The Linear Model of Innovation (II): Maurice Holland and the Research Cycle

Benoît Godin
385 rue Sherbrooke Est
Montreal, Quebec
Canada H2X 1E3
benoit.godin@ucs.inrs.ca

Project on the Intellectual History of Innovation
Working Paper No. 3
2009

Previous Papers in the Series:

1. B. Godin, *Innovation: the History of a Category*.
2. B. Godin, *In the Shadow of Schumpeter: W. Rupert Maclaurin and the Study of Technological Innovation*.

Project on the Intellectual History of Innovation
385 rue Sherbrooke Est, Montreal, Quebec H2X 1E3
Telephone: (514) 499-4074 Facsimile: (514) 499-4065
www.csiic.ca

Abstract

In 1928, Maurice Holland, Director, Engineering and Industrial Research Division, US National Research Council, produced a paper on what he called the "research cycle". He portrayed the development of modern industries as a series of sequential steps from basic research to commercialization of technological inventions.

This paper documents the source or context of the research cycle, the arguments on which it relies, and the aim to which it was put, namely persuading more industrialists to build research laboratories in order to accelerate the development of industries. This paper suggests that Holland has turned a frequently-heard but poorly-formalized argument into a "theory", paving the way for what came to be called the linear model of innovation.

The principle of discovery first and utilization after is the oldest thing in man’s history (W.R. Whitney, in A.P. Sloan et al, Science and Industry in the Coming Century, *The Scientific Monthly*, 39 (1), 1934, p. 74).

The Linear Model of Innovation (II): Maurice Holland and the Research Cycle

The emergence of the industrial research laboratory is without doubt one of the major innovations of the late nineteenth and early twentieth century. In the United States alone, there were three hundred such laboratories in 1920, as reported in the US National Research Council's directory, one of the first systematic sources of data on industrial research. [1] The research laboratory necessitated new management techniques and important financial resources. But the returns to firms were enormous: "a very small investment in research often produces colossal returns". [2]

The emergence of industrial laboratories led to the support of industrial research associations by governments, as done by the Department of Scientific and Industrial Research (DSIR) in Great Britain, [3] and to discourses from industrialists and their representative organizations to convince more industries to invest in research, as a way to accelerate the development of industries. The National Research Council has been an

[1] The Research Council used a "liberal interpretation" that let each firm decide which activities counted as research: "all laboratories have been included which have supplied information and which by a liberal interpretation do any research work" (National Research Council, *Research Laboratories in Industrial Establishments of the United States of America*, *Bulletin of the NRC*, vol. 1, part 2, March 1920). On statistics of industrial research and development (R&D) for the beginning of the twentieth century, see D. E. H. Edgerton (1987), Science and Technology in British Business History, *Business History*, 29, pp. 84-103; D. E. H. Edgerton and S. M. Horrocks (1994), British Industrial R&D Before 1945, *Economic History Review*, 47, pp. 213-238; D. C. Mowery (1986), Industrial Research, 1900-1950, in B. Elbaum and W. Lazonick (eds.), *The Decline of the British Economy*, Oxford: Clarendon Press, pp. 189-222; D. C. Mowery and N. Rosenberg (1989), The US Research System Before 1945, in *Technology and the Pursuit of Economic Growth*, Cambridge: Cambridge University Press, pp. 59-97; D. C. Mowery (1983), Industrial Research and Firm Size, Survival, and Growth in American Manufacturing, 1921-1946: An Assessment, *Journal of Economic History*, 43, pp. 953-980.

[2] T.B. Robertson (1915), The Cash Value of Scientific Research, *The Scientific Monthly*, 1 (2), November, p. 144.

[3] Some authors have documented the origins of the DSIR, but the organizations' activities have been poorly studied. On the efforts of DSIR to promote in industrial research, see Committee on Industry and Trade (1927), *Factors in Industrial and Commercial Efficiency*, Part I, chapter 4, London: Her Majesty's Stationery Office; D. E. H. Edgerton and S. M. Horrocks (1994), British Industrial R&D Before 1945, *op. cit*. pp. 215-216.

ardent promoter of these ideas in the United States, defending the importance of science to industrial development beginning after World War I. [4]

It is from the efforts of the National Research Council that the first version of what came to be called the "linear model of innovation" emerged. The linear model of innovation is a very popular "theory" used until recently to explain technological innovation. It suggests that technological innovation starts with basic research, then moves on to applied research and then development. Once development is completed, the technology is produced on a large scale by industry, then diffuses through the economy. But where does this model come from? In two previous papers, Godin has claimed that 1) the linear model of innovation does not come from V. Bush, as usually suggested. It is rather a social construction from many authors, among them industrialists, over many decades; [5] 2) W. R. Maclaurin from MIT, as a theorist on technological change, brought the model into science and innovation studies. [6]

