Cyber-Physical Systems and the New Socio-economic Paradigm: Technology, Knowledge and Human Capital

Rainer Masera

Abstract The cyber-physical regime change in the world economy entails large potential benefits, but also significant risks. A "knowledge paradigm" is taking shape: technological advance and human capital are the pillars to transform economies and societies and reap the benefits of creative innovation. The paper highlights the twin concurrent revolutions of servitization and digitization, which represent key features of the new economic landscape. Significant investments in good infrastructures—broadly defined—is indispensable for sustainable and inclusive growth. In this perspective, Italy represents a negative paradigm: in the past two decades it lagged behind in terms of insufficient and inefficient infrastructure accumulation. This is a fundamental factor to explain the country's dismal productivity performance.

1 Introduction

It is a great honour and pleasure to present a paper at the 30th Villa Mondragone Conference. Let me start by paying tribute to the intellectual and operational achievements of Professor Luigi Paganetto. He has made all this possible, he has created out of an abandoned palace in ruin an outstanding center of research and education. Professor Paganetto was able to blend successfully the physical, financial, intellectual, human resources necessary to create the now world-famed Villa Mondragone event. He was also capable of attracting Ned Phelps, Nobel Prize in Economics in 2006, into this successful process. Ned gave—and gives—an extremely important impulse throughout the years. His presence today is a coronation of the continuing collaboration of the two minds over the three decades.

The themes of this Conference are of outstanding importance: conditions of and policies for world sustainable and inclusive growth. Good investment in human and physical capital is key to strive for these objectives. The aim of this paper is to offer a

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small contribution to the subject, in the light of the seminal works of Luigi and Ned. I will make specific reference to the Nelson and Phelps (1966) model and to the Paganetto (2004) approach and their subsequent variations and updates.

This paper highlights the twin phenomena of servitization and digitization, which represent key features of the new economic landscape. It also brings to the fore the need for good investments to upgrade and increase the total stock of material and immaterial capital. Paganetto (2004) was one of the first to underline that the main Italian economic problems stem from the very low/negative growth rates of Total Factor Productivity (TFP). Attention is drawn to two key specific Italian problems, which contribute to explaining the country's very poor performance: the quality and the amount of investment in infrastructures broadly defined.

2 Risks and Opportunities of the Emerging Socio-economic System

The emerging technology revolution brings forth huge possible benefits, but also grave potential risks. Education is key to transform a critical moment of change into a favourable juncture for advancement at national and global level, to tame the Schumpeterian (1942) "gale of creative destruction". Automation, artificial intelligence (AI) and cyber-physical systems (CBS) will replace workers not only in industry, but across the entire economy. According to estimates presented by the World Economic Forum and its President Klaus Schwab (2017), nearly half of existing jobs could be at risk, replaced by "intelligent machines", but the potential new jobs can more than match this massive displacement.

Education will represent a fundamental driver in adapting human capital to the new environment. Work competitiveness in the emerging labour markets will require novel competences and skills, both for students entering the labour markets and for displaced workers. High quality education—focused on the current and prospective challenges -encompasses the whole range of ages: not only K-12, undergraduate and graduate schools and universities, but also lifelong learning. Technology will facilitate adaptation of education. Scalable on-line methodologies will integrate traditional approaches in "blended" environments.

The specific reference to Industry 4.0 (Roser 2015, 2016) helps identify the current revolution, but is too narrow. The reference scenario must be broadened from three angles:

i. the perspective of the whole socio-economic system
ii. the new features of "servitization" and of "digitization"
iii. the "knowledge economy" (Par. 2).

To start with, the common indication of four technological revolutions (Fig. 1) is too narrow in scope.

