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The origins of the economics of innovation

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Abstract. This study suggests that the origins of the economics of technical change go back to many years before Schumpeter's contributions. The Scottish philosopher John Rae with his book *Statement of Some New Principles on the Subject of Political Economy*, issued in 1834, put forward the basis of the Economics of innovation individuating the nature, causes of technological innovations (e.g., steam engine) and effects of technological progress on economic growth of nations. Rae also discusses the evolution and role of vital technologies for the wealth and employment in Europe and North America. Overall, then, Rae's work is basic for the origin of the Economics of innovation, for defining the domain of this discipline and for explaining the effects of vital technologies in society. However, the conclusions of this study are tentative. There is need for much more detailed research into this research topic.
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1. Introduction

The economics of innovation is a fertile and rather recent specialization field within the economic theory[1]. Around the mid-20th century it emerged as a distinct research field born of the coming together of different topics such as industrial organisation, sociology, history of technology, firm theory, management of technology and so forth. The interaction with other sciences, such as biology, physics, cognitive psychology, information theory and mathematical statistics has been a constant stimulus for this branch of economics.

This article aims at throwing light on the origins of the economics of innovation. After a brief description of the contributions made by economists of the 1800s, a period called by some authors pre-Schumpeterian (Grandstrand, 1994), the essay shall focus on the work of an author who is not very widely known among scholars of this branch of literature: J. Rae (1834; Ferrara, 1856; James, 1965; Coccia, 2005).

In the 19th century, when analysing economic phenomena, several scholars did not talk explicitly about innovation but such a concept can be drawn from the references they made to terms like science, technology, invention, machines and so forth. Among the economists before Smith, i.e. the Physiocratic and the Mercantilist scholars, references to technology were scarce and haphazard (Roll, 1954). Nevertheless, some economic ideas concerning technology did already exist. For instance, the idea that a temporary monopoly could serve as economic incentive in order to generate technical inventions was clearly expressed for the first time in the "Statute of Monopolies" in England in 1623. Francis Bacon (1561-1626) believed in the power of science to better economic conditions and standards of living. Before Bacon (and Galileo Galilei) the connection between science and

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practical activities was clouded by a religious and philosophical system of thought that aimed at achieving the salvation of the soul. In his book, *New Atlantis* Bacon (1629) addressed issues concerning the first basic concepts of what was later to be called the economics of innovation. Smith (1776) claimed that the specialization and division of labour produced an increase in the skills of workers, allowed for a save in time and for the introduction of new pieces of machinery. While Bacon considered science, technology, politics, industry and religion as deeply interrelated activities, Smith attributed to the economic sphere self-regulating characteristics, influenced by technology but ruled by an invisible hand. In the chapter on machines, Ricardo (1817) referred to technology that lessens workload. In Granstrand's opinion (1994), the scholar who before all others dealt with the interpretation of the economics of technology was Babbage (1791-1871) in his book *On the economy of machinery and manufacturers* dating back to 1832. Granstrand claims that, even though this work from 1832 has nowadays been forgotten, it could be to industry and technology economists what Smith's book has been to economics in general. Marx (1890; 1975) instead is usually claimed to be the first scholar who explicitly dealt with technological change from a macroeconomic point of view. In fact, he analysed innovation as a social process and its relationship with capital and labour that can generate class struggle and distribution problems. Another scholar who investigated the field of technology was Veblen (1899; 1904), who emphasised the importance of machinery and of engineers as a class (the relevance of the engineering profession was recognised also by Auguste Comte who considered engineers as a connecting link between science and technology). Veblen was also in favour of an evolutive approach in economics and stated this when economics started to set the paradigms of the neo-classical school (Marshall, 1890).

Considering the 1900s, Schumpeter (1939) is the first scholar who analysed the role of innovation in modern economies in a systematic manner. His distinction between invention and innovation is well-known and such a distinction points out that an invention is the creation of new knowledge regardless of its actual utilisation, while innovation must be regarded as the actual utilisation of knowledge for production purposes in order to do, in the economic field, *things differently*, according to his famous expression. The economist from Harvard also analysed the effects of innovation on firms, sectors and markets and his stance in relation to monopolies is especially renowned (Schumpeter, 1911; 1942).

The purpose of this research is to throw light, as already stated above, on the origins of the economics of innovation and, from this point of view, it aims at examining in greater depth the contribution given by the economist-philosopher, John Rae (1796-1872), who in his work dating back to 1834 provided a detailed analysis of the causes of inventions and of their effects on mankind, on the environment and on the economic growth caused by their accumulation.

The idea of studying Rae's contribution originated from remarking that in the history of economic thought on innovation, especially in Italy, references to the economist Rae are scarce, while the writer of this paper believes he played a fundamental role in establishing the paradigms of this branch of economics. The Italian scholar who gave the most consideration to Rae was Ferrara (1856), who included Rae's works in volume XI of the Bibliotecadell'Economista (the Economist's Collected Works), after his curiosity had been raised by a quote by Stuart Mill (1848). The Italian economist considered Rae's works worthy of inclusion in his Collected Works, despite the fact that these had escaped Mac Culloch's investigation and were excluded from *Literature of Political Economy*. Besides rediscovering the significant role of the Scottish philosopher in the birth of the economics of innovation, this article aims at trying to deduce from Rae's works a definition of this branch of economics, integrating it with later works on innovation in order to single out its structural characteristics and scientific purpose.

Rae's life and works will be described below (section 2) with specific reference to his attacks against the theory of free trade contained in Adam Smith's book *The*

wealth of nations and to what some economists and historians have stated about him, in order to give him his rightful place in the history of economic thought. Section 3 will focus on the author's analysis of the inventive activity since this analysis anticipated several concepts that were later developed within the economics of innovation. This section will also attempt to provide a definition of economics of innovation by drawing from some concepts included in Rae's work. A further discussion and some concluding remarks complete the research.