In this short paper, I document the very first (version of the) linear model of innovation, and show what it owes to the Research Council and its "campaign movement" to promote industrial research. The model was suggested by Maurice Holland, Director, Division of Engineering and Industrial Research, National Research Council. It was part of a series of papers and a book Holland wrote over a period of five years (1928-1933) on the importance of research for industrial development and, as he called it, the "revolution by research": research as a modern method of accelerating industrial evolution. [7]

---

[4] R. C. Cochrane (1978), *The National Academy of Sciences: The First Hundred Years 1863-1963*, Washington: National Academy of Sciences, pp. 227-228, 288-291, 338-346. See also: National Research Council (1933), *A History of the National Research Council, 1919-1933*, Reprint and Circular Series of the National Research Council, No. 106, Washington, pp. 17-20.
[5] B. Godin (2006), The Linear Model of Innovation: The Historical Construction of an Analytical Framework, *Science, Technology, and Human Values*, 31 (6), pp. 639-667.
[6] B. Godin (2008), In the Shadow of Schumpeter: W. Rupert Maclaurin and the Study of Technological Innovation, *Minerva*, Forthcoming.
[7] M. Holland (1928), *Industrial Explorers*, New York: Harper & Brothers Publishers, p. 8.

The US National Research Council

During World War I, the US National Academy of Sciences convinced the federal government to give scientists a voice in the war effort. A National Research Council was thus created in 1916 as an advisory body to the government. Very rapidly, the Council developed an interest in industrial research. In fact, the close links between the National Research Council and industry go back to the beginnings of the Council. Industrialists were called upon in the First World War's research efforts, coordinated by the National Research Council. After World War I, most big firms became convinced of the necessity of investing in research, and began building laboratories for the purpose of conducting research. [8] In this context, the Council was part of the "movement" to persuade more firms to invest in research.

In 1919, the Council organized a division of Research Extension to promote its science and technology interests in industry, and to persuade firms to establish research

---

[8] On the emergence of industrial research, see: US National Research Council (1941), *Research: A National Resource (II): Industrial Research*, National Resources Planning Board, Washington: USGPO; M. Sanderson (1972), Research and the Firm in British Industry, 1919-39, *Science Studies*, 2, pp. 107-151; K. Birr (1979), Industrial Research Laboratories, in N. Reingold (ed.), *The Sciences in the American Context: New Perspectives*, Washington: Smithsonian Institution Press, pp. 193-207; S. B. Saul (1979), Research and Development in British Industry from the End of the Nineteenth Century to the 1960s, in T. C. Smout (ed.), *The Search for Wealth and Stability*, London: Macmillan, pp. 114-138; D. F. Noble (1977), America by Design: Science, Technology and the Rise of Corporate Capitalism, Oxford: Oxford University Press; G. Wise (1985), *W. R. Whitney, General Electric, and the Origins of US Industrial Research*, New York: Columbia University Press; L. S. Reich (1985), *The Making of American Industrial Research: Science and Business at GE and Bell, 1876-1926*, New York: Cambridge University Press; D. A. Hounshell and J. K. Smith (1988), *Science and Corporate Strategy: Du Pont R&D, 1902-1980*, Cambridge: Cambridge University Press; A. Heerding (1986), *The History of N. V. Philips' Gloeilampenfabriken*, New York: Cambridge University Press; J. Schopman (1989), Industrious Science: Semiconductor Research at the N. V. Philips' Gloeilampenfabriken, 1930-1957, *Historical Studies in Physical and Biological Sciences*, 19 (1), pp. 137-172; M. B. W. Graham and B. H. Pruitt (1991), *R&D for Industry: A Century of Technical Innovation at Alcoa*, New York: Cambridge University Press; D. A. Hounshell (1996), The Evolution of Industrial Research in the United States, in R. S. Rosenbloom and W. J. Spenser (eds.), *Engines of Innovation: US Industrial Research at the End of an Era*, Boston: Harvard Business School Press, pp. 13-85; J. K. Smith (1990), The Scientific Tradition in American Industrial Research, *Technology and Culture*, 31 (1), pp. 121-131; E. Homburg (1992), The Emergence of Research Laboratories in the Dyestuffs Industry, 1870-1900, British Journal for the History of Science 25, pp. 91-111; G. Meyer-Thurow (1982), The Industrialization of Invention: A Case Study from the German Chemical Industry, *Isis*, 73, pp. 363-381; M. A. Dennis (1987), Accounting for Research: New Histories of Corporate Laboratories and the Social History of American Science, *Social Studies of Science*, 17, pp. 479-518; D. Mowery (1984), Firm Structure, Government Policy, and the Organization of Industrial Research: Great Britain and the United States, 1900-1950, *Business History Review*, pp. 504-531; T. Shinn (1980), The Genesis of French Industrial Research, 1880-1940, *Social Science Information*, 19 (3), pp. 607-640.