Along with many other authors on the epistemology of applied science advance (Kuhn 1970; Masera ed. 2010), I prefer to identify six overlapping long waves of

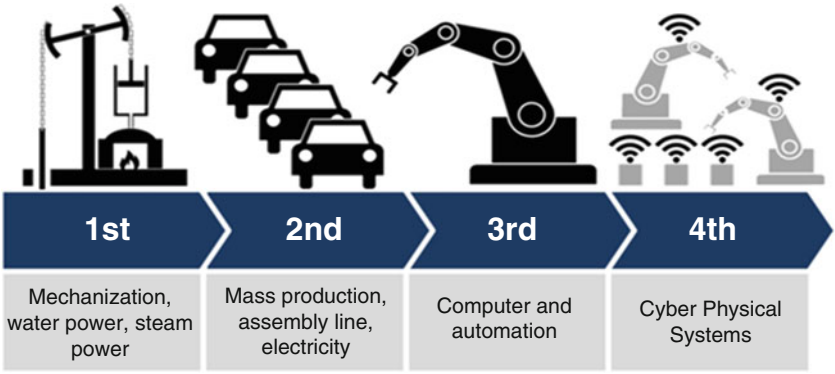

Fig. 1 The 4 industrial revolutions. Source: By Christoph Roser at AllAboutLean.com under the free CC-BY-SA 4.0 license

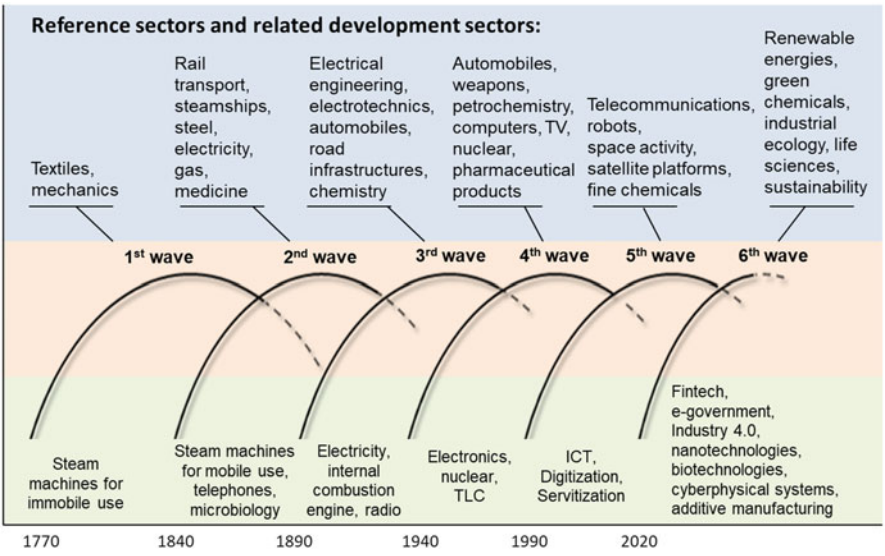

Fig. 2 The long waves of innovation in the economy. Source: Author

economic and social innovation, starting with the fixed-steam machines at the end of the eighteenth century (Fig. 2).

The successive technology waves made for dramatic changes in the proportion of workers moving from the primary sector (agriculture, mining) to the secondary sector (industry, manufacturing, construction). More recently a massive shift occurred towards the service industry which comprises banking, insurance, finance, public services, healthcare, tourism.

Currently, with what I indicated as the sixth global wave, the knowledge economy is taking shape. It centers on information technology, education, scientific

Table 1 The traditional separation of goods and services. Goods vs Services

Goods	Services
Tangible	Intangible
Produced in factory	Produced in buyer seller interaction
Can be stored	Cannot be stored
Transfer of ownership	Transfer of ownership does not take place

Source: Author

research, human capital and e-government (some have coined the term of quaternary sector to mark the change). These factors drive human capital and technological advancement and are key in transforming our economies and societies, in making it possible to fully exploit the potential unleashed by the CPS and the internet of systems.

The new wave of innovation impacts not only industry, but all sectors of the productive system. Digitization and servitization blur and reshape the boundaries of economic sectors and the features of value chains. A holistic network approach is critical to understand and guide the processes in the new complex/interactive socio-economic systems. In this perspective, the importance of good universities and technology-advanced, cost efficient education becomes critical.

The common key distinction between goods and services, summarized in Table 1, fades.

The system becomes characterized by a continuum of goods and services, increasingly "bundled" together. Pure goods and pure services loose importance. This has profound implications for economic analysis, which have not yet been fully systemized. In the classical economy—Smith, Ricardo, Marx, and also in the view of key neoclassical economists, Marshall, Walras, Pareto—the focus was on the production of goods by means of goods. Services were considered of secondary importance: "*Services pass out of existence in the same instant that they come into it and are of course not part of the stock of wealth*" (Marshall 1920).

