ENGINEERING EXPERTISE AND THE CANADIAN EXPLOITATION OF THE TECHNOLOGY OF THE SECOND INDUSTRIAL REVOLUTION

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Canada was arguably the most successful exploiter of the new technology of the Second Industrial Revolution. That concatenation of more scientifically based technological developments occurring late in the nineteenth century gave a great boost to economic performance throughout the European world. After a couple of decades of languishing economic growth, the pace of change was invigorated right at the end of the nineteenth century so that many countries entered the new century in vibrant condition, developing more rapidly as the new technology boosted productivity in many areas of their economies. In the language of the New Growth Theory, here was a technological shock of great consequence. Mass production of cheap steel led the way, supplanting the older iron technology. Then there was the electrical revolution, providing not only a new form of prime mover to power manufacturing but an array of technically new, electrically-based processes, and an assortment of new consumer products as well. Scientific chemistry also came into play. Commodities came to be produced by chemical synthesis, and entirely new elemental combinations were found to have valuable uses. Finally came the internal combustion engine. It found application in the early twentieth century not only in powering automobiles but in agricultural machinery, marine uses, and stationary power sources as well. In short, there was a great burst of technological innovation that has long been recognized to have invigorated the turn-of-the-century economy.

These remarkable developments of technology greatly enhanced productivity. That was not their only consequence since they also added greatly to the range of products that people could enjoy, and they allowed people to do things such as fly and talk to people on other continents. The revolutionary nature of these developments makes productivity comparisons exceedingly difficult. Nevertheless, one of the things they did was to make possible the production of goods using fewer or cheaper resource inputs. In the standard language of economists they brought favourable shifts in production functions. That is why they are commonly looked upon as an important source of economic growth. Caution must nevertheless be exercised in evaluating the changes since in so many cases there were such important modifications in the very nature of the products. With what does one compare the instantly switched-on, high lumen electric light, or the unit-drive electrical motor? Is the automobile just a faster, more comfortable carriage? Some sense of the dimension of change can be gained for reasonably comparable products. Open hearth steel, for example, could be produced with fewer resource inputs than crucible steel. Paper from wood pulp was much cheaper than paper from rags. An outstanding example was aluminum produced by the Hall-Héroult process, but that in turn required vast amounts of cheap electricity. These types of developments, though, exemplify what we mean by technologically-based increases in total factor productivity. The surge of technological developments that occurred in the last quarter of the nineteenth century and early years of the twentieth, what is often referred to as the Second Industrial Revolution, was especially fruitful of productivity and growth enhancing developments.

This paper builds upon the premiss that Canada benefitted greatly from these technological developments, more so arguably than any other economy. The question of primary interest is how it was that Canada was so well able to exploit this new technology and to benefit so much from it. The absorption and implementation of new technology is not a simple nor automatic matter. It does not happen without cost. Resources have to be used to incorporate the new technology into the production structures of any economy. New Growth Theory makes this essentially a matter of investing in human capital, but that is surely too vague and simplistic a way of putting it. In reality, the process of absorption and exploitation of new technology is almost certainly a lot more complicated. It may have many dimensions. Still, we need to strive to understand it.

Consider first the case that Canada was in the forefront of exploitation of the technology of the Second Industrial Revolution and able to accomplish more with it than other economies of the European world. It is not necessary to prove that in order to motivate this paper. It really only matters that the new technology played an important role in the growth of the Canadian economy in the years between 1897 and the outbreak of World War I.[1] That in itself would make an investigation worth while. It appears, however, that the Canadian case was outstanding, that Canada may have accomplished more with this technology than other national economies. If so, that gives special force to an exploration of the Canadian case.

The electrical technology appears to have been especially beneficial. It freed the Canadian economy from a long-standing limitation of energy resources in the era of steam, since coal was found only at the eastern and western extremities of the country, and not at all in the most heavily-populated central heartland.[2] Hydraulic resources, with which electricity could be generated, abounded in Canada. Chemical processes allowed Canadians to make use of other abundant natural resources.[3]. The new technology generated a range of new products for Canadians to manufacture, and new ways to make them. The main impact of the internal combustion engine and the automobile industry to which it gave rise came almost entirely after the period under consideration here, but steel was another matter. The new technologies of producing steel by either the Bessemer converter or the Open Hearth process had been invented some time before 1897 but widespread implementation outside of Britain had been limited before the late years of the nineteenth century. Modern steel making was being introduced in the United States by the 1880s so, by 1897 Canada was something of a late-comer to the steel revolution. Nevertheless, the big expansion of the Canadian steel industry at the turn of the century played a major role in the sharp acceleration of the country's economic growth, and is squarely a part of Canada's participation in the Second Industrial Revolution.

The economies of European countries had progressed only slowly over the years from the cyclical downturn of the mid-1870s through to the mid-1890s. The subsequent couple of decades was generally a period of rapid industrialization and economic growth. In that setting, as was noted above, the growth experienced by Canada was more rapid than that of any other country. The rate of growth of real per capita income in Canada over the whole of the period from 1897 to

1913 exceeded that of any other country at that time. As I have elaborated on more fully elsewhere (McInnis, 1999), the period of Canada's most notable reliance upon, and greatest benefit from, the technology of the Second Industrial Revolution was the decade 1897 to 1907. There was a short but fairly sharp recession in 1907 that marks a determinate termination of a phase of growth in the Canadian economy. In the years that followed the economy continued to grow rapidly in absolute terms, but in a way that was much more related to agricultural settlement on the western plains. At the same time the rate of per capita income growth in this later period was substantially lower than in the 1897-1907 decade, and no different from the rates of growth achieved by most industrial economies at that time. It is the 1897-1907 decade that stands out as Canada's glittering era of economic development. Average annual rates of growth of real per capita income for the two periods 1897-1907 and 1897-1913 are shown in Table X.1 for the set of advanced economies for which such data are available. The salient point is that Canada leads the pack, whichever period is considered. It is in the 1897-1907 decade, however, that Canada's record looks so outstanding. It grew significantly faster than Australia or New Zealand or the United States and much more rapidly than the rest of the European economies. It's closest comparator was Italy, which grew at an average rate over that period of 3.85 per cent per annum while the growth rate of Canadian real per capita income was 4.43 per cent. The United States grew at just 3.0 per cent.[4] Between 1870, when reliable national income data become available, and 1913, Canadian real per capita income converged upon the level of the United States. Two-thirds of the narrowing of the gap came in the years between 1897 and 1907.

[Table X.1 about here]

Especially since I am arguing that Canada’s success derived mainly from industrialization, it would be instructive to compare rates of industrial growth in the post-1897 period. This has to be done with considerable caution since there is not presently available a conventional index of industrial production for Canada that covers the years under consideration. Rates of growth of industrial production can be calculated for seven leading countries, including the United States and Japan as well as the prominent European nations.[5] The Canadian measure that is available, the growth of the industrial component of GNP, is not precisely the same thing but can be used for a rough comparison.[6] Over the decade 1897 to 1907 Canadian industrial growth, at 8.02 per cent per annum, was much faster than that of any of the other countries for which comparisons can readily be made. The demographic base of the Canadian economy was also growing faster than that of other economies and that should be taken into account. In Table X.2 Canadian per capita industrial growth is compared with that of seven other countries for which data can readily be obtained. For Canada, the extent to which the growth of real industrial product exceeded the growth of population stands out, well above that of any European country and is almost a full percentage point above that of the United States, the country commonly thought to be the world leader in industrialization at this time. It has been more common for writers to look upon the entire period from 1897 to 1913 as a piece and so in Table X.2 that comparison is given as well. It is evident that the rate of growth of Canada’s industrial production tapered off after 1907, while it’s population growth rate went up. As a consequence, looking at the entire 1897-1913 period, the per capita growth of industrial production in Canada was not greater than in the United States. Canadian industrialization was still more rapid than that experienced by European nations; more rapid than that of Germany, the nation that is often looked upon as the epitome of industrial development at that time; more rapid than that of Sweden, a country of similar size to Canada and one that was similarly utilizing the new technology to good effect. The closest to Canada's achievement was that of Italy.

