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TECHNOLOGY-CHANGE CHANGES: IMPLICATIONS FOR UNIVERSITIES AND R&D-SECTOR

Technology change and the resulting increase in labour's productivityis the major contribution of bourgeoisie. Yet, as the path and the velocity of technology's evolution changes, the phenomenon induces systemic modifications challenging the very nature of capitalism itself. This in turn alters the role of the R&D and academic institutions in the modern society. The present paper contributes to this discussion. We follow a theoretical framework that combines epistemological and economic growth theories in order to suggest the induced changes. Next we discuss the modern role of academia and R&D. We conclude by presenting hypotheses for further research and discussing the induced policy implications.

Keywords: technology change, role of Academia, role of R&D-sector.

Introduction. Knowledge is the driving force of the human society. Knowing the way how human knowledge evolves is therefore a main issue in ecumenical philosophic discussion.

Epistemology developed two main rival approaches: on the one hand the traditional Anglo-Saxon view, where the sense of (quasi-) linear continuity prevails: the "new" arises upon (and not aside) the "old", having neither "all-embracing" retrospections, nor "shooting stars".

In the post-war period, "logical empiricism" – the tradition that was developed by the "Vienna Circle"(Schlick, Waismann, Neurath, Hahn and Carnap) and builds upon the critical assimilation of the work of Russel and Whitehead [16] and Wittgestein [17]. – becomes the main philosophic trend in the Anglo-Saxon area. Science is purely a connotative procedure: based on simple empirical generalizations; theoretical terms first and then theoretical laws can be developed. The evolution of knowledge is a **continuous, accumulative process**. The progression of attested theories succeeds through the integration of an older theory in the wider spectrum of a new one. (This is the core of the theory of "Reduction" – Nagel [9]).

In contrast, there is the range of non-linear considerations, stretching from chaotic modeling of stochastically emerging evolutionary ideas to the endogenously generated sequence of longer lasting scientific paradigm shifts.

In the sixties, the dominance of "logical empiricism" has been hardly contested. The book of Kuhn, "The Structure of Scientific Revolutions" [7], can be considered as the turning point in modern epistemology. According to the new current, the extreme positivistic approach is misleading; in order to support a primitive empiricism it sacrifices the main factor of scientific evolution, namely the creativity and imagination of the researcher. The development of science is not a linear accumulative process, but it is a complex phenomenon, with phases of continuity and discontinuity, with deep, radical revisions and breaks. (The contribution of the development of the "history of science" as a separate field by Alexandre Koyrè and Herbert Butterfield in 1959 was very crucial for this recognition.)

Kuhn's basic perception is that the scientific ideas of each epoch are being structured in a sovereign system, which cannot be evaluated on the basis of the contemporary criteria and values. The evolution of science is a **radical, discontinuous succession of violent turnovers**. "Normal science" is the daily activity of a "scientific community" that adopts a specific paradigm – a network of theoretical assumptions, terminology and methodological principals, as well as social and ethical values. It means the confrontation of this scientific community with issues and questions that may arise, by making use of the existing, approved paradigm. As "normal science" evolves, "abnormalities" are being accumulated. Sooner or later, a period of "extraordinary science" is setting up, meaning the confrontation of contradictory "paradigms". This period of crisis results in a "scientific revolution", meaning the domination of a new paradigm, authorized through its generalized acceptance by a new scientific community. A new period of "normal science" will be initiated, where polemic is cooling down, social creativity is being canalized again and scientific productivity is blowing up.

The influence of the pre-existing "logical empiricism" is obvious, as Kuhn recognizes the period of "normal science" as the one where actual science is fruitfully developed. It is also quite interesting that Schumpeter [12] uses a similar schema in order to describe the historical evolution of different schools in economics. He also understands the development of economic ideas as non-linear: a succession of revolutionary periods, "classical" periods and periods of confusion. For a discussion of the application of Kuhn's framework in the history of economic thought look also Blaug [2] and Hutchison [4].