These models were superseded by the services wave. In turn, this was regarded as one of the causes of declining productivity growth. Baumol (1962) showed that the secular increase in services—with inherent lower productivity growth—would necessarily undermine the dynamics of TFP.

The knowledge economy and the bundling of goods and services lead to a different paradigm.

An example of the new boundaries is offered precisely by the models of e-Teaching and e-Learning. The traditional university lesson disappeared as it was given, according to the Marshall model. The e-Lesson is now stored and made available through different e-platforms over time and space. It can be "consumed" by the students endlessly and everywhere: it becomes therefore a parcel of the available stock of knowledge. A new service/product is brought into existence: a "durable" cost efficient good/service replaces the "perishable" service. Constant interaction between teachers and students (digital teaching and learning), also

through "virtual c@mpuses" (Unimarconi model), and reference to MOOC benchmarks[1] permit and require real time improvement and update of lessons.

Similar innovation processes take place in respect of many intangibles, which acquire and require physical and electronic characters and become therefore akin to manufacturing products. Many examples could be explored of this two-way convergence. The digitization of the automotive sector (where cars have already more than half of their value embedded in electronic components, software and connecting instruments, leading to virtual driving) transforms the traditional car product into a (rented) car as service provider. e-Commerce (Amazon, Alibaba) is another instance of the bundling between goods and services. Rolls-Royce aerospace industry with "power by the hour" has changed the value creation model of a typical industrial firm. Netflix and Spotify deliver media services which replace the need of buying Cds, DVDs, media-products. Phillips offers a service LED lighting proposition package to airports (Schiphol).

In sum, "servitization" becomes a key feature of the new production systems, with technological innovation bundling together industry and services.

"Digitization" is the key corresponding enabling process, which is based on the transformation of analogue into discrete digital values in all areas and sectors (Schumann et al. 2018). This was the basis of the internet revolution, which made it possible to blend physical and digital assets. Value creation chains changed and new business models emerged. Dynamic integrated platforms were created by linking together hardware, software and content provisions (Coreynen et al. 2016; Vendrell-Herrero et al. 2017; Gilli 2018).

3 Comparative and Competitive Advantage in the Knowledge Economy

The knowledge economy can be seen as an extension of the information/internet society (the fifth wave in Fig. 2). The concept was introduced by Peter Drucker (1969) "from Manual to Knowledge worker", who credits Fritz Machlup for developing his approach. Knowledge generates economic—tangible and intangible—value, which can be incorporated into machines. Knowledge and education become human capital, which is the key productive asset, embodying a large proportion of technical progress. This leads to a rethink of the original Solow production function paradigm (Solow 1956).

Comparative advantage gives way to competitive advantage. The traditional workers must acquire specialized computer literacy: the education system correspondingly adapts towards STEM (Science, Technology, Engineering, Math) training. More generally, continuous innovation requires lifelong learning with corresponding changes in teaching techniques and skills. The fundamental

[1] See for instance L. Breslow et al. (2013) and Coursera (2018).

difference between knowledge and information societies lies in the capacity to select, transform and enact information into true knowledge and effective action. In turn, this requires adapting and networking all key infrastructures of the system.

Human, physical and computational elements give rise to embedded systems. Similar new architectures are behind both CPS, the Internet of Things (IoT), and the Internet of Services (IoS).[2] A well-known example is the so-called 5C architecture (Connection, Conversion, Cyber, Cognition, Configuration, Bagheri and Lee 2015). At the first level, devices of a CPS are able to self-connect and self-sense. In the conversion level, machines use the self-aware information to self-predict potential issues. At the cyber level, each machine can create its twin and self-compare for peer-to-peer performance. In the cognition function, the outcomes of self-assessment and evaluation are made available to human remote visualization and check. Finally, at the configuration level, the production system activates self-optimization, adjustment and configuration for resilience.