laboratories. In 1924, the Division merged with that of Engineering, which had objectives closely resembling those of the former. Maurice Holland, who had been director of the Division of Engineering since 1923, became Director of the new entity: the Division of Engineering and Industrial Research. [9] Holland, who has studied at the Lowell Institute of MIT, came from the Army Air Service, where he had been Chief of the Industrial Engineering Branch. He remained at the Engineering and Industrial Research Division until 1941, when the division moved from Washington to New York and the position of director was abolished. Holland then became a consultant to industry in matters of industrial research. [10]

According to R. C. Cochrane, official historian of the National Research Council, the Division of Research Extension and that of Engineering "merged with the expressed purpose to encourage, initiate, organize and coordinate fundamental and engineering research in the field of industry and to serve as a clearing house for research information of service to industry". [11] "Through a massive speaking and publication effort [the Division] proceeded to sell the research idea to industrial executives, trade associations, and the public (…)". [12] As G. P. Zachary put it, "the division had been a hotbed of activity, preaching to corporations the benefits of funding their own research". [13] It conducted special studies on industrial research, arranged visits to industrial research laboratories for executives, organized conferences on industrial research, and collected data on industrial research. [14] It also helped set up the Industrial Research Institute – an

---

[9] V. Bush had been Chairman of the Division from 1936 to 1940.

[10] After more than fifteen years of advisory work to industry, Holland published: M. Holland et al. (1958), *Managements Stake in Research*, New York: Harper.

[11] R. C. Cochrane (1978), The National Academy of Sciences, *op. cit.,* p. 338.

[12] *Ibid*. p. 290.

[13] G. P. Zachary (1997), *Endless Frontier: Vannevar Bush, Engineer of the American Century,* Cambridge (Mass.): MIT Press, 1999, p. 81.

[14] The collection of data was one of the influential outputs of the National Research Council. In the very early years of the Council, a research information committee, then a Research Information Service, was put into place. The Service was concerned with the inter-allied exchange of scientific information (R. MacLeod (1999), Secrets among Friends: The Research Information Service and the Special Relationship in Allied Scientific Information and Intelligence, 1916-18, *Minerva*, 37 (3), pp. 201-233). After the war, these activities ceased, and the Service reoriented its work toward other ends. The Service became "a national center of information concerning American research work and research workers, engaged in preparing a series of comprehensive card catalogues of research laboratories in this country, of current investigations, research personnel, sources of research information, scientific and technical societies, and of data in the foreign reports it received" (R. C. Cochrane (1978), The National Academy of Science, *op .cit*., p. 250. See

organization that still exists today. Holland was largely responsible for the initial organizational meeting of the Institute in 1938. [15] Since the beginning of the 1980s, the Institute has honoured Holland through the Maurice Holland Award, which recognizes the best papers published in its journal, *Research and Technology Management*.

One important vehicle or output of the Division of Engineering and Industrial Research, as well as of members of the Research Council's Board and committees, among them J.J. Carty and F.B. Jewett from AT&T, was addresses, often reproduced in the Council's *Reprint and Circular Series*. [16] As J.J. Carty put it: "The large corporations are being asked to explain the nature of their research organizations, and the advantages which are derived from them. It is believed that in this way those of our manufacturers who are not yet informed will become interested in research methods and organization and results". [17] One type of address produced concerned the importance of research to industry, while another concentrated on the benefits of science to society. Holland himself produced several papers, and he is a good representative of the discourses of the time.

Holland developed two types of arguments for promoting the cause of industrial research. The first dealt with the development or "evolution" of industries, as he called it. Certainly he believed that science advances civilization, and is a "story of higher standards of living, increased comforts, better health, easier working conditions, more leisure and leads the betterment of mankind". [18] However, his main concern was research as a factor for progress in industry. To Holland, we are in the era of science in industry, heralded by

---

also: National Research Council (1933), A History of the National Research Council, *op .cit.*, pp. 44-48). As part of these activities, the Research Information Service regularly compiled a series of directories, among them one on industrial research laboratories. The National Research Council's directory has been a very influential tool for statistics on science in the United States. For decades, government departments and public organizations have used the Council's directory to survey industrial research.

