper cables to transmit the message— his invention created an alternative: wireless communication using electro-magnetic waves. It resulted in the Wireless Mania in science and engineering.

Guglielmo Giovanni Maria Marconi (1874-1937) —son of the Italian noblemen Guiseppe Marconi and the Irish/Scots Annie Jameson— also being fascinated by electricity and the Herzian waves, the private educated young Marconi started experimenting on his own in the attic of his parental home. Soon he was able to create a circuit for ringing a bell without a connecting cable: his wireless system was conceived. It took some further experimenting in the garden, every time increasing the distances bridged without a wire. By 1896, he had a working artefact. As Britain was at its zenith, both as a seafaring nation (Britain 'Ruling the Waves') and as an industrial nation (Britain as 'Workshop of the World'), it was decided that the best environment for further

developing his invention was to be found in Britain. After arriving in England and some further experimenting, he applied for a patent, obtained it in 1987 and created a company in the same year. Marconi soon discovered that he had entered a hornet nest of conflicting interests that emerged from the Wireless Hype in the scientific and engineering community. Scientists from different countries disputed his work, claiming priority over the work of a young tinkerer. The Post Office was initially quite content with his invention, gave support for further experimenting as their own experiments had failed. However, that changed when commercialization came into play. The War Office, Royal Navy and Army, also claiming priority, were similarly curious and soon illegally copied his design. Germany, developing imperialistic aspirations, had their own scientists working on wireless communication. After all, wireless was too important to leave to the whims of a foreigner.

However, that foreigner continued his experimenting, showing quite some aptitude for publicity. He managed to demonstrate his system to British, Italian and Russian royalty, on sailing Regatta's in England and America, crossed the Atlantic with messages between boats and his wireless stations. This all heralded by the press worldwide. Evading the Post Office Monopoly, he started a

