In the Shadow of Schumpeter:
W. Rupert Maclaurin and the Study of Technological Innovation

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Abstract

J. Schumpeter is a key figure, even a seminal one, on technological innovation. Most economists who study technological innovation refer to Schumpeter and his pioneering role in introducing innovation into economic studies. However, despite having brought forth the concept of innovation in economic theory, Schumpeter provided few if any analyses of the process of innovation itself.

This paper suggests that the origin of systematic studies on technological innovation owes its existence to the economist W. Rupert Maclaurin from MIT. In the 1940s and 1950s, Maclaurin developed Schumpeter's ideas, analyzing technological innovation as a process composed of several stages or steps, and proposed a theory of technological innovation, later called the linear model of innovation. The paper also argues that Maclaurin constructed one of the first taxonomies for measuring technological innovation.

In the Shadow of Schumpeter:

W. Rupert Maclaurin and the Study of Technological Innovation[1]

J. Schumpeter is a key figure, even a seminal one, on innovation. Most economists who study technological innovation refer to Schumpeter and his pioneering role in introducing innovation into economic studies. Researchers from SPRU, among them C. Freeman for example, are among the most active promoters of Schumpeter as the "father" of innovation studies (Freeman, 2003). They have also developed schematic representations of Schumpeter's view on technological innovation that remained influential for several years (Freeman, 1982: 211-214; Rothwell and Zegveld, 1985: 60-66).

Without doubt, Schumpeter developed important ideas with regard to innovation: innovation as a source of economic change (Schumpeter, 1928; 1942: 81-86; 1947), (major) technological innovation (clusters of technological innovation) as a source of business cycles (Schumpeter, 1912; 1939). To Schumpeter, innovation consists of any one of the following five phenomena: 1) introduction of a new good; 2) introduction of a new method of production; 3) opening of a new market; 4) conquest of a new source of supply of raw materials or half-manufactured goods; and 5) implementation of a new form of organization (Schumpeter, 1912: 66). Certainly, we also owe to Schumpeter, among others, the distinction between invention and innovation. While invention is an act of intellectual creativity – and in his words "is without importance to economic analysis" (Schumpeter, 1939: 85) – innovation is an economic decision: a firm applying an invention or adopting invention. To Schumpeter, technological innovation was defined as a new combination of means of production, that is, as a change in the factors of production (inputs) to produce products (outputs) (Schumpeter, 1939: 87).

Despite having brought forth the concept of innovation in economic theory, Schumpeter provided few if any analyses of the process of innovation itself. Certainly, he dwelt slightly on the subject when he professed that there was little dependence of innovation

[1] The author wants to thank two referees for very valuable comments on a first draft of this paper.

on invention, as several authors have commented (Solo, 1951; Ruttan, 1959): “Innovation is possible without anything we should identify as invention and invention does not necessarily induce innovation” (Schumpeter, 1939: 84). He also put the entrepreneur (Schumpeter, 1912) and, later, the large firm (Schumpeter, 1942: 131-134), at the center of the innovation process. But Schumpeter did not explain how innovation came about; neither did he study the factors and conditions that lead to innovation.

This paper suggests that the origin of systematic studies on technological innovation owes its existence to the economic historian W. Rupert Maclaurin from the Massachusetts Institute of Technology (MIT). Maclaurin is an author totally forgotten today. One finds nothing in the literature on his biography, neither is there anything on his role in the literature on technological innovation, except old citations in footnotes (Schmookler, 1959: 631; Nelson, 1959: 107; Enos, 1962: 308; Mansfield, 1968: 34; Jewkes et al., 1969: 171). It is the thesis of this paper that Maclaurin further developed Schumpeter’s ideas, analyzing technological innovation as a process composed of several stages or steps, and proposed a theory of technological innovation, later called the linear model of innovation. The paper also argues that Maclaurin constructed one of the first taxonomies for measuring technological innovation in the literature, an influential taxonomy that led to current indicators on high technology.

This paper concentrates on Maclaurin’s contribution to understanding technological innovation as a process. This is, in fact, the main and important contribution of Maclaurin to the study of technological innovation. He did fill in what was missing in Schumpeter’s writings. On others of Schumpeter’s ideas, like economic change or dynamics (creative destruction), Maclaurin did not contribute much, and neither did he contribute to economic theory more generally. However, he did discuss the role of technological innovation in business cycles, and he was in total agreement with Schumpeter. His thoughts on this issue will be briefly presented below.

The first part of this paper presents a short biography of Maclaurin from the available material in the published literature and some archival material. [2] The second part discusses how Maclaurin's study of technological innovation, conducted in the 1940s, led to a theory of technological innovation consisting of sequential steps from research to commercialization. The third part looks at Maclaurin's contribution to the measurement of technological innovation, particularly the classification he developed for measuring firms' innovativeness.