[15] A small group of R&D leaders known as Directors of Industrial Research (1923) opposed Holland's plan. Nevertheless, the Institute was launched in 1937 as the National Industrial Research Laboratories Institute, renamed the next year as the Industrial Research Institute. It became an independent organization in 1945.

[16] On industrial members of the Council and the role of basic research, see: R. Kline (1995), Construing Technology as Applied Science: Public Rhetoric of Scientists and Engineers in the United States, 1880-1945, *Isis*, 86, pp. 194-221.

[17] J.J. Carty (1920), Science and the Industries, *Reprint and Circular Series of the National Research Council*, No. 8., p. 2.

[18] M. Holland (1931), Industrial Science: A Gilt Edge Security, *Science*, 74 (1916), September 18, pp. 279-282, p. 279.

the vanguard of industrial research laboratories. [19] The industrial research laboratory is "one of the basic factors in economic and industrial progress". [20]

As evidence that research is "the prime mover of industry", [21] Holland made frequent use of data on the number of firms listed on the New York Stock Exchange that had research laboratories. To Holland, "the advances of industrial technology are reflected in the quotations on the Stock Exchange". The market leaders are "those companies best known for their extensive research activities". The research activities of these companies "have put them in first position, among the leaders of American industry, and research enables them to maintain that position". Because there is "a direct relationship between the research rating and the security ranking [economic strength] of the leaders of the American industry", [22] at several times Holland predicted the development of the "technical or science audit":

> Statistics, barometer charts, business cycles, bank deposits, and car loading as indicators of the state of industry or trade are accessories after the fact. They are based on past performance. Research, on the other hand, is an industrial X-ray revealing basic causes and fundamental conditions. The work of the research laboratory today is the commercial product of next year (…). The banker reassures himself by studying economic charts, business cycles, financial statements (…). But now, he is learning that a new measuring rod is at hand, a survey of research methods. The day will come, and shortly, when before granting a loan, the banker will insist on asking embarrassing questions" regarding the research policy of his client. [23]

> In the not far distant day forecasting futures by a study of the present trends of research in industries will be reduced by trained observers to the same simple formulas and computations which now govern the transactions in May cotton and December wheat on the New York Exchange. In the "technical or science audit" of an industrial company, barometer charts based on [the] technical, not the commercial, state of industry will appear. The technical audit (...) seems to be an inevitable development. [24]

---

[19] M. Holland (1928), Research, Science and Invention, in F. W. Wile, *A Century of Industrial Progress*, American Institute of the City of New York, New York: Doubleday, Doran and Co., pp. 312-334, p. 312.
[20] *Ibid*. p. 314.
[21] *Ibid*. p. 315.
[22] M. Holland (1931), Industrial Science: A Gilt Edge Security, *op. cit.*
[23] M. Holland (1928), Industrial Explorers, *op. cit.*, p. 9-10.
[24] M. Holland (1928), Research, Science and Invention, *op. cit.*, p. 327.

To Holland, research is one of the best forms of security for industry. It is insurance against competition, and against economic depression. To illuminate this latter belief, Holland used the data from the National Research Council's directory on industrial research laboratories and conducted a survey of research expenditures. [25] Out of 1,600 corporations, 231 replied to the questionnaire. The study was motivated by the Great Depression and its effect on industrial research. It looked at the amounts spent for research in 1929 and 1931, with projections for 1932 and 1933, broken down by industry and firm size. From the numbers obtained, which showed a decline in research expenditures, Holland nevertheless concluded that companies had maintained their expenditures at a remarkably high level, despite the recent business conditions. Ninety percent of directors "place their faith upon research for future technical development", claimed Holland. [26] To Holland and his co-author, "research is a tool which brings returns; it is a leading factor of industrial progress". [27]

In Holland's view, research was also a factor in a country's competitiveness, and this was the second kind of argument he developed. He frequently compared the organization of research in the United States to other countries, among them Great Britain, Germany, France and Japan. The analyses were qualitative rather than quantitative because of the paucity of data in other countries as compared to the United States. Internationally-comparable statistics would become available only in the 1960s. [28] Nonetheless, Holland's lesson was that in European countries there was more public funding of research than in the United States, and much excellence in pure science. However, in America "the rewards of applied science are better recognized by industry", and because of this, the country had advanced to first place among nations of the world in term of industrial science. [29] To Holland, "research and its applications are the universal tools of

