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How “General purpose technologies” trigger long waves of economic development and thereby generate diversities of innovation

Como “las Tecnologías de Uso General” desencadenan ondas largas de desarrollo económico y por tanto generan diversidades de innovación

I. INTRODUCTION

“General purpose technologies” (GPT) that can be applied to a multitude of economic activities and sectors cause fundamental structural changes in the whole economy and in the way how economic life is organized. They allow for developing new markets and introducing new products, processes and organization principles to the market and thereby triggering fundamental changes in all parts of the economy and society. Because of this impact on all sectors of the economy GPTs generate “long waves” (Kondratieff 1935, in German: 1926) representing long-term surges of economic development. The internet as the major outcome of the fusion of modern information and communication technologies is the dominant GPT in the current long wave that followed the Fordist mass production which was the preceding long wave’s GPT. This paper shows that long-term structural change is influenced by the emergence and dissemination of GPTs and that the behavior of economic agents and activities of economic policy makers exert a strong influence on a country’s possibilities to benefit from applying the new technologies. It is shown that during the unfolding of a long



EXECUTIVE SUMMARY

Long-term structural change is influenced by the emergence and dissemination of general purpose technologies (GPT) that generate "long waves" of economic development. The paper shows that the long-wave dynamics is characterized by major diversities of innovation and that economic agents and policy makers strongly influence an economy's ability to benefit from new technologies. Information and communication technology as the dominant GPT of the current long wave and other, emerging technologies that possibly act as a GPT of the next long wave (e.g. Industry 4.0) are put into the long wave-context.

RESUMEN DEL ARTÍCULO

El cambio estructural a largo plazo se explica por la aparición y la difusión de tecnologías de propósito general (GPT) que generan "ondas largas" de desarrollo económico. El trabajo muestra que la dinámica de las olas de larga duración se caracteriza por marcadas diversidades de la innovación y que los agentes económicos y los responsables políticos influyen de manera significativa en la capacidad de una economía para beneficiarse de las nuevas tecnologías. La tecnología de la información y la comunicación como actual paradigma dominante de la actual onda larga de cambio tecnológico y otras tecnologías emergentes que posiblemente actúan como tecnologías de propósito general de la próxima oleada de cambio tecnológico (por ejemplo, la Industria 4.0) se ponen en el contexto de la teoría de las ondas largas de cambio tecnológico.

wave, typically, different diversities of innovation (Hilpert 2019) emerge and predominate.

In the next section a model of long waves of economic development will be presented in a nutshell. This is followed by an analysis of the phases that a long wave consists of and a discussion of the diversities of innovation that are typical for the specific phases. Then information and communication technology as the dominant GPT of the current long wave and other, emerging technologies that could possibly act as a GPT of the next long wave (e.g. “Industry 4.0”) are put into the context of the model. The final section concludes with insights from the long wave model for understanding diversities of

innovation. This article builds on the author’s contributions to the Handbook of Politics and Technology (Scherrer 2016) and to the edited volume “Diversities of Innovation” (Scherrer 2019); both books were edited by Ulrich Hilpert and published by Routledge.

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**2. “LONG WAVES” OF ECONOMIC DEVELOPMENT –
A BRIEF INTRODUCTION¹**

Based on empirical research of long economic time series Kondratieff (1935) detected that the era of industrialisation is characterized by long waves/surges of economic development of 40 to 60 years duration. While he already suggested that technological change would play a major role for understanding long-term economic development and its cyclical nature, Schumpeter (1939) embedded Kondratieff’s idea into a theoretical framework of innovation. Neo-Schumpeterian and evolutionary economists like Freeman and Perez have focussed on newly emerging GPTs (“core technologies”) that have an impact on all sectors of the economy and unleash “technological revolutions”. The key factors or key inputs are characterized by clearly perceived and rapidly falling relative cost, an almost unlimited availability of supply over long periods, and a clear potential for use or incorporation of new key factors in many products and processes throughout the whole economic system.