Standard economic growth literature, specifically endogenous growth theory, contributes to the above discussion, as the evolution of technical change is the main reason for which the economy grows in "steady state". The country's openness, the effectiveness of the political system, socio-political views and liberties, structural characteristics and spatial specificities are being employed in order to explain the ability of a society to develop (and / or to imitate and incorporate) practically applied innovations.

Moreover, Romer [15] introduced two effects with respect to the way how existing stock of knowledge affects researchers' "productivity": first, the positive effect – **stepping on shoulders** – which means that new innovations step upon the existing applied ideas; second the negative one – **fishing out** – which starts from the idea that the set of exploitable applications is limited, given the possibilities defined by the present scientific paradigm.

Those two effects will be of key-importance in our following, theoretical discussion: first, we introduce them in a framework that links modern epistemological agenda with the long waves of economic activity; then, based upon this model, we develop a theoretical hypotheses that explains the alteration of the way how technology changes. Following, given the theoretical scenario, we discuss the induced modification in the role of academia and R&D sector. The paper concludes with relevant policy implications and proposals for further research.

A theoretical discussion: How changes *Technology-Change*

Zarotiadis and Ozouni [20] associate the tradition of Koyrè, Butterfield and Kuhn with a dynamic combination of *stepping on shoulders* and *fishing out* effects that generates a cyclically evolving set of applied ideas within a given scientific paradigm. Thereby, they first rationalized scien-

tific cycles on the basis of underlying socio-economic conditions; second, they developed a model that simulates long waves of economic development, as the result of a cyclical evolution of applied knowledge and thereby of labor's productivity.

(Note that Kuhn, although he adopts a socio-political terminology in order to describe the succession of different periods in the evolution of human knowledge – alone the use of the term "scientific revolution" is indicative, he does not proceed in linking them to the development of human society, even if he, probably, had something similar in his mind. After all, the new current that arises in place of "logical empiricism" asserts that science is a human construction, a cultural phenomenon, similar to art, religion and policy. It interacts with all other sectors of social reality, being affected from endogenous, as well as exogenous factors.)

The following two diagrams depicture the main notion of the specific theoretical framework. In the first we see that, for the duration of a scientific paradigm (vertical axis), *fishing out* starts from not being an issue at all (in the beginning, all discoverable applied ideas are "available"). As applied ideas keep on being discovered, finding new becomes more difficult. Therefore FO-component starts from 1 and falls gradually to zero. The opposite is true for *standing on shoulders* effect: SOS component starts from zero and reaches asymptotically 1 as we exhaust the attainable applied ideas within the specific scientific paradigm. If we put both effects together (multiplication), we get the solid line representing the cyclical evolution of researchers' "productivity" in applied research, again during the given scientific paradigm (for more details on the underlying probability-logic see in Zarotiadis and Ozouni [20]).