[25] M. Holland and W. Spraragen (1933), *Research in Hard Times*, Division of Engineering and Industrial Research, National Research Council, Washington.
[26] M. Holland and W. Spraragen (1933), Research in Hard Times, *op. cit*., p. 5.
[27] *Ibid*., p. 16.
[28] B. Godin (2005), *Measurement and Statistics on Science and Technology: 1920 to the Present*, London: Routledge.
[29] The view that the United States is best in applied research but lacks basic research is an old one, going back to the nineteenth century. On a critique of this interpretation of research in America, see: N. Reingold (1971), American Indifference to Basic Research: A Reappraisal, in N. Reingold, *Science: American Style*, New Brunswick and London: Rutgers University Press, 1991, pp. 54-75. The view also served as an

industry (...) and may be, at some future time, the biggest items in the balance sheet of foreign trade”. [30] “Any nation which can completely integrate research in the industrial structure (...) has the biggest promise of an industrial future in the highly competitive world markets of today”. [31]

Holland believed that what makes industrial research so influential is systematicness: industrial research is systematic and organized search. “There was a time in the history of mankind”, Holland stated, “when new products or processes were discovered by accident, rather than deliberately invented (…). “Industrial research properly organized, properly equipped with a selected personnel, making proper use of new fundamental knowledge, and properly coordinated with all other functions” has now replaced the rule of thumb. [32] “Scientific research has made of invention a systematic, highly efficient process”. [33]

The idea of organized research was a major idea of the time – and it would have great influence on the way officials define and measure research right up to the present. Before Holland, industrialists like C. E. K. Mees, Director of Research Laboratory, Eastman Kodak, and author of a classic book on the management of research, [34] had discussed the idea in these terms. [35] It had also been discussed by economists. [36] In general, organized research was contrasted to individual and heroic inventors. Holland himself contrasted “the formidable research organization” to the “vanishing independent American

---

argument for launching science policy in Europe in the early 1960s. See: B. Godin (2002), Technological Gaps: An Important Episode in the Construction of Science and Technology Statistics, *Technology in Society*, 24, pp. 387-413; B. Godin (2008), *The Place of Universities in Science, Technology and Innovation Policies: a Historical Perspective*, Communication Presented at the International Workshop “The Changing Role of Public Sector Research in Innovation”, Center for Advanced Studies, Norwegian Academy of Sciences, Oslo, 26-28 March.

[30] M. Holland (1932), Industrial Research Abroad, in M. Ross (ed.), *Profitable Practice in Industrial Research*, Sponsored by the US National Research Council, New York: Harper, pp. 119-152, p. 119. See also: M. Holland and D. North (1948), Research in America and Europe, in C. C. Furnas (ed.), *Research in Industry: Its Organization and Management*, Princeton: D. van Nostrand, pp. 499-527.

[31] M. Holland (1932), Industrial Research Abroad, *op. cit*., p. 150.

[32] M. Holland and W. Spraragen (1933), Research in Hard Times, *op. cit*., p. 12.

[33] *Ibid*., p. 13.

[34] C. E. K. Mees (1920), *The Organization of Industrial Scientific Research*, New York: McGraw Hill.

[35] C. E. K. Mees (1916), The Organization of Industrial Scientific Research, *Science*, XLIII (1118), 2 June, pp. 763-773.

[36] R. C. Epstein (1926), Industrial Invention: Heroic, or Systematic?, *The Quarterly Journal of Economics*, 40 (2), pp. 232-272.

inventor". [37] According to Holland, less than five percent of patents that reach the commercial stage are the result of individual, independent inventors. The lesson was clear: historians and philosophers who trace the records of basic inventions back to the "only firsts" do "not take into account the fact that a great invention is not the completed result of a single man - it is the resultant of many inventions, the composite of a number of realized ideas merged into a workable whole". [38] "All the great inventions can be traced back beyond the time of their popularly acclaimed 'inventions', and some of their beginnings go back beyond the births of those who are heralded as their inventors". [39]

The argument for the cumulative nature of invention goes back at least to the second half of the nineteenth century when, for example, it was used during the "patent controversy" in Great Britain, as C. Macleod has documented. [40] Sociologists in the early twentieth century also discussed the idea in terms of genius, or great men, versus culture. [41] Holland himself also got into this debate:

> Genius no longer plays the leading role in the drama of modern industry (…). The laboratory has become the adventurer on the frontier of industry (…). The research worker is a unit in the organization, his equipment is modern and technical, his training is that of a specialist (…). No single inventor, independent or otherwise, could have developed the transatlantic telephony, much less brought it into successful commercial operation. This was the product of organized effort. Each worker does its bit in the struggle of man to control the forces of nature. [42]