W. Rupert Maclaurin

W. Rupert Maclaurin (1907-1959), professor of economics, was born in New Zealand. He was the son of Richard C. Maclaurin (1870-1920), the sixth President of MIT from 1909 to 1920 and a successful fund-raiser from industrial partners. W. Rupert Maclaurin studied at Harvard University, attended the Graduate School of Business Administration and received his MBA in 1932 and his DCS in 1936. He became assistant professor at MIT in 1936, associate professor in 1940 and professor in 1942. Maclaurin helped strengthen the Department of Economics and Social Science at MIT, and founded its Industrial Relations Section (1937). [3]

Maclaurin served as secretary to the committee on Science and Public Welfare, one of the four committees that assisted V. Bush in the preparation of *Science: the Endless Frontier* (Bush, 1945). The report from the Bowman committee [4] was one of the most important, dealing with the state of research in universities, government and industry, having conducted a survey for measuring the national budget devoted to R&D in the United States, and having proposed forms of public support for science, among them a National Research Foundation.

[2] The MIT Institute Archives and Special Collection has no biographical information on Maclaurin. I have used most of what I could find in the published literature as well as some archival material from the Rockefeller Foundation.
[3] As part of the Sloan School of Management, the section was renamed the Institute for Work and Employment Research (IWER) in 1997.
[4] I. Bowman (Chairman), President, Johns Hopkins University.

It was as head of the Industrial Relations Section that Maclaurin got interested in technological change, as he called it, and as a precursor to the term technological innovation. [5] Early on, he approached the Committee on Research in Economic History of the Social Science Research Council, itself interested in promoting investigation of the entrepreneur's role in American industry, with a proposal to jointly sponsor an investigation of technological and industrial expansion. Supported by a grant from the Rockefeller Foundation, Maclaurin initiated the first systematic and long-term research program on "The Economics of Technological Change".

According to K. T. Compton, President of MIT from 1930 to 1948, "professor Maclaurin and his associates have opened up a very important field of inquiry" (Compton, 1949: xi). Under Maclaurin's guidance, the department of economics of MIT launched a series of studies on technological change that addressed two major problems: determining the principal economic factors responsible for the rate of technological progress in various industries, and determining the conditions in industry that are most conductive to steady technological progress with a minimum of frictional unemployment.

To conduct his research program, Maclaurin sought advice from Schumpeter. In a letter dated July 1944, Schumpeter suggested to Maclaurin the way innovation should be studied, namely through historical analysis of industries and business (Hedtke and Swedberg, 2000): [6] "So far as general theory goes", stated Schumpeter, "the emphasis is not so much on the relation between innovations and economic development or business cycle, but (…) continues the classical tradition. All the classics (see, for instance, J. S. Mill) mainly explain economic change by the increase in the available means of production (…)". More appropriate, according to Schumpeter, were historical works (like those of J. H. Clapman, V. Clark, P. Mantoux, A. P. Usher and S. C. Gilfillan), together with industrial monographs and biographies of business leaders. "Consistently pressed" by Schumpeter, as he put it, to push his investigations further, Maclaurin followed Schumpeter's recommendation: "The economist, making empirical studies of industrial

[5] Until then, Maclaurin had worked on economic planning and job changes in industries (Maclaurin, 1937; Myers and Maclaurin, 1943).

change, is faced at the outset with the difficult problem of whether to confine his analysis to measurable data. There is much that the statistician can do to explain the characteristics of economic development in modern industry. But there are many important questions that he cannot tackle at all" (Maclaurin, 1950b: 90). Maclaurin devoted his academic career as economist to the study of these "important questions" through historical analyses.

A Theory of Technological Change

To Maclaurin, as he stated in 1943, "although economists have long been interested in technological change, there has been very little investigation of the factors influencing the rate of technological progress in particular industries" (Bright and Maclaurin, 1943: 429). He was right. Until then, the study of technology was mainly the concern of historians (A. P. Usher) and sociologists (W. F. Ogburn, S.C. Gilfillan, H. Hart), increasingly the concern of managers and management schools (C. E. K. Mees, C. C. Furnas), and the concern of a few economists interested in the impact of mechanization on employment and, as a by-product, in labour productivity as a measure of the effects of technology.

Studying technological change in its economic dimensions was the task to which Maclaurin, as economic historian, devoted himself entirely from the early 1940s onward. To Maclaurin, the study of technological change, a term he contributed to popularizing, [7] is concerned with *factors* responsible for the rate of technological development in industry, and the *conditions* which are more conducive to technological progress (Bright and Maclaurin, 1943: footnote 1). As a first step, he chose the fluorescent lamp, looking

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[6] I owe this reference to D. A. Hounshell, Department of History, Carnegie Mellon University.