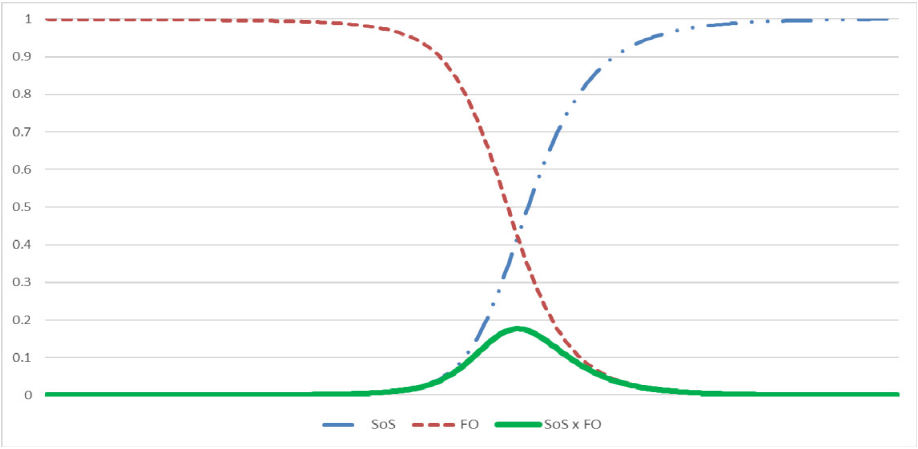

Diagram 1: Cyclical evolving "productivity" of researchers in applied research

Based upon this hypothesis, the model proceeds in simulating the evolution of the productivity of labour (affected directly by the produced applied ideas) and thereby of the produced (real) income in the economy. As we can easily imagine, the resulted picture is a longer lasting cycle of economic activity, presented in diagram 2. In that sense, we reproduce and we provide a reasoning for a widely suggested empirical phenomenon, namely the coincidence of long waves with the periods of "scientific paradigms".

Zarotiadis and Ozouni [20] proceed in their theoretical analysis and describe the phase where the "limits" of the present scientific paradigm are being reached in a way that is quite similar to the perception of Kuhn (shortly presented above): "*as we exhaust the limited set of applications … anxiety accumulates gradually in the society. Sooner or later, this tension will be released, leading to new, revolutionary developments of our social knowledge, setting up a new period, where new, previously unthinkable applications can be developed*". Beside to "production" of applied ideas, they also model the activity of researchers in searching for innovative, basic knowledge, in other words for revolutionary ideas that question the existent paradigm and move the frontiers for the applied research ahead. The emergence of a new scientific paradigm can be seen as the result of a **Poisson process** with an arrival rate ε, which, in other words, is the probability for having a new Paradigm Shift in the next moment (approximately now). As we move towards the limits of the existing paradigm, εtends to unity.

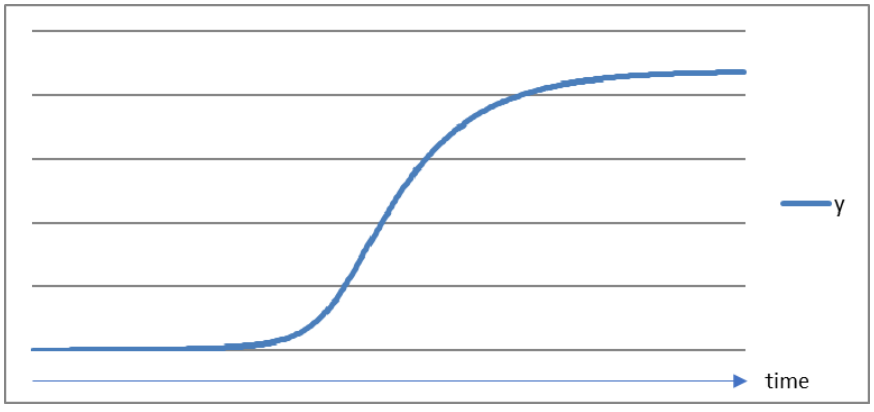

Diagram 2: Simulation of Long Waves of economic activity (y: per capita income)

A straightforward analytical expansion of the above is to provide an endogenous determination of how strong the new scientific revolution will beand/or when it will occur, given the specific socioeconomic characteristics of that time. Zarotiadis and Ozouni [21] start from their notion that "*scientific anxiety*" accumulates the more the limited set of

applications is being exhausted. Along with the probability of overcoming the current scientific frontiers, as we reach asymptotically the limits of the present paradigm, also the expected intensity of the breakthrough to come rises too. Thereby, the two theorists elaborate the following hypothesis: "*the earlier a scientific breakthrough occurs … the shorter will be the duration of the new SP, the earlier will probably occur the next scientific breakthrough*".