Despite this down-grading of the inventor as genius in the industrial area, there are still geniuses in Holland's view. He has simply substituted for the old ones a different kind. In *Industrial Explorers,* Holland devoted over 300 pages to documenting the story behind

[37] M. Holland (1928), Research, Science and Invention, *op. cit*, p. 331.
[38] *Ibid*. p. 332.
[39] *Ibid*. p. 333.
[40] C. Macleod, (1996), Concepts of Invention and the Patent Controversy in Victorian Britain, in R. Fox (ed.), *Technological Change: Methods and Themes in the History of Technology*, London: Harwood Academic, pp. 137-153.
[41] W. F. Ogburn (1926), The Great Man Versus Social Forces, *Social Forces*, 5 (2), reprinted in O. D. Duncan (ed.), *W. F. Ogburn on Culture and Social Change*, Chicago: University of Chicago Press, 1964, pp. 33-43.
[42] M. Holland (1928), Industrial Explorers, *op. cit.*, p. 4-6.

the nation's leaders of industrial research, among them: W. R. Whitney (Director of Research Laboratories, General Electric) "a molder of genius", E. A. Sperry (Chairman, Board of Directors, Sperry Gyroscope), F. B. Jewett (Vice-President, ATT), C. E. K. Mees (Director of Research Laboratory, Eastman Kodak) and A. D. Little (consultant). To Holland, the industrial leader and "the research laboratory [have] become the prime mover for the machinery of civilization". [43]

The Research Cycle

In a paper written for a book published in 1928 to celebrate the centenary of the American Institute of the City of New York, Holland developed his idea on the research cycle, as a precursor to what came to be called the linear model of innovation. Why is research the prime mover of industry, Holland asked? Because it "reduces to the minimum the period between the scientific discovery and mass production". As evidence that research reduces what he called the "time lag" between discovery and production, Holland portrayed the development of industries as a series of successive stages. He called his "sequence" the "research cycle". It consists of the following seven "steps": [44]

- Pure science research
- Applied research
- Invention
- Industrial research (development)
- Industrial application
- Standardization
- Mass production

To Holland, the first two steps are two main divisions of modern research, and the distinction between pure and applied science is one of motive: pure science research is fundamental and has for its objective the discovery of facts and principles; applied

[43] M. Holland (1928), Research, Science and Invention, *op. cit*, p. 334.
[44] *Ibid*. pp. 315-316.

research "is consequential and controls them". "The one is the foundation; the other the superstructure". These two kinds of research have been amply discussed – and contrasted – in history, and Holland simply uses the same vocabulary here. [45]

Invention is the first successful product coming out of the previous two steps. However, it is industrial science, the fourth step, that turned the invention into a viable product. Industrial research is "the method of scientific research applied to the problems of industry". It is intimately interwoven with other steps or activities, like standardization, testing, material control and process development.

To Holland, "the speeding up of the period of the cycle, the reduction to the minimum of the time lag, is the criterion of the effectiveness of scientific research as an industrial aid". [46] To substantiate his "theory", Holland used bits of history, and spent twelve pages discussing the historical development of industries. In recent history, five industries have gained pre-eminence in the industrial landscape because they have developed from basic inventions (electricity, automobile, radio, electrochemical, telephone). In the case of electricity, the steps in the research cycle are:

- Volta (1779) the discoverer of current electricity.
- Sturgeon (1825) applying Volta's results to an electromagnet.
- Faraday (1831) the inventor of the dynamo.
- Siemens the industrial developer.
- Edison the industrial applicant.
- The modern industry, with a "book value" of $25 billion (mass production).

Holland offered similar stories for the other industries. All five industries "closely follow the successive stages in the research cycle": [47] the telephone "industry", for which research "has been the largest single factor" in its development, the incandescent lamp

[45] See, for example: J. J. Carty (1924), Science and Business, *Reprint and Circular Series*, No. 24, National Research Council.
[46] M. Holland (1928), Research, Science and Invention, *op. cit*, p. 316.
[47] *Ibid*. p. 326.

industry, [48] the radio industry, [49] the electrochemical industry, [50] and the automobile industry. [51] In the latter case, “not since the first invention of man, whatever it might have been in prehistoric time, has any human product attained such pre-eminence in industry in so few years as the automobile”. [52]

Then Holland contrasted the modern industries to older ones (textiles, fisheries, iron and steel), namely “the last to recognize the importance and value of research work”. “It has taken centuries to accomplish in them what has been done with the aid of research in a few decades” in the modern industries. According to Holland, the technology in the textile industry has “changed but little since the days of King Tut”. [53] The industry “is permeated with tradition and trade prejudice, based on a technology handed down from generation to generation, from father to son”. It is art rather than industry.