2. John Rae and the theory of nature and laws of capital

John Rae, an Scotsman born in Aberdeen on the June, 1st1796, graduated from the University of Aberdeen and later attended the faculty of medicine at the University of Edinburgh without completing his studies. In 1822, he emigrated to Canada where besides teaching he also worked as a doctor. After a period in Canada, he moved to California and then to the Hawaiian islands of Maui, where he practiced a fruitful teaching activity. Later he went to live in New York City where he died on the 12th of July 1872 (Eatwell *et al.,* 1987; James, 1951; Website The History of Economic Thought, 2004). Rae is remembered for his book issued in 1834 *Statement of Some New Principles on the Subject of Political Economy in* which he attacked Smith's theories and put forward his own sociological capital theory. Rae's theory on capital had a strong influence on the entire Austrian school (Roll, 1954) whose main representatives were Menger, Wieser and Böhm-Bawerk (1900; Mixter, 1897; 1902). The first drew conclusions concerning the theory of value-utility, the second worked on the theory of cost and distribution and the latter on the theory of capital and interest. Rae did not possess a wide knowledge of other works concerning the field of economics and developed several of his concepts autonomously. He stated that the nature of wealth in general and the laws that determine its increase and decrease must be considered the true object of philosophical investigations, i.e. the subject matter of studies carried out by economists. According to Rae, Smith's book contained two mistakes: 1) the purpose of a true economist is to investigate the ultimate nature and causes of national wealth, but such an investigation was neglected in his book; 2) Smith used the results of laws as if they were laws themselves, thus exchanging effects with causes. Rae claimed that while writing his work Smith had not followed Bacon's philosophy on induction.

After having considered Smith's mistakes, Rae set himself the goal of describing the true nature and cause of wealth of nations and of the way in which it increases and decreases. His book is divided into three volumes (or three books according to the terminology he adopted). In the First Book, he tried to demonstrate how some principles similar to those used in *The wealth of nations* could be the strongly objected. In the Second Book, he analysed the nature of wealth and the laws that control its increase and decrease. Finally, in the Third Book, he described the practical application of his doctrines and principles.

Dorfman (1966) placed Rae among American Northern Protectionists because he was a great supporter of financing and subsidies to new-born firms and believed that legislators should support the progress of science and technology (*art* according to Rae's terminology). The funds could be taken from duties on the importation of luxury goods that, in Rae's opinion, would reduce lavishness and encourage saving. At first, the book was meant to be published in England but then Alexander Everett pushed him to publish it in Boston, also because there was a reduced rate in the State of New York. Everett explained his decision with the fact that the language was too technical and did not lean very much towards the protectionist cause. In actual fact, Rae's book was well written and could be used as a textbook for university students but it met with little success because the true obstacle it had to face was the fact that many did not consider luxury as a downfall, besides the opposition to Smith's theories who was very well-known in the English-speaking world.

In his book *History of Economic Analysis* Schumpeter (1954) drew attention

above all to Rae's chaotic life saying that "*…a nervous sensibility made him a failure at everything he touched…*" (p. 468). Referring to his work "*As a rule, a work presenting novel ideas will not elicit response if it lacks the support which comes from being written by a well-known author. We ought, therefore, to be surprise at response it met with rather than at the fact that it did not meet with more"* (p.469). Schumpeter said that he marvelled at the fact that Rae's book had been noticed by J. S. Mill and had often quoted in his famous book. In relation to this matter he stated: "*J.S. Mill was invariably fair and generous…the most influential textbook of economics, was insufficient to introduce Rae to the profession or to rouse any curiosity concerning the rest of the book! Or, alternatively, if this impression is wrong and any considerable number of Mill's readers did take it up, there was not one among them to realize its true importance"* (p.469). Brewer (1998) said that Schumpeter had been influenced by Rae but the difference between them concerning the study of development is what Schumpeter called vision rather than analysis.

Towards the end of the 1900s, some scholars published a series of articles on Rae highlighting above all the relationship between economic growth and technological change within his philosophy. Brewer (1991; 1998) analysed in great depth the differences between Rae's and Smith's thoughts concerning the sources of economic growth. Rae accused Smith of ascribing economic growth exclusively to the accumulation of capital that in turn depended on individual saving decisions. Rae was, according to Brewer, the first economist to view technological change as the main cause of economic growth. Furthermore, both Smith and Rae believed that savings must be invested. The first, however, was a supporter of laissez-faire and thought that State intervention reduced savings and as a consequence the economic growth; Smith considered saving as an exogenous variable. In Rae's doctrine savings, population and invention were endogenous variables; moreover, growth was a function of innovation:

> It is invention, which showing how profitable returns can be got for the capital, and subsistence procured from the population that may most fifty be esteemed the cause of both, (Rae 1834: 31).

In Rae's opinion invention needed to be supported in order to promote saving; its causes were independent from individual saving decisions, causes that were open to the legislator's influence, while individual saving decisions were not. Another distinction between Smith and Rae is the cause relation between division of labour and invention. The first maintained that the division of labour led to the creation of new machinery and therefore of inventions, while the latter (Rae) claimed that inventions led to the division of labour.

In his article, Ahmad (1996) gave a more specific description of Brewer's interpretation concerning Smith and Rae; here is what he stated:

> Brewer's position that for Smith the division of the labor is implied by accumulation is not fully supported by evidence from "The Wealth of Nations". This also means that invention is not implied by accumulation either, since for Smith invention results directly from the division of labor. Hence accumulation and the division of labor (leading to invention) remain two separate elements in the process of growth… Let us now turn to Brewer's generalization concerning Rae-That for him invention is the sole independent cause of wealth and growth of income, and all other factors, including accumulation, are simply its consequence. The idea is encapsulated in Brewer's already cited praise of "Rae's conception of growth as wholly driven by invention (Brewer, 1991: 11). However, a quotation Brewer himself cites from Rae would seem to negate this position (Rae 1834: 264). Thus, the results of the two principles can be added indicating a parity of significance between the accumulative principle and the principle of invention, rather than the dominance of one over the other and certainly not one as a by-product of the other. In numerous other places, Rae attributes the difference in the economic growth of difference societies to differences in their accumulative principle (Ahmad, 1996: 444-445).