The literally path-breaking new GPTs fundamentally change the structure of existing markets and make it possible to develop new markets and to apply new modes of organising economic activity and relations between economic agents. They can be combined with already known technologies which facilitates their roll-out out

over the whole economy. In order to capture the potential benefits of these technologies, major investment in new infrastructure and skills is required, the rules – formal and informal – in economy and society need to be adjusted, and attitudes and behaviour of individuals, firms and public entities need to allow for such fundamental change to unfold. This process of re-structuring is time consuming (therefore: long waves) and provides huge opportunities for entrepreneurs.

A model that generates such long surges through endogenous technological change needs to answer four questions (Rosenberg and Frischak 1983):

- What are the necessary and sufficient changes in the environment that can bring out a bandwagon-like diffusion of basic innovations”?
- Why do technological innovations lead to long periods of economic expansion followed by similarly long periods of stagnation spanning two to three decades, each?
- Is the impact of innovations or clusters of innovations strong enough to cause a sizeable macroeconomic impact?
- Are there mechanisms endogenous to the economic process to make the waves repeat themselves?

The Perez model of long waves (Perez 2002) can answer these four questions. It is the most often used model of technology-driven long waves (Gallegati 2019), and henceforth it will be used as vehicle of analysis. At the model’s core there are interrelated radical breakthroughs (“technological revolutions”) that lead to the emergence of a new GPT that has the capacity to profoundly transform the economy by establishing a new “techno-economic paradigm” (Perez 1983). In this setting, innovations that are driven by a new GPT are not only considered as technological phenomena, but innovations are complemented by socio-economic change. This can be illustrated with the dissemination of automation and computerisation that first endangered jobs of blue-collar workers, and since these tendencies progressed white-collar jobs have also been at risk (O’Gorman and Donnelly 2019) and the resultant underemployment of medium skilled workers might undermine innovative capacities (Sandulli and Gimenez Fernandez 2019). Strengthening innovation systems by combining vocational and academic qualifications (Vassiliadis 2019) could be a possible response to such a socio-economic change that is initiated by applications of a new GPT.

KEY WORDS

Technological Change, Information Technology, Techno-economic Paradigm

PALABRAS CLAVE

Cambio Tecnológico, Tecnologías de la Información, Paradigma Tecnológico-Económico.

Therefore, the absorptive capacity of society and adapting to the required changes become most relevant for implementing a new GPT² and for mobilizing its potential economic benefits. A “set of ‘best practice’ principles, that break the existing organisational habits in technology, the economy, management and social institutions” (Perez 2002, 7) emerges and thereby establishes a new “techno-economic paradigm” (TEP). The TEP disseminates to all sectors of the economy and all realms of society and thereby drives a long development surge that typically goes through several phases. The concept is not deterministic because economic agents and policy makers can choose on how to adapt to the newly emerging TEP and on different time paths of adaptation. By implication, strategic choices of society determine the economic benefits that can be derived from a new GPT and its related TEP and explain why these benefits differ across economies/societies.

3. DIVERSITIES OF INNOVATION DURING THE PHASES OF A LONG DEVELOPMENT SURGE

A development surge starts with the “*Irruption*” of a new set of technologies from a small industrial base that allow a step change in potential productivity in practically all economic activities (Perez 2002, 8). Initial technological or scientific breakthroughs in the new TEP have regularly occurred long before, but do not yet have an encompassing economic impact in this phase because much experimentation with the new technologies is still needed as the road to fully exploiting the economic potential of the new GPT is not yet clear. While some firms already successfully innovated and invested in the new GPT, uncertainties and economic risks of applying the new technologies in many sectors are still high.

Given the high degree of uncertainty concerning how to make concrete use of the new GPT, the prevailing “old” TEP is still attractive for many economic agents. The benefactors of the old TEP still defend their business model although gains from investment tend to diminish, and the big bulk of investment in this phase, therefore, is about incremental improvements within the prevailing paradigm. While proponents of the new GPT feel themselves restrained by the existing institutions, investment in the new GPT increases fast, but only from a low level, in industries that develop the new technologies and in a small number of industries that make intensive use of it.