As the US National Science Foundation (2018) aptly put it:

> CPS technologies are transforming the way people interact with engineered systems, just as the Internet has transformed the way people interact with information. New, smart CPS drive innovation and competition in a range of application domains including agriculture, aeronautics, building design, civil infrastructure, energy, environmental quality, healthcare and personalized medicine, manufacturing, and transportation… with major societal implications.

In the knowledge economy highly-skilled, constant-learning, managers and workers are the drivers of value creation and of oversight of CPS. A necessary condition for a firm to be successful is to become a "learning factory". Unskilled labour will inevitably become less valuable and will be increasingly displaced by low-wage workers and machine competition. Socio-economic tensions are inherent in this complex process of creative destruction; understanding and managing these risks is key in today's global risk environment (Oliver Wyman 2018).

4 Good Infrastructures and Trias Politica

Good infrastructures play a crucial role for economic and social development in the knowledge paradigm (Masera 2017) (Fig. 3).

Adequate investment in innovation infrastructures is indispensable for supporting companies and public administration in the current evolutionary process,

[2] A key implication of the IoT is the digitization of physical infrastructure, which embeds information technology to allow for networking with other infrastructures and with, for instance, persons, cars, trains, lorries, and goods. Sensors, near-field-communication devices and wireless technologies make it possible for physical equipment and assets to become "intelligent", warn on impending (endogenous/exogenous) risks and connect with persons and other infrastructures. This is an instance of a more general phenomenon: the bundling of assets and services made possible by advances in technology.

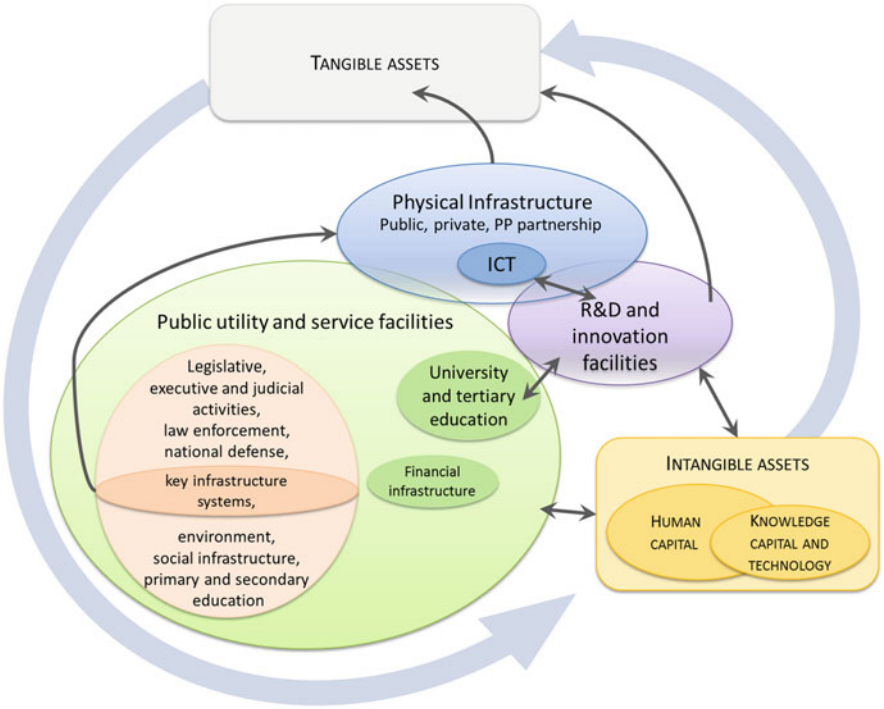

Fig. 3 The infrastructural system: physical capital and intangible capital. Source: Author

characterized by significant break points (Paganetto and Phelps 2010). These infrastructural requisites—broadly defined—involve research and development, and human capital, beyond traditional physical capital, as is detailed in Fig. 4. The two types of capital are often "bundled". The aforementioned arrays (servitization, digitization and twin capital) create a new economic and societal paradigm and pose critical challenges. It is estimated that at world level, over the next two decades, some $60 trillion worth of new infrastructure investments would be required: the key is to create efficient infrastructure in a deepened fruitful partnership between public and private sources.