Anyhow, Ahmad agreed with Brewer on Rae's causality that inventions imply

the division of labour. Finally, Wakatabe (1998) stated that, in his book, Rae had attempted to piece together a theory of growth that is knowledge-based, i.e. an endogenous model of growth, and drew an accurate analysis and interpretation of this model. A thorough treatment of Rae's thought was presented in Aberdeen on the occasion of a conference for the bicentenary of his birth (Rae, 1996; 27th-29th March). Input from various scholars who participated in the conference was collected in the book *The economics of John Rae* (Hamouda *et al.,* 1998). Moreover, The Canadian Economic Association (CEA), since 1994, offers the Rae Prize every two years. The CEA argues that: the prize has been named after John Rae born in Scotland in 1776, who did most of his work in Canada and was a genuine precursor of the endogenous growth theory.

The research carried out in this paper shall focus on Chapter X of Rae's Second Book, entitled *Of the causes of the progress of invention, and of the effects arising from it*, because, in my opinion, it includes some important concepts regarding the economics of innovation of which Rae was a forerunner, in addition to an early definition of that branch of economics which has today taken on a fundamental role in explaining the development laws of modern economic systems.

3. The roots of the economics of innovation among philosophy, history of technology and economics

> Invention is the most important of the secondary agents, to the influence of which man is subject (Rae, 1834: 208).

Considering the title of Rae's chapter that is being analysed here, he referred to the progress of inventions, from which it can immediately be understood that the difference between invention and innovation was not wholly clear to him, a distinction that was later explained by Schumpeter, as pointed out above. That being stated, the aim of this section is to underline the significance of Rae's work because his writings anticipated several important concepts that were later developed within the economics of innovation. Rae's doctrine was based on three crucial factors (Brewer, 1998): 1) invention had causes that were different (and antecedent) from the current level of saving; 2) laissez-faire generated an invention equilibrium level that was second best; 3) State intervention could and should have brought the invention equilibrium to an first best situation.

The first concept that will be pondered upon is that of incremental innovation, which according to the more recent literature is a set of elementary improvements of the product and of the production process. In relation to this, Rae drew some remarks that anticipated such a concept, by showing how improvements were stimulated by need:

> Tracing any invention upwards to its first beginning, we shall discover, that these have been exceedingly rude and imperfect, proceeding from the simplest, and what would seem to us, the most obvious observations; and that it has advanced towards perfection, by having been led to change the materials with which it originally operated, and passing from one to another, has at each step of its progress discovered new qualities and acquired new powers (Rae, 1834: 224).

Another concept Rae developed regards the learning process, which is important for almost all scientific discoveries and has become one of the cornerstones of the evolutionary theory of economic change (Nelson & Winter, 1982; Dosi, 1988; Malerba, 1992),

> Abstract and scientific truth can only be discovered, by deep and absorbing meditation; imperfectly at. first discerned, through the medium of its dull capacities, the intellect slowly, and cautiously, not without much of doubt, and many unsuccessful essays, succeeds in lifting the veil that hides it (Rae, 1834: 213-214).

As stated above, in fact, in his book Rae meant to make up for the lacks in Smith's work by singling out the true causes that generated the wealth of nations and in doing so he designated the following elements as the causes of the progress of inventions:

a. firstly, he talked about the intelligence of men of genius; while Schumpeter maintained that the engine that pushed the system towards development was the innovating entrepreneur, Rae believed that the genius was the one who put to work an energy that without him would have remained at a standstill; moreover, Rae distinguished men of genius from common men who were characterised by an natural inclination towards imitation. In addition to this, Rae also distinguished inventors from people who simply passed knowledge on:

> It is thus that genius manifest the potency of the principle that inspires it, and that the simplest lays of the simplest bard, may have a power passing far, that of the triumphs of the statesman, or the warrior. The one wakens energy, otherwise dead, into action, the other merely directs that action (Rae, 1834: 211). It is necessary to premise, that for the present purpose, two classes occasionally confounded together, must be kept apart. Real inventers, the men whom we have alone to consider, differ from mere transmitters of things already known. The latter are an acknowledged, and very useful class, in all societies, but, they neither encounter similar difficulties, nor produce similar effects to the former (Rae, 1834: 213). The inquirer into principles, again, takes a wider range, it is not tile morality or religion of Italy, of France, of Britain, of North America, after which he seeks, but religion and morality in general (Rae, 1834: 218).

b. the second cause of the progress of invention was the scarceness of certain materials

> Some metals are found in quantity pure, the ores of some are easily reduced, of others with great difficulty. Of all the substances he attempts to classify, none, from their number and variety, give greater trouble to the mineralogist. The discovery of the qualities of such portions of these metals as were found pure, would soon make them be considered as the most useful of substances, and occasion their being sought after with avidity. The supply of them in this state being exhausted, or they who had employed them moving into regions where they could no longer be found, recourse would gradually be bad. to the more pure and more easily reduced ores, and from thence to metals, and ores wrought with greater difficulty. Thus we find that gold, silver, and copper, the metals that most frequently occur native, were those first in use; iron came last, and was probably then esteemed the most precious. Weapons of gold and silver were edged with it, in the same manner as were wooden implements, such as the old English spade, in more recent days. But for the gentleness of the ascent, it is altogether likely, that the art would never have attained the eminence it has gained. Had the earth, for instance, possessed no metallic stores but the more abundant ores of iron, by far the most useful in the present days, it seems not unlikely, that no metal would ever have been wrought (Rae, 1834: 226).

c. the third cause was the fusion of principles originating from within different fields or principles that were already known but were applied to new fields and, as is manifest, generated synergies thanks to phenomena that are today called cross-fertilization phenomena. These made it possible for inventions and innovations to develop following a geometrical rather than an arithmetical progression. Rae quoted watermills as an example:

> When arts are brought together, they borrow from each other. Men perceive that some materials, or instruments, or processes, employed in the one, could they be transferred to the other, would be the cause of its yielding larger returns. They are encouraged, therefore, to attempt the change, and experience shows, that such attempts perseveringly pursued, are generally successful (Rae, 1834: 237).
>
> Thus, from the union of the productions of the inventive faculty exercised on at least three arts, came the rude model of the present water-mill. Its progress was at first slow.
>
> It was owing to an invention, like so many others, the result of necessity and genius united, that the use of water-mills became more general.
>
> Important as these engines were in themselves, from their immediate utility, they were more so in their effects. Men's minds were directed to the advantage of what is termed machinery, instruments that is giving new

> velocity and direction to motion, and to the power of inanimate agents, generative of motion, of both which the mill afforded the first eminent instance.
>
> The productions of the union of arts also propagating others, like all generators, their increase goes on, to borrow a phrase of common use in inquiries connected with these, when there are no retarding checks, not in a simple arithmetical, but in a geometrical progression (Rae, 1834: 243-245).