As "stepping on shoulders" accumulates, productivity of researchers, even in basic research, rises continuously. Scientific breakthroughs become more often, which leads to SP of shorter duration. The general feeling in our days that "things change more rapidly", as well as the inconclusiveness of relevant literature with respect to the duration of current scientific paradigm is indicativefor that. The fourth long wave initiates after 1940 (in 1945 for Europe) and was related to the revolution in natural sciences. This period is also known as the era of atomic energy, oil, automobiles and steel technologies connected with highly structured technology research. Shortly afterwards, the electronic revolution made its appearance with the emergence of the first computers (Mandel, 1980/2003, p.p. 135-136, 1978/2004; [23, p. 39]). The end of the fourth long wave opened a vigorous debate. Some of the analysts state that after the 1970' and the 80', a fifth long wave began, associated with the revolution in electronics, telecommunications and informatics [3, 5, 13, 14]. Some believe that we are still in the longer-lasting downswing of the fourth long wave [18], while others assume that now begins the sixth wave, associated with new developments in nano-bio technologies [8, 19].

The **path of technology change** slowly transforms from **a smooth succession of cycles into a (log-) linear, evolution**.

The following diagram (first presented in Zarotiadis and Ozouni [21]) depict this alteration: in t_1, t_2 etc. we have the subsequent paradigm shift (A_1, A_2, etc. represent the respectively shifted frontiers). As history evolves, changes in the scientific frontier become more often, yet shorter. In the margin, innovations that alter the very structure of our basic knowledge appear continuously, aside to the evolving applied knowledge, transforming thereby the cyclical in a (log-) linear evolution.

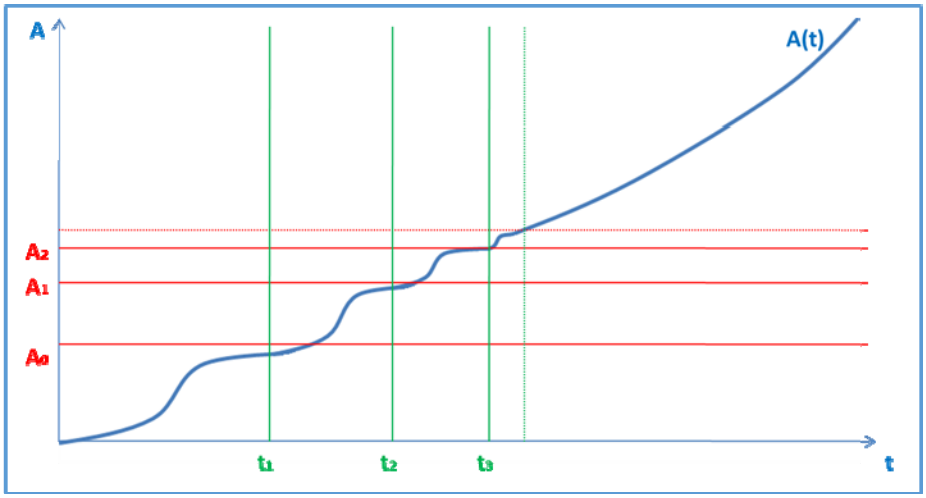

Diagram 3: Transformation of the path of accumulation of applied knowledge (A_t)

Next to the above described "path-effect" on the process of technology-change, the intensification of change rate itself and the accumulated "stepping on shoulder" over the modern scientific history provokes a "**level-effect**" that questions the very basic nucleus of capitalism, despite the significant, undergoing evolution: the accumulated applied, technical accomplishments reach a level where marginal costs of (re-) producing economic goods is dramatically reduced, being therefore relatively unaffordable low compared to necessary fix capital invested.

Zarotiadis [22] describes in more details this "*de-commercialization of goods and services*", in other words the **maturation of the prospects of a socialization of production**, resulting from the endogenous, systemic development itself: "*… capitalist competition itself is the driving force of a counter-systemic technical change…*" leading to the "*…de-commercialization: decreasing MC/FC…* (marginal over fix costs)*… Last but not least… this endogenous process of de-commercialization causes barriers in the usage of "technological revolution" as a way-out of the recurring systemic crisis; yet, there is an alternative to artificial excludability: structural reforms that enhance the efficiency of the public sector, while broadening the socialized sector of the economy*".

Academia and R&D in the new socioeconomic environment

The generalized feeling in contemporary modern societies but also the data and the relevant literature confirm the above theoretical hypotheses. Paradigms shifts appear gradually more often – see the picture in diagram 4 – while the inconclusiveness with respect to the currently valid revolutionary framework support the gradual transformation of the path. On the other, the deeper course of de-commercialization contributes to the systemic turbulences in the cornerstones of bourgeois economy.