Investment in knowledge and research plus selection of human capital according to the principles of ability and merit are fundamental for activating and sustaining virtuous circles of innovation, productivity, competitiveness, and employment. This positive loop is synthetized in Fig. 5 centred on knowledge and technology capital.

The basic infrastructure of a civil society can be identified in the Trias Politica (Montesquieu 1748, Fig. 6) namely the relationship between democracy, politics, government, the judicial authorities, and law enforcement entities.

The functions of the Trias extend over a number of powers that include drawing up good laws and enforcing them, effectiveness of government, sustaining crime prevention and punishment against illegality, providing efficient public

A. Public utility and service systems	- Legislative, executive and judicial activities (*trias politica*) and public order - National/local public administration - Education system and universities - Healthcare system - Selection and financing mechanisms for infrastructure development - Protection and management systems for environmental, cultural, artistic and historical resources (including *green infrastructure*) - Civil defense network - National defense network - Financial infrastructures
B. Physical infrastructure	- Transport networks (roads, railways, airports, ports and inland waterways) - Energy networks and infrastructures (electricity, gas, oil) - Renewable energy and *smart grids* - ICT capital - Aqueducts and water mains - Networks for integrated waste management - Land protection infrastructure - Urban energy efficient housing and infrastructure
C. Research & development and innovation facilities	- Knowledge capital and technology - Laboratories and research facilities - Scientific and technological parks - Patents, trademarks and copyrights - Software - Organisational methods

Fig. 4 The infrastructures of a country-system broadly defined. Source: Author

administration. This analytical framework (Masera 2017) is akin to that of country governance—as defined and operationally measured by the World Bank—which refers to

> "the process by which governments are selected, monitored and replaced; the capacity of the government to effectively formulate and implement sound policies, and the respect of citizens and the state for the institutions that govern economic and social interactions among them" (World Bank 2018).

The Trias/country governance "context infrastructure" is itself amenable to accumulation/decumulation, with corresponding improvement/deterioration in