In Rae's opinion, this effect as well as technological progress was made easier where there were men who belonged to different cultures and where there were consistent trade and financial dealings:

> I take it, that it is chiefly from this circumstance, that the seats of commerce have been. so generally the points, from whence improvements in the arts have emanated.
>
> Thus, also, countries where various different races, or nations, have mingled together, are to be noted, as coming eminently forward in the career of industry. Great Britain is a remarkable instance of this; so are the United States of America. When individuals meet from different countries, they reciprocally communicate and receive the arts of each, adopt such as are suited to their new circumstances, and probably improve several. Servile imitation can there have no place, for there is no common standard to imitate. Countries again, where only one art is practised, and where the population is composed of one unmingled race, are generally servilely imitative. Such are some purely agricultural countries.
>
> In modern Europe, too, the strength of the effective desire of accumulation, seems to have been always greater, than in any other part of the old world.
>
> It is worth while to remark, that there is a considerable analogy in this particular, between the different conditions of society in that continent and Asia then, and what exists between them now, in Europe and North America. The general wages of labor seem always to have been higher in Europe, than in Asia, in the same way as the wages of labor in North America, are now higher than in Europe. The same process, too, that carried the arts to Europe, seems now aiding their passage across the Atlantic. As flame often sets against the wind for that it is fed by it, so invention seems to hold its course against opposing obstacles,. for these obstacles excite its powers and minister materials to their action (Rae, 1834: 237-239).

Furthermore, according to Rae (1834), a multiethnic environment created large-scale habits and originated what today is known as the global village;

d. social changes were the fourth cause. In Rae's opinion, social events able to shake the motionlessness of systems stimulated the inventive and creative faculties of men; therefore, by means of revolutions (social and/or cultural) systems moved from involutive states to evolutive states making it possible for inventions and innovations to find a push towards development:

> But, though there are two of the circumstances giving strength to the principle of accumulation, on which the progress of the inventive faculty is equally dependent, there are yet a set of causes, the effects of which, while they paralyze the exertions of the one, rouse the other to activity. Whatever disturbs, or threatens to disturb, the established order of things, by exposing the property of the. members of the society to danger, and diminishing the certainty of its future possession, diminishes also the desire to accumulate it. Intestine commotions, persecutions, wars, internal oppression, or outward violence, either, therefore, altogether destroy, or, at least, very much impair the strength of the effective desire of accumulation. On the contrary, they excite the inventive faculty to activity. The excessive propensity to imitation, which is natural to man, seems the only means by which we can account for this diversity of effects. Men are so much given to learning, that they do not readily become discoverers. They have received so much, that they do not easily perceive the need of making additions to it, or readily turn the vigor of their thoughts in that direction. "They seem neither to know well their possessions, nor their powers; but to believe the former to be greater, the latter less, than they really are." Whatever, therefore, breaks the wonted order of events, and exposes the necessity, or the possibility, of connecting them by some other means, strongly stimulates invention. The slumbering faculties

> rouse themselves to meet the unexpected exigence, and the possibility of giving a new, and more perfect order t elements not yet fixed, animates to a boldness of enterprise, which were rashness, had they assumed their determined places. Hence, as has often been remarked, periods of great changes in kingdoms or governments, are the seasons when genius breaks forth in brightest lustre. The beneficial effects of what are termed revolutions, are, perhaps, chiefly to be traced, to their thus wakening the torpid powers; the troubling of the waters they bring about, undoes the palsy of the mind.… (Rae, 1834: 222-223). War itself, so great an evil to the individuals within the scope of its ravages, is evidently the only manner by which, in certain states of society, an amelioration can be induced.
>
> The aim of science may be said to be, to ascertain the manner in which things actually exist. (Rae, 1834: 255-256).

e. the fifth cause was the stimulus caused by need

> Necessity thus taught its inhabitants the general use of coal, in which, happily, its territory abounds. But what of this material lay close to the surface, and the fields immediately beneath, having been wrought out, the miner was urged on by the increasing wants of his countrymen, and the abundant materials before him, to penetrate still deeper, and the labors of generations formed large excavations, in regions, far beneath the surface (Rae, 1834: 245).

f. finally, science was also a factor

> In the ancient world, science, as founded on a generalization of the experiences of art, was little prosecuted. It is only in modem times, that the science of experience has come to form an element of importance, in the general advance of invention.
>
> It is clearly on the antecedent progress of art, that the foundation of the hopes of Bacon, for the future progress of science, rested. His philosophy may be fitly described, as a plan to reduce to method the chance processes that had been going on before, by which men, as we have seen, happening on one discovery after another**,** grope their way, as he expresses it, slowly, and in the dark, to fresh knowledge and power. The progress of the philosophy to which he has given his name, as well as that of the science of mathematics, have unquestionably discovered to us many general truths, and theorems of art, and form therefore a new element influencing its progress. The great moving powers will, however, still, I apprehend, be found to proceed from the principles, the action of which we are now to attempt farther to trace through particular instances (Rae, 1834: 240).
>
> It is indeed true that the philosophy, in the introduction of which he bore so eminent a part, has, in these latter ages, been a very effective promoter of the dominion of man, and, mixing with art, has much purified and dignified its spirit, and greatly increased its powers, turning invention in this department from particulars to generals, and converting art into science. This has more especially happened in the chemical sciences, and those connected with them, a sphere to which, I may be allowed to observe, his system seems particularly applicable. There, science begins to lead and direct art; in other departments she rather follows and assists it (Rae, 1834: 254).