However, the textile industry, together with other older industries, has “at last succumbed to the research idea”, and has reduced the time lag to something less than fifty years. These industries have “experienced greater development in that period of five decades than all the centuries that went before”. [54] Holland concluded that there was “striking evidence of the cycle of research” [55] and “unmistakable evidence of the successive stages in the research cycle from the discovery in pure science to mass production”. [56]

Holland’s idea of the research cycle is the first “theory” on the role of basic research in industrial development. Unlike his predecessors, Holland turned a frequently-heard but poorly-formalized argument into a theory. The “high value which captains of industry have placed upon science as a live, productive asset” [57] he explained with a series of

---

[48] Davy (1800) → Starr (1841) → Edison/Swan (1878), “in rapid succession” → then industrial research (1902 and after) → mass production of $90 million.
[49] Maxwell → Hertz → Marconi.
[50] Wohler → Hall.
[51] Selden (1895) → Duryeas/Olds (1900) → Ford (1903).
[52] M. Holland (1928), Research, Science and Invention, *op. cit*, p. 318.
[53] *Ibid*. p. 317.
[54] *Ibid*. p. 324.
[55] *Ibid*. p. 319.
[56] *Ibid*. p. 322.
[57] *Ibid*. p. 327.

steps determining industrial development, of which research is the first step leading to the commercialization of inventions.

Slightly more than ten years later, the second discussion of the “research cycle” appeared in the literature. It came, once again, from a National Research Council publication. In 1941, the US National Resources Planning Board published a study on industrial research produced by the National Research Council. The study was a voluminous report: nearly 400 pages. [58] Thirty writers, from academia, industry and consultancy firms, contributed, analyzing “the nature, extent and welfare of industrial research”. According to Holland, it was “the most complete history of an era of industrial research and the most dependable evaluation there is in a field where reference literature is scarce”. [59] Indeed, the report contributed to the crystallization of several concepts which would become influential in subsequent years. [60]

In the introductory chapter to the report, R. Stevens, vice-president at Arthur D. Little, identified several “stages through which research travels on its way toward adoption of results in industry” - the third and fourth stages corresponding more or less to what we now call development: [61]

- Pure science research
- Applied research
- Test-tube or bench research
- Pilot plant
- Production (improvement, trouble-shooting, technical control of process and quality).

With this definition, Stevens not only offered a list of detailed activities involved in (research and) development, but he also paved the way for the statistical measurement of

[58] US National Research Council (1941), Research: A National Resource, *op. cit*.
[59] M. Holland and D. North (1948), Research in America and Europe, *op. cit*., p. 502.
[60] B. Godin (2007), *What is Science? Defining Science by the Numbers, 1920-2000*, Project on the History and Sociology of Science, Technology and Innovation Statistics, Montreal: INRS.
[61] R. Stevens (1941), A Report on Industrial Research as a National Resource, *op. cit*. p. 6-7.

the development category. [62] As he reported, "there is a wide difference of opinion as to the point at which research begins and commercial development and operation begin". [63] The definitions would only be standardized in the 1950-60s. However, the limitation did not prevent Stevens, like Holland, from developing demarcations and classifying sequential stages from research to commercialization.

Conclusion

Research cycles and linear models of innovation would proliferate in the following decades, becoming a taken-for-granted fact. [64] To the best of my knowledge, Holland's research cycle is one of the first systematic applications (or adaptations) of the life-cycle model to science, technology, and innovation studies. [65] The life-cycle idea was very popular in biology and geology in the seventeenth and eighteenth century, particularly among evolutionists. [66]

The research cycle is the very first of what came to be known as linear models of innovation. Holland had in fact systematized and further developed an idea that had already been in industrialists' minds for some time. For example, in 1920 C. E. K. Mees, director of the research laboratory at Eastman Kodak, described the development laboratory as a small-scale manufacturing department devoted to developing "a new process or product to the stage where it is ready for manufacture on a large scale". The work of this department was portrayed as a sequential process: development work is "founded upon pure research done in the scientific department, which undertakes the

---

[62] B. Godin (2006), Research and Development: How the "D" got into R&D, *Science and Public Policy*, 33 (1), pp. 59-76.
[63] R. Stevens (1941), A Report on Industrial Research as a National Resource, *op. cit*., p. 6.
[64] B. Godin (2006), The Linear Model of Innovation, *op. cit*. On a rare and subsequent use of the term "research cycle", see D.A. Schon (1967), *Technology and Change : the Impact of Invention and Innovation in American social and Economic Development*, New York : Delta Books, pp. 50-52. Schon's research cycle refers to historical stages in the development of industrial research : craft, then science, then technology.
[65] Prior to Holland, the life-cycle analogy existed in the early sociology of invention (growth and use of invention). Later applications are: bibliometrics (citations life-cycle), management of technology (product life-cycle), and sociology of science (life-cycle of disciplines).
[66] B. Godin (2010), *On the Genealogy of Concepts and Categories in Science, Technology and Innovation Studies*, INRS: Montreal, Forthcoming.