[7] Before Maclaurin, the term technological change appeared very sporadically in the economic literature, jointly with technological (or technical) progress (or advance), and meant the substitution of labour for capital as factors in industrial production. In the late 1930s, the US Works Projects Administration, as part of a project on Reemployment Opportunities and Recent Change in Industrial Techniques, started using the term more regularly to discuss changes in employment due to technology. Then, in the early 1940s, Maclaurin gave the term a new meaning concerned with the development of new products, rather than the use of technical processes in production. By the early 1950s, Maclaurin used both technological change and innovation, as would be the case in the literature for the next decades.

at the factors affecting its development and introduction. His first conclusions appeared in 1943. He identified four factors leading to technological change in the industry since the 19th Century: 1) capabilities in research and product engineering (laboratory), 2) degree of competition, particularly the presence of small firms; 3) demand; and 4) alternative technologies (incandescent lamp).

To Maclaurin, venture capital appeared as the main obstacle to technological change in the industry (as it was for the entrepreneur in Schumpeter's writings). He developed this idea further in a paper published in 1946 (Maclaurin, 1946). Here, Maclaurin identified entrepreneurial skills and venture capital as major factors in technological change. Using radio as a case study, he illustrated "the steps which are required to bring a new scientific concept from the theoretical stage to a successful commercial product". Maclaurin studied the pioneering scientists (J. C. Maxwell, H. R. Hertz, J. J. Thomson, O. W. Richardson) and concluded that none were consciously thinking about commercial development. Rather, this was the role of the independent inventors (like G. Marconi). However, added Maclaurin, "without the pioneer work of the university physicists, the practical development of radio communications would have been impossible". To Maclaurin, "we cannot rely on [established] industries to convert [risky] scientific advances into new products and processes". Large industries (ATT, Western Union, Postal Telegraph) "made no outstanding contributions to wireless in the early years". To Maclaurin, success in technological change depended on managerial skills and venture capital. [8]

These studies were only a beginning. After more than five years of study, Maclaurin began producing a more complex story. In fact, he had then become quite confident that he could propose a theory of technological innovation composed of several steps or stages, the first of which was fundamental science. To Maclaurin, fundamental research and its funding were decisive factors in technological change. To account for this role, he suggested that technological innovation was a sequential process composed of "four

[8] Maclaurin identified the following sources of capital: the inventor himself, wealthy individuals, investment companies.

distinct stages": fundamental research, applied research, engineering development and production engineering (Maclaurin, 1947). The source of this "shift", or addition (fundamental science as decisive a factor as venture capital), probably comes from his involvement (as secretary) with V. Bush's *Science: The Endless Frontier*. To Maclaurin, "*Science: the Endless Frontier* is a very important document and should be read by all businessmen who are interested in science". What preoccupied Maclaurin was, echoing the Bush report, "the danger (…) that with the tremendous stimulus which has been given to scientific research by the war, the emphasis will be on applied research to the detriment of further advance in fundamental research" (Maclaurin 1947).

Two years later, in 1949, Maclaurin developed his ideas on technological innovation in a book-length study on the radio industry (Maclaurin, 1949), followed by a condensed paper (Maclaurin, 1950b). "Until quite recently", stated Maclaurin, "we have neglected to explore [Schumpeter's] provocative suggestions". "Much of the traditional apparatus of economic analysis has been concerned with entrepreneurial decisions on costs and prices of existing products. Economists have apparently not yet come to recognize the full impact of science and engineering (…). A useful theory of economic development will have to be based on the dynamics of technological advance". In his book, Maclaurin offered a historical and current account of how the process of technological innovation took place in the radio industry. He looked at the role of fundamental science and how the men of science (M. Faraday, J. C. Maxwell, H. R. Hertz) were not consciously thinking about the commercial possibilities of their research, but how fundamental research was nonetheless vital to industrial development. He discussed the role of inventors (G. Marconi, R. A. Fessenden, L. De Forest) and the need for entrepreneurial skill, or the capacity to carry through a successful innovation, and for venture capital. He analyzed the structure of the industry composed of large and monopolistic firms like Western Union, Bell Telephone, and General Electric, *versus* a few new companies taking risks in unexplored areas.

To Maclaurin, the radio industry was a direct outgrowth of the revolution in physics and its application to the study of electricity. New discoveries came to be translated into commercial practice by entrepreneurial skill or by innovators, but not by established companies. To Maclaurin, large firms were more interested in buying up competition and making prospective agreements (Western Union), or primarily concerned with acquiring undisputed national supremacy (ATT) through monopoly and patents. [9] To Maclaurin, an important quality of the "inventor-entrepreneur" was his "capacity for visualizing important new scientific developments". For the second time in as many years, Maclaurin had elected fundamental science as a factor in technological innovation: "radical innovations are likely to be much more intimately connected than in the past in the frontiers of knowledge". This is the challenge of what he called the "second industrial revolution". To explain technological innovation, Maclaurin turned to his sequential theory: "I have tried in this study", he stated, "to emphasize the necessity of a continuum between pure science and engineering applications". To Maclaurin, "science and technology can be broken down into five distinct stages: fundamental research, applied research, engineering development, production engineering and service engineering".