Moreover, Rae underlined how the inventive faculty increased industry's rewards, thus anticipating the strategic importance of innovation for the growth of firms and sectors:

> The attempt, then, would probably never be made, but for the promptings of necessity. Its success has, two advantages. The subjection of the obstacles carries the inventive faculty a step farther forward; the larger returns made, owing to the circumstances in which the new material is superior, increase the rewards of industry. As the success of the attempt would advance the skill and the power of those who made it, so its failure would abandon them to famine (Rae, 1834: 225).

Rae tried to explain his theories by means of practical examples such as the steam engine, by pointing out the following main causes that made its invention and innovation easier (Rae, 1834: 246-247): 1) the difficulty to perform complex tasks; 2) the progresses in basic researches on latent heat; 3) the abundance of raw

materials in England; 4) the presence of risk capital supplied by the entrepreneurial class, which is today known as venture capital.

Once inventions, and I would add innovations too, were originated, Rae indicated the causes that held them back:

1. the natural human inclination towards imitation;
2. the oppositions to already consolidated habits; this concept has been mentioned again in later works of economic literature on innovation, especially by Arthur (1989) who showed the so-called lock-in effects that inferior technologies can have in relation to superior ones due to the abilities acquired by the adopters in using them;
3. the commercial aspects that drive exclusively towards researches that have an immediate application. In relation to this, Rae quoted a significant passage by Bacon (1629) which said

> There, the observations of Lord Bacon apply nearly as forcibly as ever. "It is enough to restrain the increase of science, that energy and industry so bestowed, want recompense. The ability to cultivate science, and to reward it, lies not in the same hands. Science is advanced by men of great genius alone, while it can only be rewarded by the crowd, or by men high in fortune or authority, who have very rarely themselves any pretensions to it. Besides, success in these pursuits is not only unattended by reward or favor, but is destitute of popular praise. They are, for the most part, above the conceptions of the commonalty, and are easily overthrown, and swept away, by the wind of popular opinion (Rae, 1834: 216-217).

In analysing the creation of knowledge Rae used a philosophical framework according to which the empirical data was the starting point from which the theory was derived, a questioning approach reminiscent of Locke:

> The progress of the knowledge of the natures and qualities of particular substances, gradually introduced a knowledge of the properties and natures of substances in general. Men first see in the concrete, afterwards in the abstract. Thus, the discovery of the several mechanical powers, and the knowledge acquired of the nature of each, led in time to the general principles of mechanics. A knowledge of the mathematical properties of substances, as in land-measuring, and in the regular figures of architecture, led to a perception of the general properties of figure, or of space as an affection of matter, and, at last, to the doctrine of pure space and motion (Rae, 1834: 239-240).

By continuing the analysis of his book, it is relevant to mention Rae's remark that the spatial diffusion of innovation from one country to the other where there are different cultures, climates and socio-economic environments, stimulates the inventive faculty and leads to further improvements. Concerning steam engines, he stated:

> The diversity of climates, territories, productions, other circumstances of different regions and nations, has helped it, as them, forward, and been to it as it were steps, by which, it has gained the rank it holds in the modes of human industry. Thus the peculiar circumstances of the North American continent, may, with propriety, be said to have been the exciting cause producing steam navigation, one of the most important of these steps. That country is full of great lakes and rivers, affording the easiest, and often the only means for the transport of the larger quantities of agricultural produce, that its interior sections yield.
>
> Such inland navigation is always exceedingly tedious; there were therefore peculiar reasons for the devise of some new agent to facilitate it. An agent like steam too, might evidently be employed with more safetyand chance of success, in calm inland waters, than in the great ocean. If we consider, in addition to this, the greater play which, from circumstances already enumerated, the inventive faculty enjoys in that continent, we shall see that it was there, so to say, that this improvement ought to have taken place. The point, too, in North America, where it did first actually take place, is also, as it were, particularly marked out for it. The transport between New York and Albany, by sailing, vessels on the Hudson river, was both very expensive, and pecularity tedious. Steam has there changed a voyage of days, or weeks, into one of less than sixteen hours.

> The circumstances leading on to the invention of steam land carriage, may also be noted as exemplative of this view of the subject. There were first simply railroads, to facilitate heavy drafts for short distances, from coal mines; then there was a more general use of them in all heavy drafts; finally, there was the general application of steam, as the power to effect transport of all sorts, and with all velocities, along, the smooth surface they afforded. All that was wanted for the last step was, that the mechanism should be rendered less heavy and cumbersome, and, it may be remarked, so great confidence bad been generated of the power of the inventive faculty, that the undertaking was commenced with full assurance that it would accomplish the desired improvement, although the manner how was not known. The result showed that the confidence was not misplaced…
>
> Thus, such are the steps by which invention advances, that it would seem, had there been no country like Great Britain, the steam engine might not yet have been produced; had there been none like North America, steam navigation might not yet have been practised; and again, had not Great Britain existed, metal railways and steam. carriage might have been still only in the category of possibilities (Rae, 1834: 248-249).

Incremental improvements due to technology occurred, in Rae's opinion, not only in relation to products but also in relation to services. On this matter he talked of an art that was intimately connected to the increase of wealth, that of bank trade. It had originated in the cities of Venice, Florence and Genoa, where there were frequent exchanges of substantial sums. In those societies, however, banking operations were limited to simple transfers of money. When the above-mentioned operations moved to areas where the amount of the exchange was small, like in Scotland, the inventive faculty contrived a way of facilitating, stimulating and increasing exchanges. Rae quoted a significant passage taken from Smith's *The wealth of nations* that explained such a concept very clearly

> The following extract from the Wealth of Nations will render this apparent.
>
> "The commerce of Scotland, which at present is not very great, was still more inconsiderable when the two first banking companies were established; and those companies would have had but little trade, had they confined their business to the discounting of bills of exchange. They invented, therefore, another method of issuing their promissory notes; by granting what they called cash accounts, that is, by giving credit to the extent of a certain sum, (two or three thousand for example), to any individual who could procure two persons of undoubted credit and good landed estate to become surety for him, that whatever money should be advanced to him, within the sum for which the credit had been given, should be repaid upon demand, together with the legal interest. Credits of this kind are, I believe, commonly granted by banks and bankers in all different parts of the world. But the easy terms upon which the Scotch banking companies accept of repayment are, so far as I know, peculiar to them, and have perhaps been the principal cause, both of the great trade of those companies, and of benefit which the country has received from it" (Rae, 1834: 250-251).