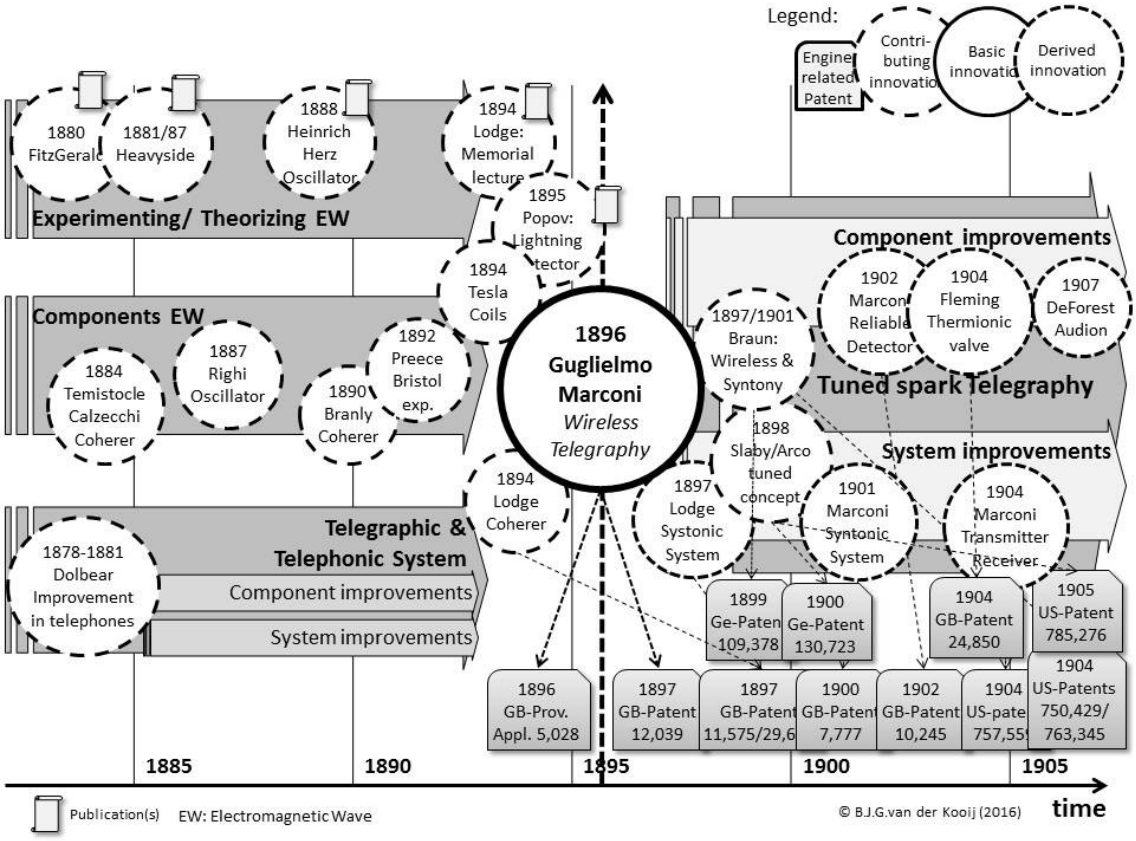

Figure 6: The Cluster of Innovations creating Wireless Telegraphy.

> maritime business for wireless shore-to-ship and ship-to ship communication by leasing his equipment. Extending his patent-protection in other countries, he started the Marconi Monopoly creating companies in America and Canada, each serving specific markets. In the meantime, improving the components and the total system, wrinkling out the youth problems of his spark-generated transmitter and improving his receiver in the early 1900s, he started selling wireless systems to companies in Britain (eg 'Lloyds of London'), and the Admiralty's of Italy, Japan, and America. Circumventing the Post Office monopoly, soon he dominated the international long-distance communication. In less than a decade, his drive, ambition and stamina had given existence to the new Marconi Wireless System penetrating society (Kooij, 2017 to be published).

This, in short, is the story of the invention of the wireless telegraph that would next be followed by the wireless transmission of sound: the radio and wireless telephony. Here also many tinkerers and thinkers contributed with their innovations using Herzian waves. Many improvements in both the components as well as the system would follow (Figure 6). Marconi, confronted with quite some opposition, using publicity as his weapon, had a vison what saw as the possibilities of his concept of 'wireless communication'. He had the guts and endurance, despite much opposition and supported by his entourage, to bring a system of communication to maturity, to confront the inevitable opposition and fight the priority battles. His personal motivation was fuelled by the opportunity, his goal was to create. In addition, his contribution to society was even so an unintended side effect.

Conclusion

What conclusions can be drawn from these observations of the Clusters of Innovations in the GPT of Electricity that created the Communication Revolution (Figure 7)?

First of all, let us consider what the inventors realized. They, challenged by the opportunity, conceptualized a communication concept that was fundamental to the (latent and actual) needs of society, solving the actual problems of the preceding communication systems, embarking on a new art. They managed to create a communication system based on their artefacts: the Morse System, the Bell System and the Marconi System. All systems which would become huge contributions to society. However, that impact of their work was an unintended side effect.

Looking at how they did that, one can observe that it was not only their *Act of Innovation* that realized their innovation. In addition, their *Act of Business*, realized with the support of their entourage, brought their basic innovations into their societies. Although they were the ones that left the beaten tracks creating the New Combination, they were not the only creative ones following similar trajectories.

Thus, in addition of their work, numerous other thinkers and tinkerers contributed to their innovation, and later improved on their work.

Next, let us look at who realized that contribution. A common denominator of all the inventors was their personality (shaped by their nature and their nurture). Considering the latter, Morse, Cooke, Bell and Marconi were children of their time growing up in their specific dynamic environments. That formed the traveller (Morse/Cooke in Europe), new emigrant (Bell in Canada) and foreigner (Marconi in England). At the moment of their contributions, they were no 'electriciens' — experts in the new General Purpose Technology of Electricity— neither as theorizing scientist, nor as a practical engineer.