By the early 1950s, Maclaurin and colleagues had developed a whole program of research on the economics of technological change, which led to several publications on different industries – glass, paper, electricity (lamp) and radio – and which arrived at similar conclusions (see Appendix 1). Given the productivity of the research program on the economics of technological change and the consensual results obtained, Maclaurin seized the opportunity of a conference on *Quantitative Description of Technological Change*, organized by the US Social Science Research Council in 1951, to derive some general conclusions from his research program. [10] Maclaurin's communication was entirely devoted to a theoretical (or taxonomic) analysis of the process of technological change and its measurement. Suggesting that "Schumpeter regarded the process of innovation as central to an understanding of economic growth", but that he "did not devote much attention to the role of science", Maclaurin proposed "breaking down the process of technological advance into elements that may eventually be more measurable". To Maclaurin, "the important point for economic development is that careful study is

[9] On the abuse of patents, see Maclaurin, 1950a.
[10] Maclaurin published his communication in Maclaurin, 1953.

needed of the institutional arrangements which are most conducive to the flourishing of all the major elements of dynamic growth". Maclaurin identified five propensities, or steps, leading to technological innovation, from research to use: [11]

- pure science,
- invention,
- innovation,
- finance,
- acceptance (or diffusion).

Such a theorization or schematization of the technological innovation process as a "sequence" was the result of over a decade of Maclaurin's work on technological change. Maclaurin's communication was in fact the first full-length discussion and theory of what came to be called the linear model of innovation. In the following decades, economists, first of all Y. Brozen, from Northwestern University, an author well aware of Maclaurin's work (Brozen, 1951a; 1951b; Ruttan, 1959; Ames, 1961; Machlup, 1962; Scherer, 1965; Mansfield, 1968), but also researchers from management schools (Myers and Marquis, 1969; Utterback, 1974), [12] organizations like the US National Science Foundation (IIT Research Institute, 1968), sociologists (Rogers, 1983), accountants and statisticians (Anthony and Day, 1952: 58-59; US National Science Foundation, 1952: 11-12) would make extensive use of the theory and develop it further.

Certainly, one finds sorts of sequential theories in the literature prior or concurrent to Maclaurin's, from historians (Usher, 1929), sociologists (Ogburn and Gilfillan, 1933: 132; US National Resources Committee, 1937), management schools (Mees, 1920; Bichowsky, 1942; Furnas, 1948), consultants (Stevens, 1941), and industrialists (Holland, 1928). But few authors considered the commercialization step, and no one had offered as systematic an analysis of the process of technological innovation as MIT's research

[11] According to Maclaurin himself, the historian of economics W. W. Rostow from MIT and his work on economic growth helped sharpen his thinking on these elements. Rostow identified six propensities involved in economic change: fundamental science, applied research, acceptance of innovation, material advance, consumption, and family. See Rostow, 1952.

program did. One often reads in the literature that the linear model of innovation comes from V. Bush. Godin has shown this to be false (Godin, 2006; see also Edgerton, 2004). Certainly, in the appendix to the Bush report, the Bowman committee, of which Maclaurin was secretary, used a taxonomy of research composed of pure research/background research/applied research and development, and argued that "the development of important new industries depends primarily on a continuing vigorous progress of pure science". But the taxonomy was never used as a sequential model for explaining socio-economic progress. It served only to estimate the discrepancy between the funds spent on pure research and those spent on applied research. In fact, the furthest Bush went in explaining the links between science and the economy was dealing with the Basic research → Development (technology) part of the linear model of innovation.

Measuring Technological Change

The conference on "Quantitative Description of Technological Change", held at Princeton in April 1951, and to which Maclaurin presented his theory, was a major conference of the time. The idea of a conference came from discussions at two committees of the US Social Science Research Council: the Committee on Economic Growth, chaired by the economist S. Kuznets, and the Committee on the Social Implication of Technological Change. [13] Following a meeting held in October 1949, Kuznets circulated a memorandum of suggested topics for the conference. He proposed looking at measurements like: patents, use (lags in use of technology), census of machines (or mechanization of industries), count of new (consumer) products, and input/output ratio. Comments were received from several researchers, Maclaurin included. All shared their enthusiasm for a conference, and proposed to present their own methods.

Thirteen papers were prepared (see Appendix 2), and about sixty people attended the conference, among them G. Debreu, S. Fabricant, J. L. Fisher, S.C. Gilfillan, S. Kuznets,

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[12] For reviews, see: Roberts and Romine, 1974; Saren, 1984; Forrest, 1991.