[Table X.2 about here]

Canadian economic historians have traditionally emphasized the settlement of the wheat growing region of the Canadian west as the driving force behind Canada's remarkably high rate of economic growth in the early twentieth century. Indeed, the period is usually referred to as the "wheat boom." I argue that Canadian economic growth, 1897-1907, was led by industrialization and especially by an industrialization that focused on those industries most reflective of the new technology of the Second Industrial Revolution.[7] Over the period in question the net output of manufacturing industry as a whole, in real terms as explained in footnote 6, grew at an average rate of 8.0 per cent per annum. This remarkably high rate of growth was admittedly a passing phase in the country's development. It was not something that could be long sustained. It was a phase that featured the high, early expansion rates of several industries that were especially impacted by the new technology. The point of my argument is that at some time or another most economies experience a phase of rapid growth.[8] What calls for emphasis in the Canadian case is that the rate of growth achieved during this spurt was extraordinarily high. Furthermore, it was not just the infant growth spurt of a newly industrializing nation. Already by 1890 Canada was substantially industrialized — a point insufficiently recognized either by Canadians or by scholars from other countries.[9] In that year only three other countries in the world had higher per capita industrial output than Canada. They were the United Kingdom, the United States, and Belgium. By that standard Canada was, by 1897, well along the route to being an advanced industrial nation. Its remarkably high rate of industrial growth cannot be passed off as simply the early stirring of a newcomer to the industrial world.

The structural pattern of this industrial growth is shown in Table X.3. There I contrast the growth of the industries most clearly affected by the new technology with a set of industries that were much less influenced. The first group should be self-explanatory. The second group comprises industries little affected by the new technology. This is not to say that there was no influence, but that it was not a predominant feature of the industries in question.[10] The industries listed in the upper panel of the table grew much more rapidly than those in the lower panel over the period under examination. In addition to the growth rate the table also shows the weight attached to each industry — the per centage contribution it made to GNP originating in manufacturing in 1907. Attention to these weights is important in considering the contribution made by the growth of these industries in the overall growth of the economy. The net output of the large iron and steel industry grew at a remarkable 16.7 per cent per year over the decade. The much smaller electrical apparatus industry grew at an even higher rate (19.3 per cent), the chemical industry at 10.3 per cent, and the non-ferrous metal smelting and refining industry at 15.8 per cent. These are stunning rates of growth.[4] One might wonder whether in the case of an industry like non-ferrous metals (in Canada copper, lead, nickel and zinc) attention to value-added in the industry diminishes the apparent importance of the industry since the principal inputs were closely associated and all part of Canadian GNP. The gross output of that industry was a little more than double its contribution to GNP. The rate of growth of gross output, however, was only slightly higher than the rate of growth of value-added (16.7 per cent compared with 15.8 per cent). The rates of growth of these new-tech industries were spectacular, and much higher than those attained by older and more traditional manufacturing sectors. Wood and wood products manufacturing, for example, which had previously been the single largest manufacturing sector, grew at a healthy, but nevertheless lower, rate of 7.1 per cent. Printing and publishing, in an era that saw the great expansion of the daily newspaper, grew by only 3 per cent. Some of the new industries, such as chemicals and electrical apparatus, were quite small in size and did not carry much weight in the aggregate national picture. The steel industry, however, was large and carried a lot of weight. That is why I give it special attention in what follows.

[Table X.3 about here]

One further point relating to the strong and successful performance of the Canadian economy has been made in a recent article by Ian Keay (2000). He shows that from 1907 onward, in a representative selection of manufacturing industries, total factor productivity in Canada was not significantly different from in the United States. That is in contrast to what was long believed to be a gap between Canadian and U.S. performance, a conclusion based on comparisons of output per worker. Lower labour productivity in Canada was evidently offset by higher productivity of capital and, in some cases of material inputs, and also by technological adaptation on the part of Canadian industries to differences in factor prices. Canadian real per capita GDP fell below that in the United States partly because labour productivity was lower in

Canada, but also presumably because of lower productivity in industries other than manufacturing.[12]

If, as I argue, Canadian economic development in this turn-of-the-century period was founded very largely upon the technology of the Second Industrial Revolution, a pressing question is how did the Canadians do it. How did they gain the requisite knowledge to carry off this impressive accomplishment?

Entrepreneurs and Engineers

Two sorts of people were involved in the successful transfer of technology to Canada.[13] These were entrepreneurs and engineers. The country had to have an adequate supply of both. There had to be entrepreneurs who were knowledgeable about the potentialities of the new technology and who had the vision to initiate projects employing it. One can ask how those people became aware of the new prospects and how they knew enough about them to initiate ventures that exploited this technology. This presupposes the existence of a cadre of educated, attentive, and well informed entrepreneurs. Before turning to the question of the supply of engineers, briefly consider first the matter of entrepreneurs. Without focusing specifically on the period under consideration here, it is often generally supposed that the Canadian economy has been weakly supplied with effective entrepreneurs.

Canada may or may not have lacked sufficient entrepreneurs to have initiated many of the projects that exploited the new technology. The issue has never been adequately addressed from this perspective. There is some anecdotal evidence. We can cite instances but we lack quantitative measures or frequencies. What can be said is that whether or not Canada was spawning the needed entrepreneurs of its own, there was an abundance of Americans prepared to do the job. We see good examples of this in the steel industry, an industry which played such a large role in the development of the period. In the case of steel, entrepreneurs from the United States were involved in all the major ventures that provided Canada with an integrated steel industry. It was a group of American businessmen who determined that by the early 1890s it had probably become profitable to produce steel in a modern integrated plant located at Hamilton, Ontario. Iron ore in America was increasingly coming from further west, via the lake shipping of the Great Lakes. The enlargement of the Welland Canal in the late 1880s meant that coal or coke from Ohio and Pennsylvania could also be brought in cheaply. At about the same time that it became attractive to produce steel at Buffalo and Cleveland and Gary, Hamilton became a feasible location. A substantial market for steel had emerged in Canada. Steel was being rolled at Hamilton and at Montreal, moreover it was a tariff-sheltered market. Furthermore, the Government of Canada offered the additional inducement of a bounty on the production of pig iron. In 1893, then, American enterprise, boosted by a healthy local subsidy, initiated the erection of steel plant at Hamilton. The severe depression of the mid-1890s, coupled with natural disaster (the newly erected blast furnace was blown down in a wind) led to the abandonment of this steel venture. At that point the project was taken up by local entrepreneurs and eventually brought to fruition. The driving force then was William Southam, the local newspaper publisher, financially backed by George Gooderham, of the Toronto distilling family. They brought into existence what would eventually be known as STELCO. The initial impetus, however, had come from knowledgeable American entrepreneurs.

At Sault Ste. Marie, Ontario, it was an American visionary, Francis Clergue, who attempted to build a great industrial empire involving hydroelectricity, paper, and chemicals, as well as steel.[15] In his mind Clergue was prepared to implement the entire Second Industrial Revolution at this remote location. Mainly what the Sault had to offer was an abundance of pulpwood and a great hydroelectric power site. There was also the possibility of a large supply of iron ore.[16] Clergue had financial backing from metropolitan America, and hefty subsidization from the Government of Canada. That, in the end, the project did not work out very successfully is another matter.[17] For a while it added greatly to Canada's industrial might.