Rae remarked also on some important implications related to the effects of the diffusion of inventions and, as a consequence, of innovations in terms of well-being (Rae, 1834: 260-61) that are summarised below:

- the increase of income both on an individual and on a social level;
- society can engage in doing new things;
- taxes can be paid on income and not on capital;
- the use of new materials.

In fact, he stated

> In this manner all improvements, by moving, the whole stock of instruments belonging to any society, to more productive orders, increase proportionably, its absolute capital and stock. Should a naturalist, in examining the nature of the surface, on the farm of an individual in a small agricultural society, make the discovery, that beneath it there was a quantity of plaster of Paris; and should the farmer, in consequence of his recommendation, sprinkling a little of this reduced to powder on some of his fields, find that it caused them to

yield double returns, his farm or the lease he held of it, might, in his eyes be doubly valuable, and he might demand in exchange, and perhaps receive two other farms of equal size in its place. Were it, however, found, that a stratum of this substance extended over the whole range of country possessed by the society, and was equally efficacious when applied to any portion of the surface, his farm would not be more valuable than other farms. The supply, however, for future wants, possessed by the whole society, would be largely increased, and the strength of their effective desire of accumulation remaining undiminished, their absolute capital would be proportionably augmented. But, as the whole stock of instruments remained the same, with the exception of the difference made, by the surface having been sprinkled with a quantity of this mineral powder, their amount, as measured by one another, would be the same as before. Some instruments might possibly exchange for a greater amount of instruments of another sort, than formerly, but this change could no more be considered an increase in the total value, than the fact of the latter instrument exchanging for a less amount, could be considered an indication of a diminution of the total exchangable value of the stock of the society. The relative capital and stock would thus remain unchanged. But, though this relative or exchangable value of the society's stock might remain unchanged, its absolute capital and stock would be increased (Rae, 1834: 259-260).

The reality of such increase is marked, in all similar cases, by at least three circumstances.

1. The members of the society possess, in general, a more abundant provision for future wants, the revenue of the whole society, and of each individual composing it, is increased.
2. The whole society, as a separate community, becomes more powerful, in relation to other communities.
3. As it is the effect of improvement, to carry instruments into orders of quicker return than the accumulative principle of the society demands, a greater range of materials is brought within reach of that principle, and it consequently forms an additional amount of instruments…

It can support the burdens of war, and the expense of all negotiations and national contracts with foreign powers, with greater case. It can also, without, inconvenience, execute a greater number of useful works and undertakings. The imposts which the state levies for such purposes, in a society where the stock of instruments is wrought up to an order correspondent to the average, effective desire of accumulation of its members, must almost always occasion some diminution of that stock. The returns coming in from their industry, being only sufficient to reconstruct the instruments as they are severally exhausted, an additional drain made upon their funds must, in most cases, prevent the reconstruction of many of them, and consequently occasion a disappearance, to that amount, of a portion of the general stock. But, when instruments are of more productive orders than the effective desire of accumulation of the society demands, the abstraction of a part of their returns by the state, to supply its exigencies, only carries them nearer, or brings them altogether to an order corresponding to the strength of that desire, and, therefore, interferes not with their reconstruction. Taxation is paid out of revenue, not out of capital. (Rae, 1834: 260-61).

Finally Rae also declared that the increase of the wealth of nations can be the effect of two principles:

1.the accumulative principle that generates the accumulation of capital;

2.the inventive principle that generates an increase of capital.

Essentially, the first principle generates a quantity of stock (accumulation of capital) that is increased by invention (volume of flow).

It thus appears, that it is through the operation of two principles, -the accumulative, and inventive, that additions are made to the stocks of communities. It would contribute something to accuracy of phraseology, and therefore to distinctness of conception, to distinguish their modes of action by the following terms:

1. Accumulation of stock or capital, is the addition made to these, through the operation of the accumulative principle.

> 2. Augmentation of stock or capital, is the addition made to them, through the operation of the principle of invention.
> 3. Increase of stock or capital, is the addition made to them, by the conjoined operation of both principles.
> Accumulation of stock diminishes profits; augmentation of stock increases profits; increase of stock neither increases nor diminishes profits. (Rae, 1834: 264).

One of Rae's most significant contributions was, in my opinion, the establishment of an early definition concept concerning that branch of economics that was later called economics of innovation and that I have tried to perfect in the light of following contributions within economic literature. Rae said:

> It is the intention of the inventive faculty, when it applies itself to the arts ministering to the necessaries, conveniences, or superfluities of life, -to the wants of our nature that the subject we treat of considers, to increase the supplies- which it is the aim of each to procure. If when it gains the ends it purposes, it really produces this increase, in doing so, it must render the labor of the members of the society in which it operates more effective, and enable them from the same outlay to produce greater returns, or from less outlay to produce the same returns (Rae, 1834: 258-259).