W. E. Leontief, J. Schmookler, S. H. Shryock and A. P. Usher. There had been a project to publish the proceedings as a book, but this was abandoned because "the papers [were] in most cases of a very exploratory character, with quite different points of view and without a sufficient thread of unity to be published in a single volume". [14] In fact, the closing session concluded that "thus far research efforts on many of the most significant aspects of technological change have failed to produce conclusive results". But "there was agreement that persistent efforts must be made to develop and test new research approaches". [15] Instead of attempting to publish the very diverse set of papers, it was decided to "distill" them into a shorter publication that would include discussions. Kuznets committed to such a paper his thoughts on technological change, making use of the conference, but he never completed his preliminary draft (Kuznets, 1951). Kuznets's draft dealt with measuring the contribution of technology to production, mainly through input-output analyses. The paper was of a methodological nature, discussing what knowledge is and how to measure it, the problem of subtracting technology as a residual from other factors or changes, [16] and the problem of attribution. Kuznets concluded that "we may be doomed to a position in which we can measure only economic growth, but not its causes".

In retrospect, the reason the conference's organizers did not publish the proceedings appears as a rather severe judgment. The papers offered analyses, methodologies and data that would define the field for the next decades, above all the production function, and many authors published their papers independently in academic journals. The only numbers that were not discussed were expenditures on R&D. Systematic data would become available a few years later only by way of the US National Science Foundation's surveys, and would occupy every speaker at a second conference organized by the US

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[13] The author thanks the Rockefeller Archive Center for access to the material from the preparation of the conference.

[14] Letter from A. J. Coale to J. L. Fisher, 6 July 1951. The Rockefeller Archive Center: Social Science Research Council Archives, Accession Two, Box 148, Folder 1690.

[15] Attachment to letter from P. Webbink to R. R. Nelson, 5 August 1960. The Rockefeller Archive Center: Social Science Research Council Archives, Accession Two, Box 148, Folder 1690.

[16] To the best of my knowledge, this was the first occurrence of the term "residual" in economic studies of technological change.

National Bureau of Economic Research and the US Social Science Research Council in 1960 (US National Bureau of Economic Research, 1962).

Be that as it may, it was at the 1951 conference that Maclaurin presented his sequential theory of innovation as discussed above. But he also discussed measurements of technological innovation at length. For each of the steps of the sequence leading to technological innovation, Maclaurin identified a series of measurements as follows:

- Pure science: major contributions, classified by field, country, and over time; prizes, awards and medals; budget; forecasts on commercial applications.
- Invention: patents (major/minor); research workers (because they are correlated with the volume of invention); records of inventions by firms.
- Innovation: inquiry over time, industry by industry on annual sales volume, productivity figures, investments for new/minor products and new firms/established (great) corporations.
- Finance (capital supply): number of new firms launched each year, their capital investments; new plant constructed.
- Acceptance (or diffusion): growth curves for a wide variety of products and services under different types of conditions, by region, between cultural groups. Length of time required for mass acceptance.

Until then, Maclaurin had not himself conducted measurements of technological innovation. The then-current measurements concentrated on counting inventions, or patents. [17] This method was unanimously criticized during the preparation of the 1951 conference. Maclaurin published his own original measurement in 1954 (Maclaurin, 1954). He looked at the role of large firms, not entrepreneurs, in what he called technological progress. In fact, Maclaurin's ideas had begun to change, and this is clear in another paper of the time (Maclaurin, 1955) (see below). As Schumpeter had done

[17] Before the work of J. Schmookler in the 1950s, most patent measurements were conducted by non-economists.

before him, Maclaurin changed his ideas about the source of technological innovation and the role of large firms. In a context of "organized" research, independent inventors were no longer considered as key figures in technological change. The large firm, with its research laboratory, was more important than before for technological innovation. This was Maclaurin's first change in thinking. Another concerned the discontinuity of technological innovation: "the process of invention can be fruitfully studied from the standpoint of a continuous flow of ideas. Yet it is equally valid to think of the process in terms of discontinuity", or major inventions, as Schumpeter had studied.

Maclaurin looked at both large firms and major technological innovations for measurement. He developed a three-level nomenclature of "technological progressiveness" [18] to classify industries and their performance in introducing important new or improved products or processes: high, medium and low (Maclaurin, 1954). The classification was based on an analysis of the most important new products and processes introduced during the period 1925 to 1950, as identified by experts in thirteen industries. Because of his methodology, Maclaurin admitted that the final rating was subjective. Nevertheless, he produced the following ranking of industries according to technological progressiveness:

Highest rate of progress
- Chemical
- Photographic
- Airplane
- Oil

High Progress
- Radio and television
- Electric light

Medium Progress
- Automobile
- Paper
- Steel

Lower progress
- Food processing
- Cotton and textiles
- Coal mining
- House assembling

[18] Maclaurin may have borrowed the term from sociologists' use of "progressivism" in studies of social innovation. See McVoy (1940).