Another American, Henry Whitney of Boston, had gained control of a major part of Nova Scotia's coal resource. He was blocked in his endeavour to fuel Boston with Nova Scotia coal by the Bostonians' recognition that Nova Scotia coal was dirty and sulphurous. Anti-pollution regulations were enacted to bar its use in the city. Whitney had to look for other uses for his coal and seized upon the idea of steel. Steel was the exciting new technology of the day and its prospects in Nova Scotia were enhanced by the recent discovery of iron ore at tidewater in nearby Newfoundland. In Whitney's scheme there was the prospect of building a great, export-oriented steel enterprise. That he did not know about the problems of quality and extraction cost of Nova Scotia coal, nor was able to keep investment expenditures under sufficient control to make DOSCO a really profitable enterprise is another matter. Whitney quickly sold out to a consortium of Toronto investors. They were prepared to put up funds for what they thought was a promising opportunity but they had not conjured up the idea in the first place. From the perspective of this paper the important point is that again in this case the entrepreneurial initiative had come originally from the United States.

There is a counterbalance to the foregoing story. The real pioneer in modern steel making in Canada was Nova Scotia Steel and its corporate forebears. In 1882 local entrepreneurs opened Canada's first modern steel furnace at Trenton, Nova Scotia, well before the giant enterprises came into existence. This was a product of local, Canadian entrepreneurship, the Drummond and McGregor families of Pictou, with the financial backing of John Stairs of Halifax. It was a successful and profitable firm. It utilized the new Open Hearth technology. Traditionally, however, the achievement of Nova Scotia Steel has been minimized because it was not an integrated plant. Like most of Britain's "modern" steel industry, it produced Open Hearth steel from pig iron smelted elsewhere. It nevertheless represented a successful pioneer endeavour in the transfer of technology, promoted by local entrepreneurs and carried through primarily by local expertise.

Other industries that were built upon important elements of the new technology may provide additional examples of both imported and indigenous entrepreneurship.[18] What we gain from them are stories, often interesting stories, but not systematic evidence that can be used to support a general explanation. The entrepreneurial role in bringing the Second Industrial Revolution to Canada remains, for the present, still largely unexplored. There remains a second issue. How did Canada obtain the technical expertise to carry through the implementation of the new technology? This is a question that concerns the supply of highly skilled manpower — scientists, engineers, and similarly highly skilled persons. The most readily identifiable are the engineers. They may not constitute the whole story but, by their expertise, they comprise a large part of the story. Where and how did Canada obtain the cadre of engineers needed to exploit the new technology of the Second Industrial Revolution? The case may be parallel to that of the entrepreneurs; if engineers were not being produced in Canada, they could always be brought in from elsewhere, particularly the United States. It would be interesting to know if that is really the way it happened.

Economists and economic historians have for the most part paid little attention to the role of engineering expertise in the development of economies. That is especially true for Canada. It has long been customary to emphasize the central role of technological progress in the growth of economies, and economic historians are wont to make the point that they were telling that story long before Solow and other economists came to emphasize it. Initial inventors are identified and accounts given of pioneer applications of the technology but little is said about how the technology diffused, about how the many imitators were able to build entire industries. There is a literature on the emergence of engineering as a profession, and on engineering education. There is also a literature on the history of science that makes frequent reference to engineers. Few writers, however, have directly addressed the issue of the contribution of engineers to economic development. An exception is Ahlström (1982), whose slender book on higher technical education and the engineering profession in the late nineteenth and early twentieth centuries in England, France, Germany, and especially in Sweden stands out as a pioneering contribution. It offers some international comparisons against which the Canadian case can be examined. Rosenberg (1998) has provided us with a careful look at the development of chemical engineering. Besides the early work of Blank and Stigler (1957), which covers engineering along with other scientific personnel, Edelstein (2001) has recently written about the supply of engineers in New York state coming from that state's institutions of higher learning. His investigations of the US case are still at a relatively early stage, but the same author has previously written about the supply of engineers in Australia (Edelstein, 1988). On the whole, however, there has been rather little attention in the literature either to the supply of engineering talent or to its role in the economy. The studies mentioned put their emphasis on engineers produced by institutions of higher learning. Those institutions kept records that are at least in principle accessible, and they often published reports. At the turn of the twentieth century, however, it may be that at least half of the practicing engineers in North America were not the products of formal education in engineering at the university level (Mann, 1918).

With an interest in numbers of people pursuing particular occupations we automatically turn to the decennial census of Canada. The occupational categories reported in the Canadian censuses of 1901 and 1911 identify several types of engineers. In 1901 they totaled a mere 2076, and that included surveyors who were grouped with civil engineers and who almost certainly would have outnumbered the engineers in that category. Engineering was not a common occupation and the number reported would have amounted to a mere 0.39 engineers per thousand people in the nation. The census also identified a few other scientifically oriented people designated as inventors, chemists (but compounded to an unknown extent with pharmacists), and a relatively large number (2583) of metallurgists and assayers. By 1911 the number of engineers of all types had increased to 5610 — in per capita terms almost a doubling (to 0.78 per thousand population) and that figure no longer grouped surveyors (who numbered 1729) with the civil engineers. This clearly was a rapidly expanding occupation. Of the engineers enumerated in the 1911 census, 44 per cent were not Canadian born. It would appear that Canada was heavily dependent upon immigrant engineers although that dependence is to some degree overstated since some of the foreign born would have come to Canada as children and have been trained or educated as engineers in this country. In 1911, 37 per cent of the non-agricultural male work force was foreign born, so engineers were not much out of line with workers of all sorts in their inclusion of people born out of the country. Although I have argued elsewhere (McInnis, 1994) that, in the four decades leading up to 1900, Canada was essentially a nation of emigration, not largely of immigration, there had been a reversal in the years immediately before 1900, and between that year and 1911 immigrants had arrived in large numbers. They included engineers along with farmers, craftsmen and laborers. The older generation of engineers practicing in 1911 also included a good number who had come to this country in the heavy immigration in the years before 1860.

It would be attractive to compare Canada to the United States with regard to the relative numbers of engineers in these early years, however incomparabilities in census classifications make this problematic. In the US censuses of 1890, 1900, and 1910 surveyors are grouped with civil engineers. Electrical engineers are grouped with the much larger number of electricians.

Blank and Stigler (1957) made adjustments to the census numbers to attempt to bring them closer to comparability over time. They deducted an estimated number of surveyors from the count of civil engineers and put forward figures for the total number of engineers in the United States in 1900 and 1910. [19] Those can be compared with the Canadian census numbers for 1901 and 1911. There is a further question of what base should be used to normalize the number of engineers for the purpose of international comparison. Simply to look at numbers of engineers per capita would fail to take into account the greater preponderance of agriculture in the Canadian economy and the lesser need for engineering services in an agricultural economy. It was also the case that the Canadian birth rate was higher and the proportion of young, non-working people higher than in the United States. A more appropriate base for comparative purposes might be the non-agricultural work force of each country. In 1900 the United States had 3.0 engineers per thousand male non-farm workers; in 1910 it had 4.6. In Canada, the ratios for 1901 and 1911, respectively, were 2.48 and 3.88. This comparison does not suggest any great lag of Canada behind the United States in the density of engineers. Furthermore, Canada was narrowing the gap. The evidence presented by Alström (1982) indicates that the density of engineers in France and Germany was considerably greater than in the United States or Canada.

More than just summary census data are needed to inform us about how Canada was supplied with engineering talent in these early years. In what follows I explore three sources of information: the development of engineering schools and the numbers of their graduates; the records of persons notable for their engineering accomplishments, to be found in the *Dictionary of Canadian Biography;* a sample of engineers practicing in Canada in 1911.