Inventions can be distinguished as autonomous or induced inventions. The first type represents a long-term contribution of a fortuitous genius who through the application of intuitive ideas to existing technology (art according to Rae's terminology), increases the set of technical knowledge. This is the kind of invention discussed in Rae's book. Induced invention, on the other hand, is the deliberate employment of time, resources and efforts in order to promote new technical knowledge. This type of invention is born in Research and Development (R&D) laboratories. In these, the basic models that explain the origin of invention and of innovation are two: the technology push model characterised by a systematic research and development activity and the demand-pull model deriving from marketing activities (Dodgson & Rothwell, 1994). In any case, there is not just one factor, which the innovative activities of the industry stems from; instead, these emerge from a complex interaction of a multitude of factors and, very often, luck plays an important role. A pure accident led Luigi Galvani in the 18th century to make the legs of a frog contract when he linked a set of different materials. Even though Galvani had not wholly understood the nature of the phenomenon, it raised a widespread interest within the scientific community that led to a series of following systematic experiments and to the discovery of the electric battery. Other examples are the laws on polarisation of reflected light, the production of penicillin, the discovery of radioactivity and so on. This highlights an outstanding feature of innovation activities, i.e. an element of unpredictability. Although the role of systematic experimentation in the invention process is a generally acknowledged characteristic, little attention has been given to the random nature of discoveries. Furthermore, the origin of new techniques largely depends on the passing of time and on the accumulation of relevant technical abilities. In fact, lessons learnt from mistakes made in the past are an important element in a successful innovation process. According to Sahal (1981), the creation of an invention is not wholly random but it is guided by underlying logic deriving from what has been learnt from past experiences. Some probabilistic schemes based on negative distributions of the binomial type have created models regarding the origins of innovations by taking into account the cumulative learning process. Regarding Schumpeter's distinction between invention and innovation, some authors (Ruttan, 1971; Jossa, 1965) consider it of scarce utility for economic analysis. In fact, in certain practical cases it is difficult to single out the point where invention finishes and innovation begins (Cozzi, 1979). From what has been said it is possible to determine that it is not easy to define the field of analysis of invention and innovation, which can concern both the subjects and the objects of innovation (Archibugi, 1988).

In any case, drawing from Rae's quote the following can be stated.

The Economics of Technological Innovation studies the inventive and creative faculty, born in a random and/or systematic manner on the basis of a cumulative learning process, applied to industrial usages (object) in order to satisfy needs, to increase individual and social well-being, to make man's labour more effective and efficient and to generate economic growth.

Furthermore, the economics of innovation analyses the sources of knowledge and those who make use of it (subjects) as well as their interdependence on economic systems (sectors) and political systems (States and nations). It finally studies the impact of innovation on the structure, strategies and performance of firms, its spatial-temporal diffusion and its related impact on the geo-economic environment.

In other words, the economics of innovation is that branch of economics that studies innovative products, processes and organisations in order to satisfy the necessities and desires of mankind (needs). Their purpose is to increase the quantity that each individual is inclined to acquire and enables mankind to obtain more products at the same cost or the same amount of products at a lower cost in order to increase individual and social well-being.

Moreover, Rae stated that:

> An improvement in the construction of a plough, enables the individuals employing that instrument to plough a greater quantity of land with the same cattle and labor, or an equal quantity of land with fewer cattle and less labor. The use of water as a power diminishes very greatly the labor necessary to perform the operations in which it is employed, and, therefore, from a less outlay, produces equal returns (Rae, 1834: 259).
>
> It is here also to be observed that, although any particular improvement, immediately, and at first, affects only the instruments improved, it very shortly diffuses itself over the whole range of instruments owned by the society. The successful efforts of the inventive faculty are not a gift to any particular artists, but to the whole community, and their benefits divided amongst its members. If an improvement, for instance, in the art of baking bread were effected, by which, with half the labor and fuel equally good bread could be produced, it would not benefit the bakers exclusively, but would be felt equally over the whole society. The bakers would have a small additional profit, the whole society would have bread for the product of some what less labor, and all who consumed bread, that is, every member of the society, would from the same outlay have somewhat larger returns. The whole series of instruments owned by the society would be somewhat more productive, would be carried to an order of quicker return (Rae 1834: 259).
>
> The various agricultural improvements with which invention enriched that art in Britain towards the conclusion of the last, and commencement of the present century, occasioned a great amount of materials to be wrought up, which before lay dormant. The construction of the plough in Scotland, and generally over the island, was so improved that two horses did the work of six oxen. The diminution of outlay thus produced, giving the farmer, from a smallercapital, an equal return; he was encouraged and enabled to applyhimself to materials, which he would otherwise have left, ashis forefathers had done, untouched. He carried off stones from hisfields, built fences, dug, ditches, formed drains, and constructed roads.
>
> Nor was this all; the stimulus reacted also on the inhabitants of the towns, and their industry was augmented by the increased returns yielded by the country, and by the new demands made by it. Improvements, too, in the branches of industry in which they were themselves engaged, of at least equal extent, carried them forward in a like career (Rae, 1834: 261-262).

4. Concluding observations

John Rae has recently been rediscovered as a genuine precursor of the endogenous growth theory. I think, he needs to be rediscovered a second time for his contribution to the understanding of the economic role played by the innovation and technology change within the economic system. Moreover, his penetrating and original insights into the invention put forward the basis of the economics of

innovation.

The first economist who discovered the significance of Rae's work was John Stuart Mill (1848) who in his famous book *Principles of Political Economy* repeatedly praised Rae's analyses concerning the causes that bring about the accumulation of capital. Mill said *in no other book known to me is so much light thrown, both from principle and history, on the causes which determine the accumulation of capital* (Bladen & Robson, 1965: 162). Mill put Rae's notions into the framework of the orthodox paradigm and by means of his concept of stationary state, he eliminated any possibility of considering the accumulation principle and the invention principle as antagonistic of each other. Although Mill's book had been very much appreciated by American protectionists, little acknowledgment was given to Rae; however, the greatest among protectionist scholars borrowed many ideas from Rae himself. In Italy, Ferrara (1856), following in Mill's footsteps, remarked that Rae's work was full of new concepts, above all concerning the formation of capital and the elaboration of a precise theory of value formulated according to the most modern investigation techniques. After such positive remarks on Rae, the scholar did not meet with very much success maybe also because of his ideas, which were too innovative for the period in which they were conceived.

The analysis of his work is, however, very stimulating and it leads to some obvious questions: why did Rae, disagreeing from Smith, explain the economic growth through the invention? Why did Rae establish a correct relation between invention (cause) and division of labour (effect)?