Maclaurin did not offer any statistics in his paper. He only classified the thirteen industries above as high, medium and low progressiveness, based on the following three dimensions: volume of R&D expenditures, number of patents issued, and number of scientists. Statistics would come a few years later, from Europe. In the late 1950s, C. F. Carter and B. R. Williams, respectively from Belfast and Keele universities, carried out a series of influential studies on innovation for the Science and Industry Committee of the British Association for the Advancement of Science (Carter and Williams, 1957; 1958; 1959a). One of these studies looked at the characteristics of firms that make them "technically progressive", or innovative, defined as using science and technology and capable of producing or adopting new products and processes (Carter and Williams, 1957: 108-111; Carter and Williams, 1959b). The suggested classification of over 150 firms in their population was: progressive, moderately progressive, non-progressive. From their calculations, Carter and Williams measured a relationship between such progressiveness and the performances of firms, like profits. However, the authors admitted that the concept of technical progress lacks precision. In fact, no precise criteria were proposed, but the following rationale was suggested:

> We think that there is no difficulty in recognizing a firm which is in the forefront of discovery in applied science and technology, and which is quick to master new ideas and to perceive the relevance of work in neighbouring fields. Similarly, there is no difficulty in recognizing a firm which is quite uninterested in science and technology, and is perfectly content to continue with its traditional methods without even examining the alternatives. What we have done is to examine the group of highly progressive firms, and to draw up a long list of the characteristics which seem to be common to all or most of them. We have then tested the less progressive firms by these characteristics. Firms of a moderate level of progressiveness give widely spread results.

The concept of technical or technological progressiveness had very few followers, and none of them have cited Maclaurin (Rothwell, 1977; Cohn, 1980). Nonetheless, the concept gave rise to that of high technology, a very fashionable concept in science, technology and innovation policies. The concept, and its measurement, emerged out of debates in the 1960s on international competitiveness and the role of technology (Godin, 2004). The US Department of Commerce, followed by the OECD, were the most active in applying this concept to policy and its measurement. In the mid-1960s, the US Department of Commerce reacted to the then-current debates in Europe, and at the OECD, on technological gaps between Europe and the United States, using a series of studies measuring trade and market share of American products in Europe. The Department concluded that the United States, not Europe, was in danger, namely of losing its supremacy. The debate gave rise to concepts like technology-intensive industries (or products), then, through the OECD, the concept of high technology. The concept owes its name to Maclaurin's categories (high, medium, low), and its measurement to a very basic ratio used in industry since the beginning of the 20th Century: R&D/sales (or R&D/value-added). What distinguished high-technology from technological progressiveness was statistics. Technological progressiveness was defined on purely subjective grounds, as admitted by the analysts, whereas high-technology came to be defined exclusively with the aid of statistics.

Maclaurin's paper on technological progressiveness was followed by one more paper before he died. In a paper presented at a conference organized by the US National Bureau of Economic Research on capital and economic growth in the mid 1950s, and in which M. Abramovitz, S. Kuznets, W. W. Rostow and A. P. Usher participated, Maclaurin discussed major inventions as cause of business cycles (Maclaurin, 1955). To Schumpeter, major innovations carry long cycles of business activity, and bring in their train a series of secondary waves of innovation. Already in 1949, Maclaurin had concluded his book on the radio industry with "impressions" on Schumpeter's idea on the role of innovation in business cycles. Impressions rather than "definitive conclusions" because of methodological limitations: the period studied was too short and concerned a single industry, many other factors than just technological innovations are involved in cyclical fluctuations, there is a time-lag between basic scientific discoveries and their practical application in new products. Be that as it may, to Maclaurin the radio industry was a secondary wave of technological innovation arising out of the major breakthrough of electricity, as Schumpeter has described.

In 1955, Maclaurin did discuss the issue of business cycles again. To Maclaurin, the Schumpeterian hypothesis linking innovation to long cycles of business activity was worth pursuing despite the lack of data. It provided a framework for the analysis of economic growth and deserved further testing. To Maclaurin, the cycle or wave from 1890 to 1945, that of the automobile, electric utilities and chemical industries, has somewhat exhausted its potential. As he put it, an explosive expansionary effect will, sooner or later, taper off. First, basic breakthroughs leading to revolutionary and discontinuous changes demand a man of exceptional vision, which is a rare phenomenon. Second, research has not been a systematic preoccupation of industries.

Maclaurin predicted that the next cycle would be that of services, because of changes in the structure of economic activity from agriculture and manufacturing to tertiary industries. His examples of service industries were transport (aviation) and housing. However, stated Maclaurin, if there were to be real economic effects, there had to be "organizational innovation" in industries: companies of national stature, research organizations, capital resources and management skills. Maclaurin predicted that "in the second half of the twentieth century innovating entrepreneurs will be drawn more from the group of men trained as social engineers than, as in the first half of the century, from those with a background in physical engineering". It "will also witness the coming of age of the social sciences".

Maclaurin was here anticipating what some authors would study in the next decades: innovation coming from industries other than those of the manufacturing sector, and innovation of a non-technological kind (organizational innovation). However, and despite this new interest, the study of innovation since the 1960s has remained mostly that of technological innovation, as was Maclaurin's program of research itself.