Innovation in the irruption phase is mostly considered a technological phenomenon, the socio-economic foundation of the prevailing “old” TEP is not seriously challenged, yet.

Diminishing gains from investment within the “old” TEP and an increasing number of successful applications of the new GPT shift the perception of the economic potential of the new technologies. This marks the begin of the second phase of a long development surge, the “*Frenzy*” phase (Perez 2002) when the interplay between real economy innovators and financial investors becomes most visible. The former ones see the time come for creating new markets and introducing new products, while the latter ones gradually shift from less risky but poorly rewarded investments within the old paradigm to investing in more risky investment projects that promise higher profitability. This can be achieved either by redirecting investment that is mostly based on the old TEP to developing countries that benefit from lower labor cost and lower regulatory standards, or by investing in the new GPT that becomes increasingly attractive. Both alternatives have in common that they involve higher risk and promise high returns, and that after a while very likely a speculative bubble builds up.

It is difficult to judge in advance which of the new business models based on the new GPT would work in the future (and which ones would not work) and therefore much speculation and tricky business gestation is involved (it is a time of “irrational exuberance”). Investment in stocks of companies that develop and apply the new GPT and establish new business models based on these technologies is huge and results in the build-up of a speculative bubble on the stock market. Ultimately a bandwagon-like development is released because many investors do not want to forgo this potential for earning high profit. Therefore, from a long-wave perspective the build-up of a speculative bubble is not an accident of capitalism but is part of the dissemination of a new TEP. Its bubble’s burst (like in 2001) marks the end of the Frenzy phase.

The *diversity of innovation* in this phase is dominated by three drivers of innovation and related investment. *First*, the technological core of the new GPT is improved and further developed. In the current long wave, the enormous increase of computing power and its cost decline (“Moore’s Law”) is a good example for the improvement of the core production factor over a rather long period. *Second*, in this phase there is still experimenting with applications of the new GPT going



on, with combining the new GPT with existing technologies, and with creating and refining business models that are based on the new TEP. Innovation and related investment rooted in the new paradigm disseminate to an increasing number of firms in various industries. *Third*, particularly but not exclusively in this phase the dissemination of a new TEP requires much investment in new infrastructure which is an innovation activity itself.

At the “*turning point*” of a development surge a mismatch becomes apparent between the still prevalent old paradigm and the new TEP. Many individuals and groups have strong vested interests in the old paradigm, and the existing regulatory and institutional framework restrains the exploitation of the new TEP’s full economic potential.

Extending and enhancing infrastructure and developing and harmonizing technical and legal standards becomes crucial for the dissemination of the new TEP and an economy’s ability to benefit from innovations that are rooted in the new paradigm. Economic agents – investors, firms, workers, consumers – need to adjust their behaviour to the challenges that come with the new TEP, and policy makers are required to adapt the institutional and economic framework. Innovation and reaping the benefits that derive from the new TEP can be impaired or at least decelerated if the institutional framework is not adequately adjusted or if its adjustment is delayed.

A prominent obstacle to innovation in this phase is the availability of finance because after the burst of the speculative bubble at the end of the Frenzy phase many investors have lost considerable amounts of capital. In this situation it is crucial for providing capital for investment and innovation to restore investors’ confidence and to give them incentives for investing in the “real” economy. In the turning point phase of the recent long wave (that covered most of the 2000s years) economic policy and monetary policy successfully avoided a recession after the burst of the speculative bubble in 2001, but at the same time this policy contributed to creating ample opportunities for financial investment and thus impaired investment activity in the real economy.

The impact of economic policy measures that are implemented in the turning point phase (and of measures that are not implemented although they would be supportive to the take-up of the new paradigm!) is not limited to this period but reaches into the “*synergy phase*” of the development surge. Infrastructure that is necessary for establishing the new TEP is available already in many areas and



many economic agents have the physical equipment that is required for access to the infrastructure. The new technologies have become more user-friendly than in the prior phases of the development surge and are socially accepted now. Specific knowledge and skills that are required to use the technologies are well developed as young generations have grown up with these technologies and parts of the older population have acquired the necessary skills at least at a basic level. Therefore, much is prepared for reaping the individual and social benefit from the new GPT.