As Brewer (1991; 1998) suggested, Smith conceived his book when the industrial revolution was still in its embryonic phase. In fact, the steam engine was invented by Watt in 1775, the first steam vehicle with four wheels dates back to 1802, steam navigation to 1807 and the first steam locomotive to 1813. The main innovations relating to the invention of steam came therefore after Smith's book and before Rae's work. The latter travelled around the old and the new world and had the chance to observe the main applications of the steam engine, as proven by his descriptions of steam navigation and the steam locomotive (he also provides an account of the innovation of movable type printing invented by Gutenberg in 1455 already existing at Smith's times); his acute remarks as well as the power of his analysis led him to explain economic growth as driven by invention and to recognise the relevance of those phenomena that would later be called revolutions of the techno-economic paradigm (Freeman *et al.,* 1982). Anyway, during the historical period when Rae wrote his works the industrial revolution was going through a growing phase, differing from Smith's period, and this influenced the author of the *New Principles* (1834). The presence of industrial revolution's great innovative wave also influenced the writings of other scholars, like Marx (1890; 1975) who claimed that the capitalist system had reached in one hundred years a level of economic progress that previous generations had not been able to reach in one thousand years.

Smith must be granted the great merit of having been the first scholar to handle economic phenomena in a systematic manner, while Rae had the merit of having explained economic growth by means of new concepts regarding invention and of having broadened the field of economic science by establishing the primary elements of the economics of innovation branch. Referring to Grandstrand's statement (1994) that the origins of the economics of technology lie in Babbage's work written in 1832, two years before Rae's work, it must be remarked that Babbage's analysis had rather an engineer's edge to it, while Rae's writings had a strictly economic foundation and explained by means of philosophy, like Smith had done, the nature and causes of the wealth of nations and how innovation is important for economic growth. The difference between Rae and Babbage it is already the titles of their books. Babbage is the pioneer of the computer and the purpose in writing *On the economy of machinery* was to examine the mechanical principles, which regulate the application of machinery to arts (technology) and manufactures. Although Rosenberg (1971) stated that Babbage's book deserve to

be regarded as possibly the earliest treatment of the economic determinant of inventive activity, he argues that the main contribution of Babbage's book is the considerable improvement upon the division of the labour and the first systematic analysis of the economies associated with increasing returns to scale. According to my opinion, the Babbage's contribution to the economic role played by invention and machinery in the course of industrial development is limited to the firms and using an approach of the engineering and information sciences.

Nowadays innovation has gained great significance and is the subject of numerous studies but, as previously stated, it is still difficult to define it and even more so to measure it. The explanation of this is that the origin and diffusion of innovation is a function of several variables and the study of its endogenous and exogenous dynamics cannot be carried out by means of only one topic, i.e. economics. This article has thoroughly analysed the work of an author who had an interdisciplinary learning (philosophy, mathematics, biology, physics, medicine, etc.), suited to the study of the technology, which allowed him to investigate invention and innovation in greater depth and to single out some fundamental concepts of the modern branch of economics that studies innovation. The defining concept here displayed drawn from Rae's analysis, of which a further refinement has here been attempted, is by no means meant to take on an exhaustive content but is intended as a first step towards correctly identifying the definition of economics of innovation.

Even though Rae had been praised by the English economist Mill, who believed Rae had clarified the causes of the accumulation of capital both from a theoretical and from a historical point of view, an attentive reader might raise the following question: why did Rae's correct economic analyses not assert themselves within the economics? The answer to such question is left to Mill (1848) who, concerning Rae's book, said

> This treatise is an example, such as not unfrequently presents itself, how much more depends on accident, than on the qualities of a book, in determining its reception. Had it appeared at a suitable time, and been favoured by circumstances, it would have had every requisite for great success. The author, a Scotchman settled in the United States, unites much knowledge, an original vein of thought, a considerable turn for philosophic generalities, and a manner of exposition and illustration calculated to make ideas tell not only for what they are worth, but for more than they are worth, and which sometimes, I think, has that effect in the writer's own mind. The principal fault of the book is the position of antagonism in which, with the controversial spirit apt to be found in those who have new thoughts on old subjects, he has placed himself towards Adam Smith. I call this a fault, (though I think many of the criticisms just, and some of them far-seeing,) because there is much less [MS, 48, 49, 52, 57 less of] real difference of [MS, 48, 49, 52 difference in] opinion than might be supposed from Dr. [MS, 48, 49, 52, 57, 62 Mr.] Rae's animadversions; and because what he has found vulnerable in his great predecessor is chiefly the "human too much" in his premises; the portion of them that is over and above what was either required or is actually used for [MS, 48, 49, 52 used in] the establishment of his conclusions. [MS conclusions.-Yet such are the conditions of celebrity, that if this author had attained it, the polemical character of his book would probably have been the hinge on which would have turned the accident of its exciting attention (Bladen & Robson, 1965: 162).

Today, however, it is easy to see that, despite the vicissitudes concerning the publishing of Rae's book and the little attention gained within the history of economic science, his work has recently raised considerable interest among scholars of economics, especially that of innovation, not only because of the originality of his exposition but also because he took into account the variable invention within his explanation of economic growth. The latter concept was later further analysed by Schumpeter himself and by Solow (1956). Moreover, the matter of economic growth explained on account of invention and technological progress and the extraordinary set of new concepts and relations included in Rae's

book, premature for the historical period when the work was conceived, give it form and substance, still revealing, almost two centuries later, all their original innovative charge and proving up-to-date in explaining the evolution of modern economic systems.

Notes

[1]Seestudies by Calabrese *et al.,* 2005; Cariola & Coccia, 2004; Cavallo *et al.,* 2014, 2014a, 2015; Coccia, 2001, 2003, 2004, 2005, 2005a, 2005b, 2005c, 2006, 2006a, 2007, 2008, 2008a, 2008b, 2009, 2009a, 2010, 2010a, 2010b, 2010c, 2010d, 2010e, 2011, 2012, 2012a, 2012b, 2012c, 2012d, 2013, 2013a, 2014, 2014a, 2014b, 2014c, 2014d, 2014e, 2014f, 2014g, 2015, 2015a, 2015b, 2015c, 2015d, 2016, 2016a, 2016b, 2016c, 2017, 2017a, 2017b, 2017c, 2017d, 2018, Coccia & Bozeman, 2016; Coccia & Finardi, 2012, 2013; Coccia & Wang, 2015, 2016; Coccia & Cadario, 2014; Coccia *et al.,* 2015, 2012, Coccia & Rolfo, 2000, 2002, 2009, 2012, 2007, 2010, 2010, 2013; Coccia & Wang, 2015, 2016; Rolfo & Coccia, 2005.

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