Those profound changes in the path and the level of the evolutionary process itself imply new requirements and roles-for academia and the R&D institutions in modern societies. Moving in an era of continuously intensified velocity of scientific changes and relevant applications, research strategies and researchers' abilities and skills must adjust accordingly:

- **R&D processes** have to become **flexible** and to **combine basic and applied research**. A strict separation of those two areas of research may not be any more sustainable given the previously described "path effect".
- Researches need to develop **abilities for creatively questioning and criticizing**, as well as **abilities** in **restating theoretical and empirical methodological issues**.

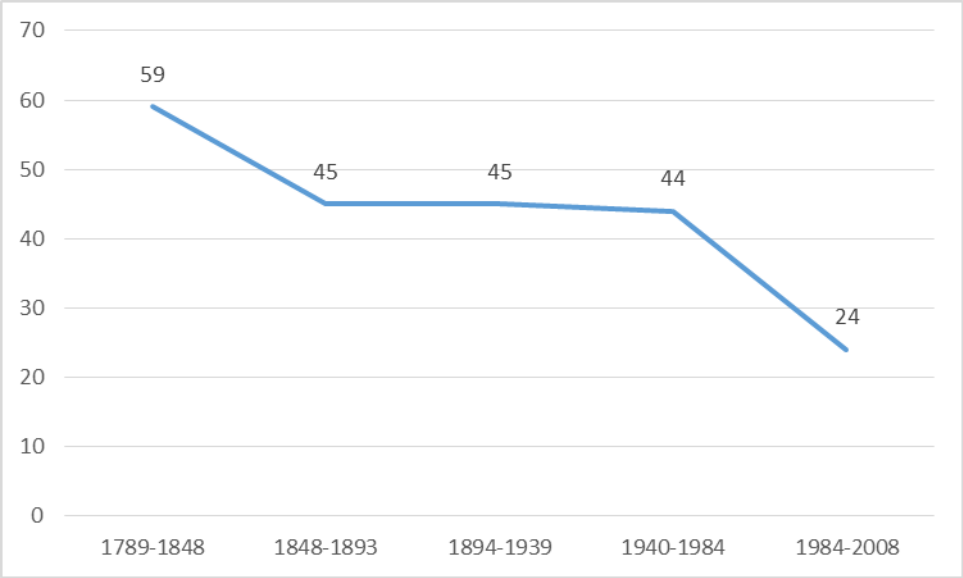

Diagram 4: Duration of the five occurred long waves [21]

This in turn calls for analogous transformations in the education provided – especially in the tertiary academic learning process, but also in the previous levels. Universities have to **strengthen**(**again**)**the theoretical and also the methodological aspects of curricula**, while the need for modern lecturing technics that enhance creative and critical thinking becomes more intense. The overused **drive for excellence** has to be **replaced** by the **desire for radicalism** and **thinking out of the box.**

Moreover, the tendency of **gradually including vocational aspects in the academic programs has to be reversed**. Truly, vocational education and applicative abilities are also very important – yet, by mixing those educational goals in the same programs and curricula we may end up not having the necessary level of acquisition. Vocational education and training institutes are indeed crucial, but so are also universities that will educate the future scientists and researchers in a proper way, being able to efficiently couple with a continuously changing scientific paradigm.

In this new epoch there is a call for more **cross-regional**, **cross-cultural**, **cross-disciplinary**, **progressive**, **scientific collaboration**. (Scientific) Breakthroughs are not simply a possibility – they became a normality. Agents need to be able to combine, to question and to create; but above all they need to be prepared to deal with those continuous changes. Therefore, another issue gets even more important in a time of intensified frequency and intensity of change: the need for underlying ethical and social-institutional foundations becomes more intense than ever.