University Education in Engineering in Canada

In the mid-nineteenth century engineers trained as apprentices, much like any other craft. Civil engineering, in its original sense of a contrast with military engineering, was as much as anything, an extension of surveying. Some of Canada's most successful engineers were self-taught. Outstanding examples of that are Benjamin Chaffey and George Chaffey Jr. , who are the principal objects of another investigation that I have underway.[20] Both did outstanding work as engineers, yet had no formal training or even much in the way of apprenticeships. Canada also drew notably on immigrants trained in Europe. Well known examples here are Sandford Fleming and Casimir Gzowsky. [21] It was the construction of canals and railways that brought forth the foremost demand for persons with engineering capability. Science, in general, was only beginning to make its way into university education. As technology became more scientifically informed, university education in science came to be more important for scientists and engineers. University programs to provide for that education began to emerge.[22]

McGill University at Montreal pioneered a diploma course in applied science in 1857 but in 1863 it was discontinued when not a single student enrolled.[23] The program was revived in 1871 and from that time forward McGill continuously offered instruction in engineering. By 1874 the McGill program had 33 students, and four years later more than double that. Five students graduated in engineering from McGill in 1874. The early 1870s saw a flurry of interest in applied science education across Canada.[24] In 1872 the Government of Ontario made provision for the establishment of a provincial technical school, separate from the provincial university in Toronto. There was considerable ambiguity as to whether this was to be a school of applied science or of crafts. The former idea won out and in 1878 the School of Practical Science became closely associated with the University of Toronto. It enrolled 7 students. At first it offered only a diploma but in 1884 the degree of civil engineer was established and in 1885 there was a single graduate. This experience may sound paltry but some of the earliest graduates of the Toronto program went on to illustrious careers in the United States and did much to establish the *bona fides* of the program.[25]

In 1874 Laval University, at its Montreal campus, established an *École polytechnique.* It began with 12 students and sent forth its first graduates in 1877. In the same year, tiny King's College in Windsor, Nova Scotia began an engineering program. Dalhousie University initiated a three-year diploma course in 1886. Not to be overlooked was the Royal Military College at Kingston, Ontario. Established in 1876, it was primarily intended to provide scientific training to military officers yet, from the outset, it had the dual objective of producing civilian engineers. Of the 20 or so students per year it turned out up to 1890, a sufficient fraction would have gone into civilian practice as to constitute a significant proportion of the graduate engineers in Canada.

It is evident, however, that prior to the early 1890s engineering education was almost a trifling matter in Canada. There was very little supply, nor for that matter, much demand. Apart from railway building it seems that not much was going on in the Canadian economy that called for scientifically trained personnel. As late as 1900 the dean of engineering at Toronto was suggesting that, with still only 10 graduates per year, his institution was producing more engineers than the economy was absorbing and that a large fraction of his graduates had to emigrate to the United States. The Canadian economy was evidently getting by with little scientific input and calling upon few engineers. The biggest need was probably for metallurgists in the new steel plants and for electrical engineers to plan the electrical generating stations and distribution systems that were beginning to be built.

Things appear to have begun to change, albeit still in a small way, in the early 1890s. New university programs were established. The existing ones experienced large increases in enrolment. In 1892 engineering enrolment at McGill and Toronto, the two leading programs, more than doubled and continued on an upward trend thereafter. The University of New Brunswick established an engineering program that saw its first graduate in 1892. Queen's University at Kingston, Ontario opened an applied science program, for financial reasons nominally as an independently organized School of Mines, and it produced its first graduates in 1897. Table X.4 shows the annual number of engineering graduates in Canada from 1890 to 1914, not including graduates of the Royal Military College. The numbers jump in 1893 but still remain remarkably small until another jump early in the twentieth century. It was not until 1904 that Canadian universities were producing more than 100 newly-minted engineers each year.[26] The net contribution to the stock of scientifically educated engineers in Canada would have been smaller still. People in all walks of life were leaving Canada in large numbers and engineers would have been among them. Still, university engineering programs were on a reasonably solid footing by the early years of the twentieth century and continued to grow. They might best be characterized as growing not ahead of national demand, nor lagging much, but hand-in-hand with it. The 105 graduates of 1904 had doubled by 1908 and had increased by another 70 percent by the time of the outbreak of World War I.

[Table X.4 about here]

Two universities, McGill and Toronto, dominated the engineering scene in Canada from the outset. McGill was the early leader. Toronto lagged considerably, catching up with McGill's output of engineering graduates only in 1908, but by 1914 the University of Toronto had surpassed McGill and was well established as the leading producer of engineers in the country. Two other university programs, the *École polytechnique* in Montreal, the only French language engineering program in the country, and Queen's University at Kingston, Ontario, made up the bulk of the residual.[27] At least on the surface this appears to be a thin basis upon which to build the foundation of engineering expertise upon which the burgeoning Canadian economy depended. It would appear that Canada was getting by on a slender few engineers in the first few years of rapid economic change but may have been producing an adequate supply by the early years of the new century. By 1914 Canada's universities had turned out a cumulative total of 3900 engineering graduates (still not counting the RMC). A not insignificant number of those would have emigrated and, as has always been the case with engineers, some would have abandoned the practice of engineering for a wide range of other pursuits, especially in business management and in public administration.

What the foregoing reveals is that Canada was not seriously failing to produce domestically educated engineers. University programs were in place and were rapidly expanding their output. By 1911 a cumulative total of 2218 engineers had graduated from Canadian universities. It appears that number can probably be fairly reconciled with the 1911 census count of 3157 Canadian born engineers (Canada, Census 1911, vol. 6). There were still numerous engineers active in Canada who had been trained through the old apprentice system although that route to the profession was rapidly disappearing after 1900. The census of 1901 (Canada, Census, 1901) had recorded 2076 professional engineers in the country. Up to that time only 667 had graduated from universities. That would imply 1409 non-university trained engineers of the older generation. If 90 percent of them survived to 1911 we might postulate that in that year there would have been 1268 non-graduate engineers practicing in Canada. By 1911 a cumulative total of 2218 had graduated from Canada's universities. Some of those would have died and more of them would have emigrated, say 22 percent.[28] That would place the estimated stock of Canadian engineers at 2998, and since there might still have been a few shop-trained engineers entering the system, that is a number that is remarkably close to the 3157 Canadian born engineers enumerated in 1911. Too much emphasis should not be placed on that apparently close correspondence. Not all Canadian born engineers would have been educated in Canada. Moreover, the graduates of Canadian university programs would not all have been Canadian born. Nevertheless, it is moderately reassuring that the numerical evidence we have at hand seems to be of the right order of magnitude. What is needed, however, is a richer body of evidence. We would like to know more about the nature of Canadian engineers — where they came from, how they were trained, and what role they were playing in the economy. The main point is that Canada was doing reasonably well in educating a cadre of engineers, and did not evidently lag far behind the United States in that regard.

Evidence from the Dictionary of Canadian Biography

The *Dictionary of Canadian Biography* (DCB) indexes its entries by categories, one of which is engineer.[29] That makes it fairly easy to access accounts of the careers of the small number of Canadians who for one reason or another were prominent enough to get a notice in the DCB. These biographical accounts can be instructive in indicating the kinds of things engineers were doing in Canada at around the turn of the twentieth century. Of course this is a select group, but not always chosen for their engineering accomplishments. Some were war heroes, others were prominent as public servants. Almost all were of an older generation since to get noticed in DCB they had to have died before 1920. One consequence of that is that their contributions to engineering and to the Canadian economy were mostly in connection with an older technology. These men, and of course they are all men, were from the generation of engineers who built the canals and the railways. Some gained prominence in the geological exploration of the country. Only a few represented the electrical and chemical technology of the new age.