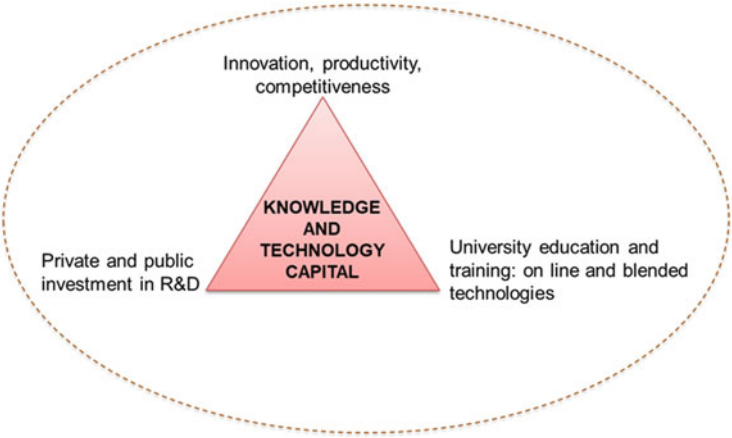

Fig. 5 The triangle of knowledge and technology. Source: Author

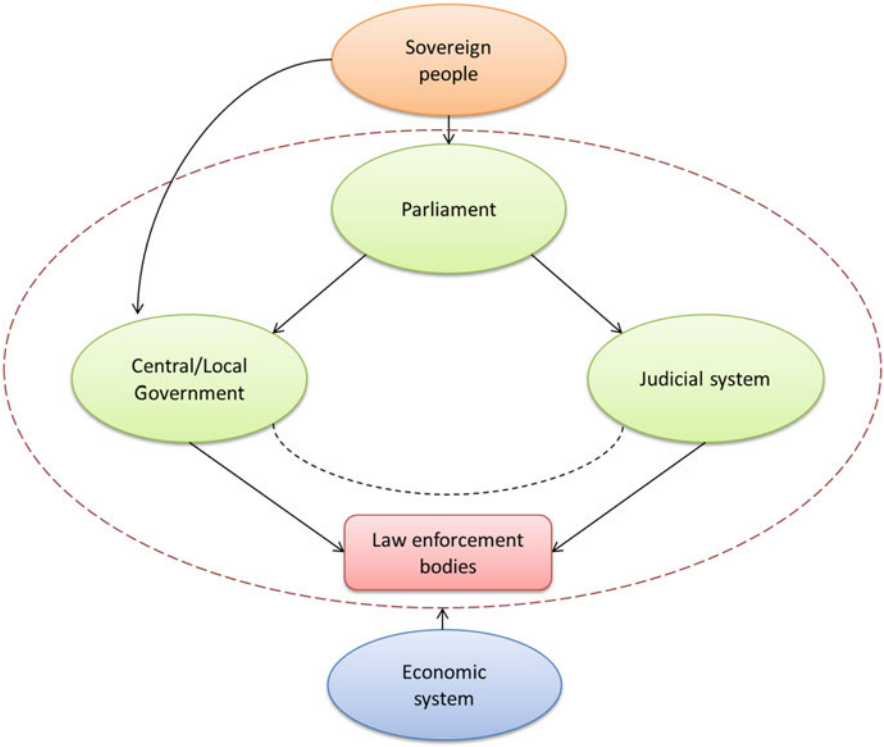

Fig. 6 Democratic society, rule of law, and market economy. The trias politica as a pivotal system infrastructure. An interpretation of Montesquieu (1748). Source: Author

performance, which can be gauged by means of the indicators elaborated by the World Bank.

More narrowly defined, a country's infrastructure comprises physical and intangible capital stocks fed overtime by investment flows. Although mainly driven by the public sector, these flows should link efficiently and complementarily with private investment, notably, but not exclusively in terms of the Private and Public Partnership (PPP) framework.

As the European PPP Expertise Centre (EPEC) based at the European Investment Bank (EIB—EPEC 2015) has amply demonstrated in its ten-year existence, it is crucial to foster the complementarities and the efficient intertwining between the two sources of capital accumulation: this is particularly relevant in the case of intangibles—education, R&D, innovation, knowledge and skills.

A key challenge ahead is to deliver cost-benefit and value-creation efficient public services, given the accelerating phase of change in the social economic systems. This is likely to require adaptation in the traditional PPP contractual model, which may be too long-term and too inflexible.[3] A shift may therefore be appropriate from concession to availability PPP structures, also to better accommodate frameworks enlarged to private institutional investors.

Successful interaction and efficient selection of investments in physical as well as R&D infrastructures and human capital are closely linked to the correct functioning of the Trias, to the effective and efficient operation of the country governance.

This virtuous paradigm can work in reverse, if country governance deteriorates, if public investment flows shrink and their quality declines. Evidence on these adverse trends can be obtained from analysis of the Italian case in the past twenty years.

5 Country Governance and Public Investment: The Italian Negative Paradigm in the Past Two Decades

The World Bank Country Governance Reports (World Bank 2018) provide evidence that during the last twenty years effectiveness and efficiency of Italy's governance declined significantly. The deterioration took place in absolute terms and even more relatively to other advanced economies, notably in comparison with the Eurozone, and with regard to all major indicators. This made the workings of the Italian economy more stringent and difficult in the single currency area. The decline in TFP for the whole economy (market plus public sectors), Fig. 7, and the grinding to a halt of real incomes growth are at the root of the economic and social deterioration and represent one of the main causes of the continued increase in the public debt-to-GDP ratio.

[3]PPP's that are characterized by very long time spans before finalization imply that the financial component can become a multiple of construction costs. This creates problems not only of financial sustainability, but also of political legitimacy.

Fig. 7 Total factor productivity for Italy (1960–2014). Source: University of Groningen and University of California, Davis, Total Factor Productivity at Constant National Prices for Italy [RTFPNAITA632NRUG], retrieved from FRED, Federal Reserve Bank of St. Louis; https://fred.stlouisfed.org/series/RTFPNAITA632NRUG, November 15, 2018

In turn, the worsening of governance standards had a lasting adverse impact on the quality/efficiency of public investment flows (Masera 2017; Visco 2018). The problems were further compounded and amplified because actual investment flows shrank during the past two decades. Centres of excellence continue to characterize the country in all areas and sectors, but their continuing successes, and even their existence, are at risk if past trends, described below, are not rapidly reversed.