The diversities of innovation in this phase are dominated by the roll-out of the new paradigm over the whole economy. Innovation is triggered because an increasing number of firms and industries adapt to the new technology and try to adjust to the TEP that has become dominant in the meantime. During the earlier phases of the recent development surge the consumer world was most markedly influenced by the internet while in the synergy and maturity phases the integration of manufacturing and ICT emphasizes the roll-out of the new paradigm to the manufacturing sector. In the synergy phase, the dominant GPT is combined with industry-specific technologies and applied to industry-specific problems and tasks which results in a broad range of innovations. Enabling innovations facilitate the dissemination of the new TEP, e.g. electronic money transfers of small amounts and other innovations in the financial sector that have facilitated internet commerce in the recent development surge. The possibilities for reaping the benefits from innovations that are based on the dominant TEP are influenced by strategic decisions about accommodating the economic framework to the requirements of the new TEP. This means both regulating the GPTs (e.g. setting technical standards), adjusting regulation in policy fields that are indirectly affected by new GPT (e.g. adjusting labor relations and developing new regulations of business transactions and competition) and exerting complementary macroeconomic policies.

Finally, a TEP reaches its last phase (“maturity”) when its potential to further increase productivity and to generate attractive goods and services becomes exhausted. While there are many firms and individuals still benefit from the dominant TEP, a growing part of the population perceives the dominant TEP less desirable compared to the attractive newly emerging GPT. Financial investors are increasingly faced with difficulties to find profitable investment opportunities within the old paradigm, and consequently “turn



away from the core countries and core sectors” (Perez 2002, 83). Innovation within the dominant paradigm shifts from being science-based to being technology-based, and market risks of innovation become relatively more important compared to technical risks (Scherrer 2019a). Consequently, both real-economy entrepreneurs and financial investors start searching for opportunities outside the prevailing paradigm thereby giving way to a new TEP.

4. WHERE DO WE STAND NOW?

Most researchers of technology-driven long waves would agree that five surges have been observed since the coming of the industrial society in the late 18th century.³ The first wave was triggered by innovations in steam power and the textile industry and started in the 1780s in Britain, the second wave by the steam railway (starting in the 1840s), the third wave by steel and heavy engineering industries (starting in the 1880s), the fourth wave by applying the principles of mass production (starting in the late 1930s), and the fifth wave by modern ICTs (starting in the second half of the 1980s). The fifth development surge has reached its synergy phase now and is going to enter the stage of its maturity (Scherrer 2019a). In this phase of the long wave, the focus of basic research tends to shift away from the core of the prevailing GPT towards developing possible new GPTs. Applied research and development in industries and disciplines in which ICTs are implemented has gained prominence. As the search for new applications within existing technologies has intensified, and technology-based innovation has become relatively more important compared to science-based innovation. The mix of input factors that are required for innovation and efficient production on the basis of the new TEP has changed, and together with regional variations of industry structure and policy responses this contributes to explain why innovation activity and the speed and intensity of adaptation to the new TEP differ across regions. The formation of dominant market players and monopolies has been fostered by the technological properties of ICT, in particular its extremely low marginal cost of production and the existence of strong network effects. Given the assumption that many firms of the ICT sector will provide the infrastructure and tools for technologies that will possibly form the core of the next wave’s GPT, some heavyweights of the fifth wave will very likely be important players also in the sixth wave.