Among those whose careers are outlined in DCB are the most prominent and famous of Canada's early engineers: Sandford Fleming, Casimir Gzowski, T.C. Keefer, Andrew Onderdonk, and Thomas Willson. Except for Willson these were all men associated with the surveying and construction of Canada's railways. In the latter half of the nineteenth century that was high on the list of the nation's need for engineers. Willson, as previously mentioned, may be the outstanding case of Canadian contribution to the new technology of the Second Industrial Revolution. Raised in Hamilton and educated at the local high school, Willson moved to New York City to promote his ideas on uses of electricity. Through an attempt to produce aluminum electrolytically he discovered, and patented, a process for making calcium carbide. Willson's patents formed the foundation of what was to become the Union Carbide Corporation. Among the first uses of calcium carbide was the production of acetylene. It was initially thought to hold considerable promise as a lighting gas. Oxyacetylene welding was introduced a bit later, in 1903. Willson sold his US patent rights to Union Carbide, retaining only the Canadian rights, and returned to his native land. There he built and operated several plants to produce calcium carbide, making effective use of cheap hydroelectricity. He settled in Ottawa and continued an active career as an inventor and promoter of new industries. He had developed a low cost way of manufacturing nitrogenous solids that could be used as fertilizer. When an ambitious plan for a chemical, hydroelectric, and wood pulp venture at Shipshaw, Quebec, faltered, Willson's assets were seized by his financier, James B. Duke, who went on to develop the site as an aluminum smelter. Willson started afresh but ran into problems getting financed as World War I had just broken out. While canvassing Wall Street in 1915, Willson died from a heart attack at the prime age of 55.

A small collection of stories about highly selected engineers does not constitute much of a data base. In the three volumes of DCB covering the period 1891 to 1920 there are 51 profiled engineers. Just under one-half (45 per cent) were born in Canada and 39 per cent were British born. Interestingly, only four individuals were immigrants from the United States. [30] The DCB as a source of information is mainly useful for the light it can throw on the detailed nature of the careers of these notable engineers. It also permits us to know something about the more prominent of the earliest engineering practitioners in Canada. Besides the fact already mentioned that they were mostly involved with the laying out of the railway system, we learn that only one-third of them had formal education in engineering or science. Many of them combined engineering with surveying or architectural practices, or had a range of business interests. They were not operating as full-time engineers. In the mid-nineteenth century large projects that required engineers were intermittent. It was common to find employment in the public service, at least for parts of a career, although that may be indicative of the selectivity of DCB. Nevertheless, it appears to be the case that in the latter half of the nineteenth century governments were more reliant upon engineering expertise than were businesses.

Brief examination of a few cases may help to give a sense of who were the engineers and what they did. William Tyndale Jennings, described at the time of his death as the dean of civil engineers in Canada, typifies the older group. He went from secondary education at Upper Canada College, the province of Ontario's most prestigious high school, to an apprenticeship with the Ontario Department of Public Works. After a short stint with the Great Western Railway he worked for Fleming on the survey of the route of the Canadian Pacific Railway. Jennings went on to become chief engineer for the city of Toronto but later took on projects all over North America as a consulting engineer. He acted, for example, as the chief engineer on the construction of the Crow's Nest Pass line of the CPR.

Job Abbott was an American of exquisite qualifications — Phillips Andover and the Lawrence Scientific School at Harvard. He came to Canada as an experienced practitioner, brought in as a consultant to the Toronto Bridge Company, which had been induced into existence by the National Policy tariff in 1879. The following year Abbott was named president and chief engineer of the company, but in 1882 he moved to Montreal to form the Dominion Bridge Company. Abbott was the driving force behind the development of that prominent firm. In 1890 he moved back to the United States where, shortly thereafter, he died at a mere 51 years of age.

Charles Esplin was of Scottish birth but had moved to Canada with his family in 1846. He was an early student of engineering at McGill and established a business erecting grist mills and saw mills. In 1878 he moved to Winnipeg in the expectation of putting up mills during the Manitoba settlement boom. When that boom came to a screeching halt in 1883, Esplin moved to the United States, and while in the employ of a Minneapolis manufacturing company patented several improvements to milling machinery. He moved on to Seattle, to Victoria, then back to Winnipeg in 1897 as engineer to the Vulcan Iron Works. Esplin claimed to have set up Winnipeg's first electrical lighting plant during his earlier stay in that city.

Thomas Macfarlane was born in Scotland and there received a formal education in chemistry, capped by study at the prestigious Saxon Mining School in Freiburg. He moved to Canada in 1860 to be the manager of the Acton Copper Company in Quebec. Five years later he was engaged by the Geological Survey of Canada, and in 1868 discovered and developed Silver Islet in Lake Superior.[5] Later he became a mining consultant to Joseph Wharton at Bethlehem Steel and tried, without success, to interest Wharton in the Sudbury Basin, which later became prominent in the production of copper and nickel. In 1881 Macfarlane was a chemist and coowner of a paint factory in Montreal. Then from 1886 onward he spent the rest of his career as the chief chemical analyst for the Department of Inland Revenue and Customs.

The final example I shall give is Thomas Pringle, a largely self-taught millwright born in Lower Canada. He developed a particular interest in the exploitation of the hydraulic power provided by the Lachine Canal. It seems that he was responsible for installing two-thirds of the 76 turbines emplaced along the canal. Pringle operated as a consultant out of the Caledonia Iron Works at Lachine and seems archetypical of the pioneer type engineer in Canada. Nevertheless, Pringle was highly adaptive and became a pioneer in the use of hydraulic power to generate electricity. His Lachine Rapids Hydraulic and Land Company was among the first to use St. Lawrence river water for that purpose. He 1892 he established T. Pringle and Son, the oldest full-scale firm of consulting engineers in the country. That firm designed the hydroelectric installations at Shawinigan Falls, at Chaudiere Falls south of Quebec City, and at the Long Sault in Ontario. Pringle was a charter member of the Canadian Society of Civil Engineers, formed in 1887.

These individual cases, and numerous others that I have assembled, serve to give something of the flavor of early engineering practice in Canada, and they point up the diversity of experiences to be found. They are far from adequate, however, to support generalizations about the supply of engineers, apart perhaps from showing that the country was capable of producing some prominent and successful engineers.

A Sample of Engineers Practicing in Canada in 1911

A published directory of engineers provides the material for a body of data on just over 400 engineers who were practicing in Canada in 1911. *Who's Who in Engineering* was published in New York, and while it endeavored to provide wide international coverage, it was very largely North American. Quite a large number of Canadians were included. Of the just over 18,000 entries, more than 15,000 of which were engineers from the United States, 705 were engineers in Canada. For each person entered there is a significant amount of useful information. Typically, this included date and place of birth, educational history with an indication of where engineering skills were acquired, the branch of engineering pursued, work histories (commonly with specific dates), and notices of other accomplishments. A geographic index separately lists all those who worked in Canada with their specific places of residence or work at the time the data were assembled.

One might worry that a *Who's Who in Engineering* would be selective of an elite and far from representative of the general run of practitioners of the profession. That does not appear to be the case. The main indicator of that is the large number of young people and recent graduates who are listed. Another is the abundance of engineers of modest situation from small towns and cities. I have no way at present to make formal tests of representativeness but there are no clear signals of alarm. All indications are that the coverage of the data is so diverse that this source should serve to give a good profile of the engineering profession in Canada.

A first edition of *Who's Who in Engineering* came out in 1922. I am working with the second edition, published in 1925, which is the earliest that I have available. This second edition is probably more suited to the task since the appearance of the first edition generated interest in the project and substantially increased the numbers and the range of responses to the next round. The data were assembled over the latter half of 1923 and the first months of 1924.

I have drawn from this listing all of the engineers resident in Canada. The sample of interest to me, however, consists of those who were practicing in Canada in 1911, toward the end of the period of especially rapid growth of the Canadian economy and the initial period of adoption of the new technology that typified the Second Industrial Revolution. To that end I have tabulated the records of 403 engineers whom the records show were active in 1911 and the information on residence and employment relates to that year. One implication is that an important source of bias would be that the data cover only those engineers who continued to be associated with the profession to 1924. Excluded would be those who died in the interval. As older members of the profession they would be more likely to have been trained by apprenticeship and not as likely to have had a university education. They would be more likely to have been born, and even trained, in Britain. Furthermore, they would more likely to have been civil engineers than adherents to one of the newer branches of the profession. Also excluded would have been those who emigrated in the period between 1911 and 1924. There has always been a sizable drain of qualified and ambitious Canadians to the United States, but the departure would also have included proportionally more of those who, in the first place, had immigrated to Canada from the United States. American engineers quite commonly worked in

Canada for periods before returning to their home country. To some unknown extent young American engineers did minor league service in Canada before returning to the majors. Finally there is that large group of people who are trained in engineering but who are drawn off into other lines of activity and who, by 1924, no longer thought of themselves nor reported themselves as engineers. We need to be conscious of the possible effect these biases might have on any conclusions that may be reached.