Let us end this section by mentioning that, in most of his publications, Maclaurin had a concern with policies, and for every step of his sequential theory he suggested solutions to current problems. First, in light of the dependence of technological innovation on fundamental research, he urged businessmen to read Bush's blueprint for science policy, and pleaded for public support of basic research (Maclaurin, 1947): “it is of critical significance to the process of innovation”, wrote Maclaurin, “that we encourage a flourishing spirit of basic scientific inquiry: the theorist posits the basic concepts, the experimentalist tests reality, and the inventor converts the results to practical achievement” (Maclaurin, 1950b). Second, in light of the poor availability of capital for starting new firms based on technology, he made a plea for “organized” venture capital: “the situation that confronts us today calls for the creation of new institutional arrangements to provide venture capital. [We need] to establish a number of investment companies, or holding companies in different parts of the country, the sole function of which will be to seek out, investigate, and finance new ventures” (Maclaurin, 1946). Third, in light of the abuse of patents by large firms, he suggested reforms to the patent system, like reducing the life of a patent to fifteen years, and increasing standards of originality for delivering rights (Maclaurin, 1950a).

Conclusion

Maclaurin has been influential in our theoretical understanding of technological innovation. His aim “was to formulate a systematic theory of technological innovation and economic growth”, [19] and he developed such a theory, which still remains alive. Despite widespread criticisms of its linearity (Schmookler, 1962; 1966), [20] the theory, or “model”, persists in people’s minds, and modern versions of the linear model often consist of Maclaurin’s theory of stages, to which feedback loops are added. Maclaurin has produced a theory of technological innovation from historical sources, and his investigations proved influential. His concept of “inventor-entrepreneur”, as that of “engineer-entrepreneur” from the US economist F. Redlich (1940), was really a precursor to that found in later historical studies like those of F. P. Scherer and T. P. Hughes (Scherer, 1965; Hughes, 1982), and Maclaurin’s qualitative method had influenced the

[19] W. R. Maclaurin, Response to Kuznets memorandum, 9 February 1950. The Rockefeller Archive Center: Social Science Research Council Archives, Accession Two, Box 148, Folder 1690.

[20] J. Schmookler was one of the first economists to systematically criticize the deterministic role of research in invention.

very first analyses of technological innovation proper (Carter and Williams, 1957; 1958; 1959a).

What is peculiar in the above story is the total eclipse of Maclaurin from view in the current literature on innovation. Bush is the scientist to whom most analysts have attributed the linear model. However, recent studies have found no trace of the linear model in *Science: The Endless Frontier*. The dominant role of Bush in public scientific affairs from the 1930s onward, and the influence of *Science: The Endless Frontier* on subsequent science policies may explain, to a certain extent, the overshadowing of Maclaurin in this regard.

Similarly, Schumpeter is the economist unanimously identified as having introduced innovation into economic analyses. However, Schumpeter did not dwell analytically on the process of technological innovation, its factors and conditions. This was the task to which Maclaurin devoted himself. He developed an original program of research for the time. He was no econometrician, but conducted economic analyses of "technological change" of an historical type, as well as interviews with firms. Certainly, he discussed, proposed and used statistics, but he would not get into the business of measuring technological change by way of the production function, as most neoclassical economists would soon do. This absence of formalization and mathematics may explain Maclaurin's disappearance from the literature on the economics of technological innovation. It surely explains his bad reputation among his colleagues. The MIT economics department was obsessed with mathematical economics and simply didn't appreciate his work from an historical point of view. [21] However, this has been the fate of every evolutionary economist. What remains to be explained is the neglect of Maclaurin in the literature on technological innovation from evolutionary economists whose story of the field focuses on Schumpeter. It may simply have to do with the search for a symbolic figure as historical father (Schumpeter), as Gilfillan put it in the case of inventors and the

[21] Robert Solow, lecturing at the department since 1949, was hired as professor in 1958. In the following decades, the field would follow Solow's mathematical approach to science, technology and innovation studies.

mythology of heroes (Gilfillan, 1935: 77). After a long depression, Maclaurin jumped off the Sheraton Copley hotel (Boston) on August 17, 1959. [22]

Maclaurin's studies are witness to a certain epoch, and this context partly contributes to explaining his sequential theory. On one hand, Maclaurin, as academic researcher and member of an "activist" scientific community much inspired by the Bush report, was concerned with fundamental research and its public support, and with the fact that, as Bush suggested, "applied research invariably drives out pure research" (Bush, 1945: xxvi). On the other hand, as an economist, Maclaurin was, as Schumpeter suggested, concerned not with invention, the study of which was the historian's task, but with innovation, defined as follows: "when an invention is introduced commercially as a new or improved product or process, it becomes an innovation" (Maclaurin, 1953: 105). To Maclaurin, "the innovator as an individual takes his place with the pure scientist and the inventor as a key figure in material progress".