Another common denominator of all the inventors was their individual behaviour. Given the context of their lives —that created the different conditions for their inventive activity— each basic innovation was the result of the inventor's individual behaviour. A creative behaviour that originated from the fascination with an idea, based on a perceived concept. Maybe combined with dissatisfaction with their ongoing life, this certainly challenged them when they were seeing the opportunity it offered. An

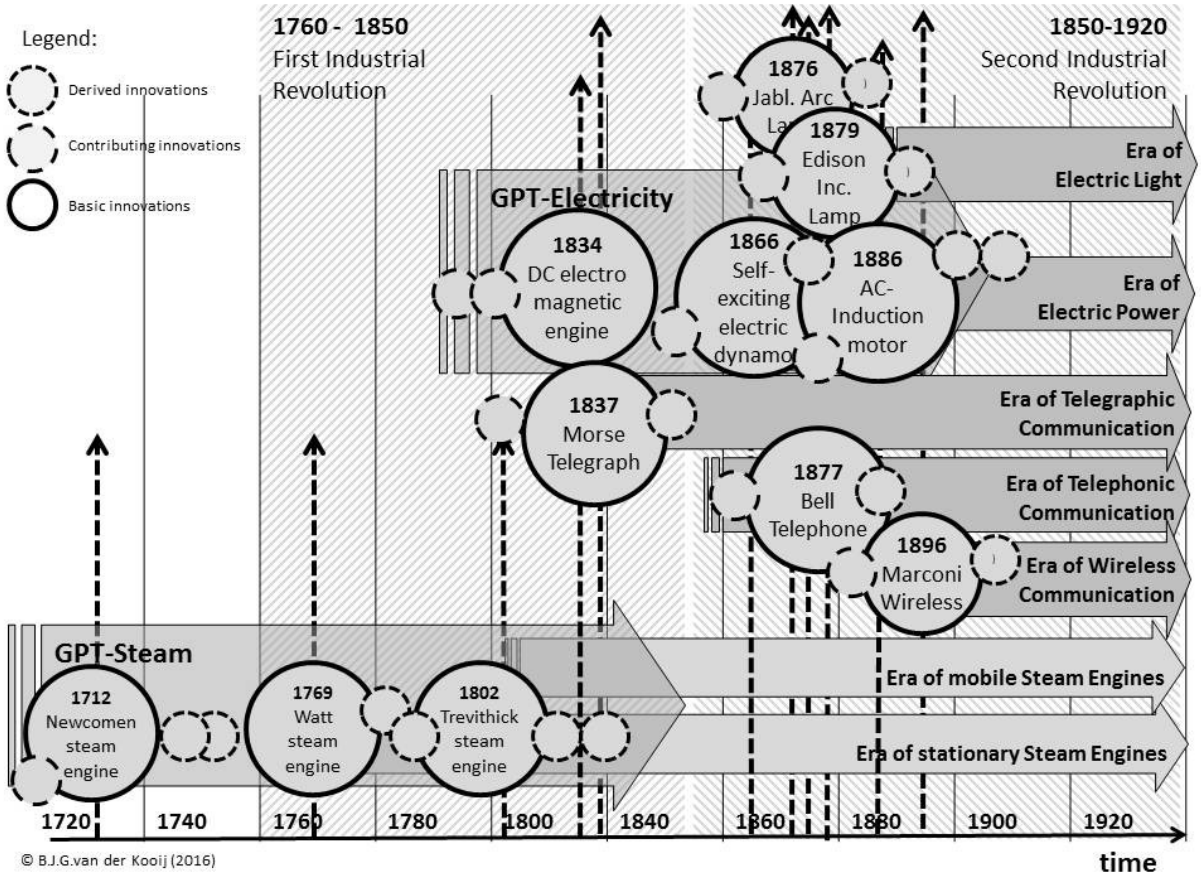

Figure 7: Clusters of Innovations in the General Purpose Technology of Steam and Electricity that contributed to the Industrial Revolutions.

The Communication Revolution is the result of the Cluster in Telegraphic, Telephonic and Wireless Communication.

opportunity that further fuelled their vision of the future to come. A vision, maybe sometimes based on unrealistic dreams, but also with practical and realizable conceptions. Next to this, more was needed, such as the courage and perseverance to implement their idea and vision, as they each had the actual courage 'to do it': to invest their time and energy, to fanatically pursue their vision, to fight for their rights, to battle their opponents. Notwithstanding all the barriers that society created, their individual Acts of Innovation and Act of Business ultimo benefitted society.

Initiated by dissatisfaction and opportunity, enforced by the conceptualization of an idea creating a vison, having the guts to implement and fight, their Acts were the *Invisible Hand of Innovation* that contributed so much to the General Purpose Technology of Electricity (Figure 7).

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