One might also speculate that the directory might over-represent American and British engineers practicing in Canada because they might have been more motivated to get notice in a directory that would bring them to the attention of their countrymen back home. If such a bias exists it works to my advantage since I shall argue that the proportions of immigrant engineers in 1911 were rather less than we might have been led to expect.

The data from the *Who's Who* sample can inform us on five variables of interest. The results, simply in terms of distributions of each of these five variables, are presented in Table X.5. The first variable of interest is age. For convenience I have categorized the ages of engineers by four groups of birth dates. First there are the "old timers", those born before 1865. They comprised only 9.7 per cent of the sample. It is worth remembering that the youngest of that group would have been only 47 years of age in 1911. Those no older than 36 years in 1911 made up 72 per cent of the sample. Clearly, engineers were predominantly a young lot.

A second variable of considerable interest is country of birth. Fully 70 per cent of the engineers in the sample were born in Canada. British born comprised 16 per cent, and Americans 12 per cent. Canada was evidently not so dependent upon immigrant engineers as has commonly been presumed. It is also interesting that the immigrant engineers were more likely to have been British than American. To some extent that was an echo of the earlier immigration experience of the country. The British by birth in the sample outnumbered the British by training, as we shall see shortly. The proportion of engineers born in the United States and those trained in the United States are more closely balanced. The proportion of engineers who received their training in Canada was two percentage points above the proportion born in Canada. The proportion trained in Britain was 13 percent and that trained in the United States about the same. There were a few instances of Canadians having received their training in Britain or the United States but the numbers are too small to support any generalizations. Some prominent Nova Scotia mining families sent their sons to the Royal School of Mines in London, and Harvard and Yale, with their Lawrence and Sheffield scientific schools respectively, drew a handful of Canadians. Overwhelmingly, though, Canadian born engineers were trained in Canada, either by apprenticeship or in one of the small number of university engineering faculties.

[Table X.5 about here]

Among the Canadian universities, McGill and Toronto, with 31 and 29 per cent of Canadian trained engineers respectively, dominated the national scene. The proportion of Toronto graduates corresponds reasonably with the university graduation records examined previously, but there is a notable shortfall of McGill products. Queen's graduates made up 8.6 per cent of the sample, and those of the *École polytechnique* in Montreal 8.3 per cent. The latter group is smaller than we would expect from the graduation numbers but it is not surprising that the *Who's Who* would draw fewer French Canadians. The Royal Military College provided the training of 4.8 per cent. That allows us to fill in a gap in the university graduation records and the number is quite plausible. All other Canadian university programs together made up 8.2 per cent, leaving 9.7 per cent of engineers to report apprenticeships or other practical arrangements. That leads me to worry about a possible bias in the sample. Charles Mann, writing in 1918 in his *Study of Engineering Education* for the Carnegie Foundation and the National Engineering Societies (Mann, 1918), claimed that, at that time, "about half of the engineers in America were shop-trained, not school-educated." Mann's reference total of engineers, from the U.S. census of 1910, includes surveyors, and electricians along with electrical engineers. The latter is a particularly egregious complication. It may well have led him to overcount engineers in his guess of 80,000. He reported (Mann, 1918, p. 18) that membership in all engineering societies together amounted to 53,000 and that would probably have been an undercount of the total. Taking that latter number as the total, however, would still place 25 per cent of engineers in the United States as having been trained other than in universities and colleges. The much lower Canadian figure — just under 10 per cent — may reflect the younger age and greater recency of engineering training in Canada, or it may also be a reflection of a less extensive development of earlier manufacturing in Canada that would have meant fewer "shops" to provide training.

With regard to branches of engineering, it is not surprising that almost one-half (47 per cent) of Canadian engineers classified themselves as civils. What is most interesting is that the next most frequent type, with 20.7 per cent, was electrical engineering. Mining engineers comprised 16.9 per cent of the total, and mechanicals only 10.1 per cent. I cannot escape the suspicion that mechanical engineers may have been undercounted. The 1911 Census of Canada recorded a somewhat larger number of mechanical than of electrical engineers. That census, however, placed 30 per cent of all engineers in the "branch not specified" category. Two hypotheses require further investigation, if appropriate data can ever be found. One is that *Who's Who in Engineering* systematically under-represented mechanical engineers relative to other types. The second hypothesis is that Canada may have had a sparse density of mechanical engineers, at least in comparison with the United States and possibly other industrial nations. There are indications from the histories of Canadian engineering schools to give a bit of support to this second hypothesis. At both Toronto and McGill mechanical engineering appears to have taken a back seat to other branches. Civil engineering was everywhere the largest program, but electrical and mining got more attention than mechanical. There are also comments made by engineering deans that Canadian manufacturers were backward in appreciation of trained mechanical engineers. By contrast, firms had little hesitation in engaging electrical engineers when they came face to face with the electrification decision. The prominence of mining engineers parallels the emphasis given to geology in Canadian science in the late nineteenth century. There seems to have been a perception that Canada had surely been amply endowed by nature. All that was required was to explore and discover. Great iron deposits were a foremost hope but it was not until well into the twentieth century that those would be found. A shortfall of mechanical engineering may represent an adaptation to the evident demand for engineers in Canada. At the same time it may have constituted a weak foundation for the development of a wider range of manufacturing industry.[32]

A final tabulation of Canadian engineers in 1911 categorizes them by the nature of their employment. Almost one-fifth were in private practice as engineering consultants. A similar proportion worked for governments. The railway companies were a large employer of engineers and we have to keep in mind that in 1911 Canada was going through a peak period of railway construction. The largest fraction of immigrant engineers were recent arrivals brought into the country to lay out new railway lines and to supervise their construction. These immigrant railway engineers were much more likely to have come from Britain than from the United States. The situation was accentuated in the years immediately to follow. In focusing the sample on engineers practicing in Canada in 1911, I set aside registrants in the 1925 *Who's Who* the ones who had graduated from college and entered engineering practice after 1911, and those who immigrated to Canada subsequent to that date. Almost all of the immigrants had come prior to the outbreak of World War I. The number was large, amounting to 23 per cent of the number of immigrant engineers in my sample who were active in 1911. The records show that a large proportion of these immigrants were employed by the railways.

Almost 10 per cent of engineers worked for electrical utilities. This was a time when the country was feverishly electrifying. Indeed that was an outstanding feature of the Second Industrial Revolution. It shows up in the allocation of engineering talent. Not only were 10 per cent of engineers working for electrical utilities but many of those in private consulting practices were involved with electrification as well.

The largest category of employment, with 35 per cent of all engineers, is a residual representing largely mining and manufacturing industries. No single sub-category of this residual appears to be large enough to tabulate separately. Many of these engineers were also involved with one or another aspect of electrification. Some were manufacturing electrical apparatus, others were organizing production processes to make use of electricity. Electrolytic smelting was being applied to a whole range of mineral products. Remotely located pulp and paper mills were among the earliest users of electrical power. Canadian General Electric and Westinghouse of Canada stand out in the manufacturing sector as employers of engineers. Both of these companies appear to have relied quite heavily upon engineers brought in from the United States although they also employed senior engineers who were born and educated in Canada. In both cases these were employees whose work histories showed that they had spent some time with the parent company in the United States. The work histories of the engineers in this "other employer" group reinforce my sense that there was a paucity of mechanical engineers in Canada. There were very few who reported being employed by the prominent machinery manufacturing firms, and there was not a single representative from the nascent automobile industry.