Recently, a bundle of new technologies has been summarized under the label “Industry 4.0” (Kagermann et al. 2013) or similar labels that claim to initiate a “fourth industrial revolution”. While many academic writers, consultants, and policy makers have hyped Industry 4.0, a socio-economic theoretical foundation of its appearance and of its implications for the economy is still lacking. This gap is closed by the long-wave perspective of Industry 4.0 which provides such a theoretical foundation (Scherrer 2019b). Many examples of Industry 4.0 applications have been implemented in firms and industries within the (still) predominant ICT-based TEP as they focus on refining, further developing, adjusting and combining ICTs with other technologies. In the long wave model this roll-out of the predominant paradigm over more and more parts of the economy represents the synergy and maturity phases of the fifth long wave. While particularly the synergy phase provides the potential for strong economic expansion, many countries have found it difficult to fully realize the benefits from the ICT-based paradigm after having entered the synergy phase in the late 2000s. Economic expansion has been sluggish compared to the synergy phase of the preceding long wave as investors’ confidence might have suffered from an unstable global economic environment and the re-regulation of the economy for accommodating the ICT-based paradigm has progressed only slowly. Insofar, many applications of Industry 4.0 are representations of the later phases of the fifth long wave and thus fit nicely to the expected pattern of the long wave dynamics.

Two elements of those technologies that are captured by the *Industry 4.0* concept, in particular, have the potential to qualify as a GPT and therefore to reach beyond rolling out the ICT-based TEP (Scherrer 2019b): *first*, the conversion of analogue data and processes into a machine-readable format (“digitization”), and the use of digital technologies that result in new activities or in changes to all kinds of existing activities (“digitalization”; OECD; 2018), and *second*, artificial intelligence. Both elements can be applied in nearly any context and the possibility to combine them with other technologies generates a multitude of possible applications. While artificial intelligence allows the step from *automatization* to coming closer to *autonomization* of economic processes, digitalization in many cases means that marginal cost of production is close to zero and, by implication, the role of marginal cost as a fundamental concept of pricing will be undermined in more and more markets and circumstances. Although it is neither possible to predict all possible uses of these two elements of Industry 4.0 nor to predict the timing when these uses will eventually become effective, they have



the potential to become powerful GPTs that do not only generate productivity increases *within* existing business models but that also form the basis of new business models in the context of the sixth long wave. Empirical evidence of current innovation processes and re-structuring efforts suggest that many firms prepare for the next GPT by digitizing their processes, and that there exist already a growing amount of applications of AI and digitalization of economic activities. These are indications that a new GPT could be forming that the sixth long wave might have entered its very early phase.

5. DIVERSITIES OF INNOVATION: INSIGHTS FROM THE LONG-WAVE MODEL

The model of technology-driven long waves of economic development improves the understanding of innovation by offering insights from various perspectives. From a *theoretical perspective*, its major scientific benefit is the endogenization of technological progress in a non-deterministic socio-economic framework that is open to interdisciplinary research (Scherrer 2016). The long wave concept provides a structure for analyzing the emergence and diffusion of techno-economic paradigms and the variation of innovation and innovation policy during the diffusion process of a new TEP from its irruption to its deployment. Technological change is not exogenous to the economy but it is a consequence of economic decisions resulting from the interplay between agents in the financial markets and entrepreneurs in the “real economy”. The long wave-concept is non-deterministic as the long development surges are transformations rather than repetitions, and because important roles are attached to economic agents and policy makers for adapting to a new TEP. While technical feasibility is a precondition for change, institutional and regulatory decisions have a strong impact on the diffusion and on the scope of technology use, and, even more significantly, on the degree to which a society can benefit from the TEP during the phases of a long wave. The long wave-model is open to interdisciplinary research as the gestation and analysis of various forms of institutional change is a research topic in many academic disciplines. *Historical* time is becoming a distinct dimension of analysis because the model also allows analysing new development paths during a long wave and both business strategies and economic policies can perform effectively only if they target windows of opportunity that open only temporarily (Hilpert 2019).

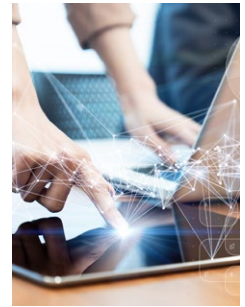
From a *business perspective* the long wave model suggests that the interplay between financial investors and real economy-



entrepreneurs is of crucial importance for explaining innovation activity. When returns to investment within the dominant paradigm diminish financial investors tend to allocate resources towards more risky ventures thereby supporting innovation activity by real-economy entrepreneurs that is geared towards a new GPT. The build-up of new infrastructure is required and contributes to explain the long duration of the waves, as this process consumes much time. The roll-out of the new TEP induces innovation in an increasing number of economic sectors and thus also provides ample business opportunities. The history of long waves suggests that the operation of the infrastructure that is relevant for the dissemination of the TEP has not always been profitable in contrast to business with hardware, software, consulting and other services that are complementary to infrastructure. As the combination of inputs required for efficient production within the new paradigm and the properties and degrees of standardization of inputs change, locational advantages of production are likely to change during the wave.