All these lead to a final holistic restatement of academic education and R&D activities: the **social-public aspects** of their nature **rebound**. On the one hand, basic questioning gets more and more into scientific education and activity. Thereby, commercialization of both, academic and research results gets more difficult, while it also becomes meaningless. On the other, the social benefits from the mixed theoretical and applied innovations are more intense. In that sense, Socialization of educational and R&D sector becomes more rational than ever.

Concluding remarks, policy implications and research hypotheses. In the present paper we started by reviewing the epistemological literature with respect to the path of scientific evolution. Next we combined the tradition of Kuhn with arguments from the school for endogenous economic growth in a model that simulates cycles of technical applications, labour's productivity and GDP during a specific scientific paradigm.

This model (being initially presented in details in previous working papers) was also the basis to discuss the frequency and the intensity of scientific breakthroughs. Starting from a hypothesis that "*the earlier a scientific breakthrough occurs… the earlier will probably occur the next breakthrough*", in combination to the notion that a long history of accumulated knowledge increased substantially the "productivity" of researchers, even in the basic research activities, we end up with two theoretical conclusions for the change of technical change: (i) the cyclical way of evolution alters into a (log-) linear one (path effect); (ii) applied, technical accomplishmentsare reaching a level where marginal costs are dramatically reduced, inducing thereby a gradual decommercialization (level effect).

All these re-intensify the question for the role, the functioning and the significance of Academia and the R&D sector, provoking substantial alterations:

(i) R&D processes become flexible and combine basic and applied research – researches need to develop the relevant, needed abilities;

(ii) universities have to strengthen (again) the theoretical and also the methodological aspects of curricula, while the overused drive for excellence has to be replaced by the desire for radicalism;

(iii) the tendency of gradually including vocational aspects in the academic programs has to be reversed – vocational education and training institutes are indeed crucial, but so are also universities that will educate the future scientists and researchers in a proper way;

(iv) there is a call for more cross-regional, cross-cultural, cross-disciplinary, progressive, scientific collaboration – breakthroughs are not simply a possibility, they became a normality;

(v) finally, all these strengthens again the need for keeping the social-public aspects in academic education and R&D.

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ЗМІНИ В ТЕХНОЛОГІЇ: ЗМІНИ ДЛЯ УНІВЕРСИТЕТІВ І НАУКОВО-ДОСЛІДНОГО СЕКТОРА

Зміна технології і пов'язане із цим збільшення продуктивності праці є основним внеском буржуазії. Проте, з ходом технологічної еволюції, це явище викликало системні зміни, що оскаржують природу самого капіталізму. Це, у свою чергу, змінює роль досліджень й академічних інститутів у сучасному суспільстві. У контексті зазначеної дискусії ми надаємо теоретичну основу, що поєднує в собі теорії гносеологічного й економічного зростання для того, щоб запропонувати індуковані зміни. Крім того, розглянуто сучасну роль наукових кіл і досліджень. У висновку представлено гіпотезу для подальших досліджень й обговорення індукованих наслідків для політики.

Ключові слова: технологічні зміни, роль академії, роль сектора науково-дослідницьких робіт.

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ИЗМЕНЕНИЯ В ТЕХНОЛОГИИ: ИЗМЕНЕНИЯ ДЛЯ УНИВЕРСИТЕТОВ И НАУЧНО-ИССЛЕДОВАТЕЛЬСКОГО СЕКТОРА

Изменение технологии и связанное с этим увеличение производительности труда является основным вкладом буржуазии. Однако, с ходом технологической эволюции, это явление вызвало системные изменения, которые оспаривают природу самого капитализма. Это, в свою очередь, изменяет роль исследований и академических институтов в современном обществе. В контексте этой дискуссии мы предоставляем теоретическую основу, которая сочетает в себе теории гносеологического и экономического роста для того, чтобы предложить индуцированные изменения. Кроме этого, рассмотрена современная роль научных кругов и исследований. В заключении представлены гипотезы для дальнейших исследований и обсуждения индуцированных последствий для политики.

Ключевые слова: технологические изменения, роль академии, роль сектора научно-исследовательских работ.