Much engineering was done on a project by project basis. Engineers were engaged to design and oversee the setting up of new plants. Once those were completed they would move on to other projects. As early as the late nineteenth century there appears to have been a well-established industry in engineering consulting, augmented by numbers of highly mobile employed engineers. This was probably an effective way of allocating scarce scientifically skilled resources. In North America this industry operated on a continent wide basis. It is an industry that has so far attracted little attention from scholars. Only by extensively examining business histories and business records will it come to be seen how important, quantitatively, was this aspect of the engineering trade. It is a good guess that the Canadian economy was able to draw upon the full extent of consulting engineers in the United States to augment whatever demands could not be met by Canadian domiciled engineers. The employment histories related by the respondents to *Who's Who in Engineering* reveal considerable mobility both across employers and across localities.

Concluding Remarks

Only very tentative conclusions can be reached from this survey of the pieces of evidence relating to engineering expertise in Canadian industrialization. This is not a topic on which there is much of an established literature to relate to. My study is more in the nature of a preliminary survey. Because Canada evidently succeeded so well in exploiting the technology of the Second Industrial Revolution, it should not be surprising that the evidence suggests that, overall, Canada was generating an adequate supply of engineers. That claim has to be qualified, however, by the fact that Canada's unusually rapid economic growth got underway in the late 1890s, before the domestic supply of graduate engineers had been much developed. Shortly thereafter, Canada's engineering schools were developing vigorously and a good supply of engineers was being domestically produced. In that earlier period, though, domestic university graduates must have been considerably supplemented, either by "shop-trained" engineers or by purchased consulting services, primarily from the United States. We should also take into account the fact that it seems that a quite small number of engineers played key roles in the development of many of the new industries. For example, one man, Alexander Holley, was responsible for the design and construction of most of the Bessemer steel plants built in the United States (see McHugh, 1980). A relatively small number of large hydroelectric installations dominated the Canadian scene. They may not have required many engineers to design and erect and it should be possible to trace the key individuals involved. Larger numbers of engineers may have been required for the continued operation of the new technology than for the initial implementation.

Especially with regard to the new technology, Canada does not appear to have been acutely dependent upon immigrants. The country appears to have been doing particularly well in implementing the electrical technology and it was making good use of its forest and mineral resources. The one serious question mark relates to mechanical engineering and the provision of adequate support for mechanical types of manufacturing. An important point that has to be recognized is that engineering services were being traded internationally in an extensive way. We know that Canadian engineers were engaged on projects throughout the world, but especially in Latin America. Canadian engineers routinely consulted on projects in the United States. That was especially the case with mining engineers. They ranged freely around the globe on a project basis. What we do not yet know is the extent to which Canadian businesses were purchasing engineering services internationally, particularly from the United States. That is something that will have to be determined by evidence from the demand side of the market although a survey of engineering consulting firms in the United States would also be helpful.

This paper has focused especially on the supply of engineering expertise. It has brought together some data that have not been previously looked at in this context. It has pointed up an important issue in Canadian economic development that needs more attention. The main thing it records is that Canada appears to have done reasonably well in generating a supply of engineers. It would be helpful to gather information from the other side of the market, to look at individual businesses and industries to inquire into their sources of engineering expertise, and the extent of their needs for it. That will be a time consuming enterprise of delving into business histories. I have done some of that for the principal industries, especially steel and pulp and paper, but Canada has not been abundantly served with published business histories and so I see a task that will be long and difficult. In the meantime, it should be helpful to have made a start at exploring the supply side. We are able to gain some perspective on the nature of the supply of engineers that Canada was able to assemble. That allows us to garner some sense of the complex detail that underlay the implementation of the fruitful new technology and to have some appreciation of how Canada was able to make such impressive productivity gains from it.

Footnotes

1.The long-appreciated fact that between 1897 and 1913 real per capita income grew more rapidly in Canada than in any other nation is sustained by Angus Maddison's most recent manipulations of the data (Maddison, 1995). That conclusion would not seem to be altered by the alternative treatment of international comparability proposed by Leandro Prados, although Prados provides data only for 1890 and 1900 as well as 1913 (Prados, 2000).

2. There is no thoroughgoing, up to date, study of electrification in Canada. For one part of central Canada the topic is examined by John Dales (1957). Some aspects of the topic for the province of Ontario are covered by H.V. Nelles (1974). One aspect of the topic, dealing specifically with productivity, but mainly for a slightly later time period, is dealt with by Peter Wylie (1989).

3. The outstanding example is the chemically based manufacture of paper from wood, but the interrelation between chemical processes and cheap electricity was also significant. Examples are the electrolytic production of calcium carbide and the electrolytic smelting of non-ferrous metals.

4. A decade is an admittedly rather short period of time. One might wonder whether international comparisons may be sensitive to the precise period chosen. That is not the case. Comparisons over various periods do not alter the conclusion. An examination of the growth record of many countries shows that really rapid growth often occurs in spurts. It is not usually

sustained over very long periods. In the Second Industrial era, broadly defined, no country outperformed Canada. Italy came closest to the Canadian growth performance. That country appears to have avoided the depression of 1907/08 and continued to grow rapidly through 1911. The peak period of Italian growth was between 1898 and 1911 when that country grew at an average rate of 4.19 per cent — closer to, but still not exceeding the Canadian performance. No other country comes really close. The peak rate of growth for the United States at this time was 3.32 per cent per annum.

5. The data are from Mitchell (1998).

6. Industrialization in Canada can be examined in terms of GNP originating in what is effectively the two-digit industry level. The available numbers are in current dollars and there do not presently exist industry-specific price series to convert these to an index of industrial production. The numbers can, however, be deflated by the same aggregate price index as is used for GNP so as to remove the effects of change in the value of money. A comparable calculation made for the United States in the same period using data from Kendrick (1961) generates a rate of change of industrial production that is virtually identical to that reproduced in Mitchell (1998).

7. The elaboration of this argument is the main subject of McInnis (1999).

8. This is not to imply that I subscribe to Rostow's model of the "take off." Gerschenkron, however, was probably on to something in emphasizing, as did Schumpeter, that economic

growth comes in discernible spurts. Those early ideas about the growth process are readily absorbed into the emphasis given to determinate “shocks” in the writings of the New Growth theorists.

9. It is most common to think of the extent of industrialization in terms of the structure of the economy — the proportion of total output accounted for by manufactured goods. It is quite true that in that sense Canada was still a predominantly agricultural economy. In 1890 manufacturing accounted for only 26 per cent of Canada’s GDP while agriculture, fishing and forestry made up 31 per cent. It is less common, but no less instructive, to look at GDP originating in manufacturing per person in the country. It is by that standard that I state that Canada was already a highly industrialized country.

10. One should not think of these industries as unaffected by the technology of the Second Industrial Revolution. Cotton textile factories in Canada, for example, were among the first to install electric lighting. Open-flame lighting had been a particular hazzard in cotton mills. Printing establishments were among the first to use electric motors to drive their machinery. Light, battery-driven motors could be used with printing machinery, and the publishing industry was in the forefront of electrification, well before the end of the nineteenth century. The newspaper in St. Catharines, Ontario was the second printing plant in all of North America to use electric motors (Biggar, 1920, p. 32).

11. They are not, it should be emphasized, simply the mechanical result of starting from a small base. The iron and steel industry already by 1897 contributed 21.71 per cent of manufacturing output, and the non-ferrous metal industry 5.56 per cent. Electrical apparatus manufacturing and rubber products were, indeed, small new industries but they did not grow notably faster than the larger, established industries.

12. This latter point is consistent with the findings of Broadberry (1997) relating to productivity differences between the United States, Britain and Germany.