The history of long waves shows also that the newly emerging GPTs could always build on the achievements of its predecessors, as it was the case e.g. with the steam railway in the 19th century (that could build on steam power) or with mass production in the second half of the 20th century (that could build on electricity). The GPT that will drive the sixth long wave very likely can also build on the preceding GPT (the internet as the major manifestation of modern information and communication technologies) but for the first time in the history of long waves it will be possible to use the preceding GPT explicitly as a powerful tool of research and innovation. Together with even more systematic research and development effort of firms this might accelerate the development and dissemination of new technologies and thus the duration of a long wave might be shortened. If future long development surges will actually become shorter depends on the characteristics and perceived risks of the new technologies, and on the scope and willingness of society to adapt to technology-driven change.

While it has been argued that there exist strong implicit rationalities of innovation there are also ample opportunities for economic policy makers to intervene, foster, change and to take advantage of new GPTs at different points of development (i.e. phases of the long wave). From an *economic policy perspective*, in addition to the importance of properly timing policies the long wave model suggests that for the full economic benefit from a new GPT becoming effective several types of policies are required (Scherrer 2019b). The *first* type of policies refers to policies that are directly





related to the regulation of the dominant GPT (e.g. technical standards). While in the current fifth long wave legal foundations of internet commerce (e.g. digital signature) had been established early, the development of IoT-standards – which are required for rolling out ICT particularly in the manufacturing sector – has come only recently. The regulation of privacy and data security is a most interesting example how new phenomena that come with a new GPT are conceived differently by different societies and how differently societies respond to it. On the one hand after long discussions the European Union adjusted its legal frame to the requirements of the “new” TEP by releasing the General Data Protection Regulation only in 2016. On the other hand, privacy and related issues – even taking differences in political systems into account – do not seem to raise major concerns in all societies. A *second* type of policies addresses areas beyond technology policy and refers to policy fields that are indirectly affected by the new TEP. Such policies refer to adaptations of existing regulations and implementing new regulations in various fields (e.g. labor relations, competition policy, social security systems) and to policies that address the changing skill requirements.

While the idea of implementing these two types of policies is rather straight-forward, the long wave-model highlights a *third* type of policies that comprise complementary macroeconomic policies and thus reach beyond the above mentioned micro-oriented policies (Scherrer 2019b). A new TEP starts with a focus on the supply side of the economy when the development of new technologies is fueled by financial markets and income inequality is set to increase. During the roll-out of the new TEP the purchasing power of the population – that has been affected by growing inequality – tends to restrict demand, and therefore the demand side of the economy needs to be addressed in this phase. Hence, innovation activity during the unfolding of a new TEP has implications for economic policy that reach far beyond mere innovation policy as it is understood in a narrow sense with its focus on technology, research and development.

In conclusion, a long wave view of innovation suggests that economic decisions at the individual level and strategic choices at the macro level have systematically influenced the emergence of GPTs and the dissemination of related TEPs. Different phases of economic development are represented by the long waves and are characterized by different varieties of innovation. Both from the perspective of socio-economic theory and from a business perspective it is concluded that a broad variety of innovation exists, that is even further enlarged by the many possibilities of economic policy makers to influence innovation activity.

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NOTES

1. See Perez (2002) for the original source and Scherrer (2016) for a summary.
2. Please note that the concept of techno-economic paradigm used in this paper suggests a much broader understanding of what a general purpose technology is compared to other authors' (e.g. Bekar et al. 2019) narrower understanding of GPTs.
3. For an overview see Scherrer (2016) and Gallegati (2019), for detailed descriptions see Freeman and Louçã (2001).