Starting with education, selective reference will be made mainly to OECD (2017) evidence. Currently graduates in Italy total 18% compared with a 37% average for other OECD countries. Italy is last in Europe, far behind Germany, France and Spain. Switzerland stands at 41% and the United Kingdom at 46%.

Degrees are concentrated in faculties with limited interest for the labour market, while those in all the scientific subjects and in economics are relatively few. 25% of total graduates, as against 37%in Germany, have the qualifications that offer the best job prospects, such as Industry 4.0, Fintech and e-government. There is a significant lack of STEM graduates (Cantoni 2018). Women are penalized because their degrees are mainly in the arts, philosophy and sociology with low demand. The quality of public spending in education is questionable, mainly because strict ascertainment of preparation levels is often underplayed, in line with a misleading concept of productivity. The country is in the last place in the OECD area in terms of overall spending with just 7.1% of total public administration expenditure reserved for education, almost 10% less than in 2010. Teachers and lecturers earn less than in almost all European countries. Italy is the only country in the OECD area that has allocated the same amount to the support of primary and secondary education since 1995. Eurostat confirms the last place in terms of percentage of public spending on education in the EU. More than one youngster out of five, aged fifteen to nineteen, is unemployed, does not study or follow any kind of professional training course: again

the last position in Europe for NEETs (Not Engaged in Education, Employment or Training), with the emerging risk of Hikikomori syndromes (Crepaldi 2018). The OECD PISA (Programme for International Student Assessment) Survey reveals that many students are not interested in university training. World wide education models have increasingly adopted IT and tech innovation tools and methods. Italy lags also from this point of view, notwithstanding early warnings and indications on the need to develop blended education models (Briganti 2014; Masera 2014).

Similar considerations can be made with reference to the quantity and quality of investments in physical infrastructures. Impressive and consistent evidence can be obtained from national and international sources [for instance EC (2017), WEF (2018), EIB (2018) and Visco (2018)].

Not only spending on these types of investment has dropped significantly (by 30% in the last five years), but the accounting-financial data are overestimates. Only part of the money actually spent translated into an increase in measured capital, because investments were inefficiently selected and carried out. Non-transparent processes in tender procedures and corruption often led to unacceptable increases in work duration and costs, as documented by the OECD; the Bank of Italy and the Italian Court of Auditors. These problems, linked also to overlapping, uncertain and poorly formulated rules, hindered the necessary public-private co-funding. The challenge is not only insufficient, but also inefficient spending for infrastructures.[4]

6 Concluding Remarks

CPS, AI, Digitazion and servitization are key megatrends, which reshape business models and value creation in all areas of economic systems—including the public sector. Human and physical capital become intertwined: lifelong education and (re) training are key to master these processes, to sustain competitive employment, civil and social growth. Comparative advantage gives way to competitive advantage.

Well selected and closely monitored capital expenditure in the infrastructural system is a necessary condition to cross the "traverse" for all countries. China and United States are well aware of this need. They are poised to foster infrastructure accumulation, while guaranteeing the complementarities with private investments. In particular, the aim is to ensure and maintain preeminence in terms of both physical and human AI capital.

These objectives are especially relevant in the EU where the Maastricht framework may adversely affect the significant needs for higher rates of public net capital formation both in legacy and innovative infrastructures. Corresponding adaptations of the current criteria in respect of public capital spending—subject to EIB/EFSI

[4]Also in Germany public net fixed capital formation has been relatively week in quantitative terms in the past several years (Roth and Wolff 2018). The key difference lies in the effective implementation of high quality infrastructural outlays in the Federal Republic.

monitoring—would be appropriate to ensure effective realization of the stated objective of ensuring sustainable and inclusive growth and world competitiveness of the Union (Masera 2018).

During the past two decades Italy has been characterized by the three-pronged negative infrastructure loop analysed and documented in this paper. The country is now at half way between the relaunch of Humanism—to reinstate "the centrality, dignity and creativity of man"—and the "Degenerative Attractions" (Pico della Mirandola 1486). Investment in good infrastructures, broadly defined to include the country governance, is key to reverse the perverse loop.

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