Maclaurin found a solution to reconcile his two "interests" via a theory that ultimately linked technological innovation to fundamental research. To a certain extent, a sketch of the idea was present in the Bush report and the committees' discussions on which it was based, and in which Maclaurin participated. Such a sketch was also part of scientists' spontaneous philosophy and public rhetoric since Francis Bacon in the 17th Century, and industrialists in the early 1900s. But the systematization of the idea into a sequential theory is definitely Maclaurin's construction, and the explicit definition of technological innovation as "the first commercialization of a new or improved product or process", now commonly in use, was his suggestion.

[22] According to F.M. Scherer, John F. Kennedy School of Government, Cambridge (Mass.), Maclaurin committed suicide because of lack of appreciation for his work in the MIT economics department. Personal conversation, 17 November 2008.

Appendix 1.

Publications from the MIT Program on "The Economics of Technological Change"

Books

W. C. Scoville (1948), *Revolution in Glassmaking: Entrepreneurship and Technological Change in the American Industry, 1880-1920*, Cambridge (Mass.): Harvard University Press. [23]

A. A. Bright (1949), *The Electric-Lamp Industry: Technological Change and Economic Development from 1800 to 1947*, New York: Macmillan.

W. R. Maclaurin (1949), *Invention and Innovation in the Radio Industry*, New York: Macmillan.

Dissertations

D. C. Vandermeulen (1947), *Technological Change in the Paper Industry: Introduction of the Sulfate Process*, Harvard University, doctoral dissertation.

R. L. Bishop (1950), *The Mechanization of the Glass-Container Industry: A Study in the Economics of Technical Change*, Harvard University, doctoral dissertation.

Papers

W. C. Scoville (1941), Technology and the French Glass Industry, 1640-1740, *Journal of Economic History*, 1.

W. C. Scoville (1942), Large-Scale Production in the French Plate-Glass Industry, 1665-1789, *Journal of Political Economy*, 50.

W. C. Scoville (1943), Labor and Labor Conditions in the French Glass Industry, 1643-1789, *Journal of Modern History*, 15.

W. C. Scoville (1944), Growth of the American Glass Industry to 1880, *Journal of Political Economy*, 52.

W. C. Scoville (1951), Spread of Techniques: Minority Migrations and the Diffusion of Technology, *The Journal of Economic History*, 11 (4).

[23] Scoville's work on technological change started as part of a joint project between the committee on Research in Economic History of the Social Science Research Council, chaired by Arthur H. Cole, and Maclaurins's group.

W.C. Scoville (1952), The Huguenots and the Diffusion of Technology, *Journal of Political Economy*, 60 (4), p. 294-311 and 60 (5), pp. 392-411.

A. A. Bright (1945), Some Broad Economic Implications of Hot-Cathode Fluorescent Lighting, *Transactions of the Electromechanical Society*, 87.

A. A. Bright and W. R. Maclaurin (1943), Economic Factors Influencing the Development and Introduction of the Fluorescent Lamp, *Journal of Political Economy*, October.

W. R. Maclaurin (1950), The Process of Technological Innovation: the Launching of a New Scientific Industry, *American Economic Review*, 40.

W. R. Maclaurin (1950), Patents and Technical Progress: a Study of Television, *Journal of Political Economy*, April.

W. R. Maclaurin (1953), The Sequence from Invention to Innovation and its Relation to Economic Growth, *Quarterly Journal of Economics*, 67.

W. R. Maclaurin (1954), Technological Progress in Some American Industries, *American Economic Review*, 44 (2).

G. B. Baldwin (1951), The Invention of the Modern Safety Razor: A Case Study of Industrial Innovation, *Explorations in Entrepreneurial History*, Vol. 3. [24]

[24] *Explorations in Entrepreneurial History* was a series from the Research Center in Entrepreneurial History (1948-58), founded and directed by A. Cole, Harvard University.

Appendix 2.

Papers Presented at the Conference on
"Quantitative Description of Technological Change"

J. Schmookler (Michigan State College), Inventive Activity, Technical Knowledge and Technical Change as Seen through Patent Statistics.

Alfred B. Stafford (University of Wyoming), An Appraisal of Patent Statistics.

W. Rupert Maclaurin (Massachusetts Institute of Technology), The Sequence from Invention to Innovation, With Emphasis on Capital Supply and the Entrepreneur.

S. Colum Gilfillan (University of Chicago), The Lag Between Invention and Application.

Anne P. Grosse (Harvard University), Innovation and Diffusion.

Yale Brozen (Northwestern University), Invention, Innovation and Diffusion.

Ansley J. Coale (Princeton University), The Measurement of Changes in Industrial Processes.

W. Duane Evans (Bureau of Labor Statistics), Index of Labor Productivity as a Partial Measure of Technological Change.

Gerard Debreu (Cowles Commission for Research in Economics), Effects of Technological Change on Production Potential.

Wassily W. Leontief (Harvard University), Structural Change.

Joseph L. Fisher (Council of Economic Advisers), Natural Resources and Technological Change.

Simon Kuznets (University of Pennsylvania), Ratio of Capital to Product and Technological Change.

William M. Capron (University of Illinois), Changes in Household Equipment as a Partial Measure of Technological Change.

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