necessary practical research on new products or processes as long as they are on the laboratory scale, and then transfers the work to special development departments which form an intermediate stage between the laboratory and the manufacturing department". [67] As director at the National Research Council, Holland met and discussed regularly with most industrial leaders of the country, like Mees, interviewed many of them for his book entitled *Industrial Explorers*, and thus got many occasions to sympathize with their views. The research cycle became Holland's argument to convince more firms and industries to invest in research.

However, if Holland offered a precursor to the linear model of innovation, it is to W. R. Maclaurin that we owe the most serious theory. [68] Maclaurin developed his theory from history, as Holland did. He looked at the development of the radio industry, among others, the science behind the invention and the industrial application, and identified steps similar to those of Holland. However, Maclaurin's theory was less impressionist and more systematic, and the history and his sources were better documented. It was the work of an economic historian, and the result of many years of empirical work under a program of research, the first of its kind, on the economics of technological change.

To return to Holland, one finds in the "theory" of the research cycle one of the first uses of sociologist W. F. Ogburn's concept of lag, first proposed in 1922. To Ogburn, the social maladjustment between the material culture (technology) and what he called the adaptive culture (the rest of culture) he named a cultural lag. [69] The concept would become influential after the 1930s, namely after a US President's Research Committee report on social trends, which used the concept (Ogburn was director of the committee responsible for the report), [70] and during the debate on technological unemployment. As we have seen above, the idea of a lag also served Holland in developing his "theory" on

---

[67] C. E. K. Mees (1920), The Organization of Industrial Scientific Research, *op. cit*., p. 79. Mees' sequence became, in the 1920s, the shared understanding of what invention is. As example, see: E.P. Warner (1923), The Nature of Invention, *Harvard Graduates Magazine*, 31 (123), pp. 310-317.

[68] B. Godin (2008), In the Shadow of Schumpeter, *op. cit.*

[69] W. F. Ogburn (1922), *Social Change with Respect to Culture and Original Nature*, New York: The Viking Press.

[70] US President's Research Committee on Social Trends (1933), *Recent Social Trends in the United States*, New York: McGraw-Hill.

the research cycle. [71] Holland is certainly a forerunner in the use, or rather adaptation, of Ogburn's concept, although it is impossible to document to what extent his "time lag" was really inspired by Ogburn. [72] Equally, Holland preceded Ogburn when he suggested that "there is, in fact, no surer method of forecasting industrial futures than study of the time lag between a discovery in pure science and the application of the discovery industrially". [73]

One thing is certain: it was time, according to both authors, that explained science and technology use. The research cycle is a dynamic representation of industrial development. "I endeavored", reported Holland on his visit to Japanese laboratories, "to trace the development of industrial methods from their sources and to follow them to their ultimate application". [74] To Holland, the research cycle is the "process" responsible for the evolution of modern industry. Similarly, the linear model of innovation subsequently developed in the literature on the economics of innovation, first of all by Maclaurin, comes from an evolutionary perspective on industrial development.

[71] Holland also used the term "gap" in another paper. See: M. Holland (1928), From Kimono to Overalls, *The Atlantic Monthly*, October, pp. 555-565.
[72] I have found only one occurrence of the term "time-lag" in the literature before Holland: J.J. Carty (1924), Motive and Obligation, *Reprint and Circular Series of the National Research Council*, No. 68, p. 8).
[73] *Ibid*, p. 555. On Ogburn, see : W.F. Ogburn (1937), National Policy and Technology, US National Resources Committee, *Technological Trends and National Policy, Including the Social Implications on New Inventions*, Washington: USGPO : "Since it requires a quarter of a century more or less for an invention to be perfected and to be put into wide use, it is possible to anticipate their results some years ahead" (p. 3); W.F. Ogburn (1941), National Policy and Technology, in S.M.Rosen and L. Rosen, *Technology and Society: The Influence of Machines in the United St*ates, New York: Macmillan : "Since a lapse of considerable time is requisite to the perfection and wide adaptation of an invention, the results of an invention may be anticipated in advance of its common usage" (p. 4).
[74] M. Holland (1928), From Kimono to Overalls, *op. cit*.