13. This is a transfer of technology because Canadians contributed little in the way of inventions to this new technology. What might be regarded as the very leading edge of the technology of the Second Industrial Revolution had been contributed by a Canadian. Nova Scotian Abraham Gesner had found a use for crude petroleum when he patented the illuminating oil that he called kerosene and thereby kicked off the development of the world petroleum industry. That was in 1855, and by the late nineteenth century, petroleum and its products were a long-established part of the economy. While it has many of the characteristics of Second Industrial Revolution technology, kerosene was part of an earlier age. No comparable invention was made by a Canadian to contribute to the new technology. The closest contender might be the development by Thomas Willson of the process for synthesizing calcium carbide.

14. The standard reference on the steel development at Hamilton is Kilbourn (1960), See also Donald, (1915).

15. The development of the Algoma Steel Corporation is covered by McDowall, (1984).

16. This turned out to be chimerical. The Helen Mine near Wawa, Ontario proved to have intractable ore.

17. Within a very few years the Algoma Steel Corporation entered its first of several bankruptcies. In late 2001 it was being rescued once again by large subsidies from both the Province of Ontario and the Government of Canada.

18. Electrical apparatus manufacturing also involved much American entrepreneurial direction. Both General Electric and Westinghouse played a large role in the Canadian industry through subsidiary plants. Smaller firms, like the Packard Electric Company that made transformers, were also American owned. Some of the earliest developments, however, were made by indigenous Canadian firms that later got absorbed by the large American concerns.

19. I am convinced that their adjustment, based on the relative numbers of civil engineers and surveyors in 1930, is surely too small. The proportion presumed to be surveyors is much smaller than in Canada in 1911 where the census separately tabulated surveyors and civil engineers. On the other hand, it is unclear what Blank and Stigler (1957) did about electrical engineers and they may not enter their total at all. The two miscounts would be to some degree offsetting so their estimate of the total number of engineers may not be too far off the mark.

20. Benjamin Chaffey of Brockville, Ontario was active around the middle of the nineteenth century as an architect, engineer, contractor and manufacturer. He supervised the construction of canals on the St. Lawrence River, operated a factory that manufactured lock gates for canals, contracted a section of the Grand Trunk Railway of Canada, and designed and built many of the stone piers upon which the Grand Trunk's Victoria Bridge at Montreal rested. To carry out that last project he designed a unique traveling crane for which he gained considerable fame. His engineering skills were entirely self-taught. His nephew, George Chaffey, Jr., of Kingston, Ontario was largely self-taught as well, although inspired by his uncle. George, Jr. designed and built steamships for the Great Lakes, for which he gained notice in the *Scientific American*, before going on to lay out irrigation projects in California and Australia and, in 1884, to found the Los Angeles Electric Company.

21. Sir Sandford Fleming was a Scottish trained immigrant who gained prominence as the principal surveyor and chief engineer of the Intercolonial Railway of Canada. He is also well known for his international campaign for standard time zones. In the late nineteenth and early twentieth centuries he was probably Canada's best known engineer. Sir Casimir Gzowsky was an engineer and military officer exiled from Poland for his role in an insurrection. He was an early promoter of railway development and carried out the construction of a part of the Grand Trunk Railway of Canada.

22. The literature on the development of engineering education in Canada is sparse. I have been aided considerably by the unpublished PhD dissertation of Mario Creet (1992). The published

histories of the individual institutions are scanty on the development of engineering. Young (1958) on the University of Toronto is more substantial than most of what is available. Harris (1976), has a succinct chapter on engineering and, fortunately, has tabulated the annual number of graduates of all the universities with engineering programs.

23. At about the same time King's College in Fredericton, shortly to become the University of New Brunswick, offered instruction in civil engineering under the guidance of a recently arrived British engineer. Only a tiny handful of students pursued the program.

24. The 1870s was a prime decade for the establishment of university engineering programs in the United States. It appears that Canada did not lag notably in starting university programs in engineering. The numbers, however, were small.

25. E.W. Stern was one of the very earliest graduates of Toronto's engineering school. He and Kennard Thomson (class of 1886) became renowned for their foundation designs for large New York buildings.

26. At that time, according to Ahlström (1982, p. 107), Germany was producing about 4400 new engineers per year and France more than 1400. Sweden, a country slightly smaller in population than Canada, was turning out about 175. In the United States, the institutions of New York state alone were producing more than 400 engineers per year (Edelstein, 2001, Table 10).

27. In Sweden, however, which produced more engineering graduates than Canada at the time, there were only two schools.

28. That proportion is based on the ratio of Canadian born engineers living in the United States in 1910 to the number in Canada at the time. The calculated ratio is 19.7 percent but electrical engineers could not be taken into account and they were younger and somewhat more likely to have emigrated. A figure of 22 percent seems reasonable.

29. The *Dictionary of Canadian Biography,* Francess G. Halpenny and Jean Hamelin, general editors, is an on-going project in several volumes. Volume XII, covering persons who died between 1891 and 1900, was published in 1990.

30. It should be clarified that one did not have to die in Canada to be included in DCB. Two of four Americans returned to the United States before they died, but they had engineering careers in Canada.

31. Silver Islet was one of Canada's first consequential metal mines. It was a tiny island of about fifty meters in each direction from which a very large amount of silver was extracted. An American engineer was brought in to tackle the formidable task of developing the site and the mine workings under the severe conditions encountered.

32. One might turn this into a path dependency type of argument. Adapting to the manifest need for electrical and mining engineers, Canadians may have left themselves deficient of the mechanical engineering expertise that would have allowed them to take fuller and wider advantage of all aspects of the new technology. Some commentators have long bemoaned a lack of greater development of machinery manufacturing industry in Canada. Whether or not that is a valid concern is arguable but we may here have a glimpse of one reason.

References

Ahlström, Göran (1982), *Engineers and Industrial Growth* (London: Croom Helm).

Biggar, E.B. (1920), *Hydro-Electric Development in Ontario* (Toronto: Biggar Press).

Blank, David M. and George J. Stigler (1957), *The Demand and Supply of Scientific Personnel* (New York: National Bureau of Economic Research).

Broadberry, S.N. (1997), *The Productivity Race: British Manufacturing in International Perspective, 1850-1990* (New York: Cambridge University Press).

Canada, Department of Agriculture, 1901 Census of Canada (1910), *Occupations of the People* (1901 Census Bulletin XI, Ottawa: King's Printer).

Canada, Department of Trade and Commerce, 1911 Census of Canada (1915), *Fifth Census of Canada, Volume VI: Occupations of the People* (Ottawa: King's Printer).

Creet, Mario (1992), *Science and Engineering at McGill and Queen's Universities and at the University of Toronto, 1880s to 1920s* (Kingston, Ontario: unpublished Queen's University PhD thesis).

Dales, John (1957), *Hydroelectrivity and Industrial Development in Quebec, 1898-1940* (Cambridge, MA: Harvard University Press).

Dictionary of Canadian Biography, Francess G. Halpenny and Jean Hamelin, general eds (Toronto: University of Toronto Press, various dates).

Donald, W.J.A. (1915) *The Canadian Iron and Steel Industry* (Boston: Houghton Mifflin).

Edelstein, Michael (1988) "Professional Engineers in Australia: Institutional Response in a Developing Economy, 1860-1980," *Australian Economic History Review*, 28, pp. 8-32.

_______, (2001) "The Production of Engineers in New York Colleges and Universities, 1800-1950," (paper presented to the Rochester Conference in honor of Stanley Engerman, June 8-10, 2001).

Harris, Robin S. (1976) *A History of Higher Education in Canada, 1663-1960* (Toronto: University of Toronto Press).

Keay, Ian (2000) "Canadian Manufacturers Relative Productivity Performance, 1907-1990," *Canadian Journal of Economics*, 33, pp. 1049-68.

Kendrick, John W. (1961) *Productivity in the United States* (New York: National Bureau of Economic Research).

Kilbourn, William (1960) *The Elements Combined, A History of the Steel Company of Canada* (Toronto: Clark, Irwin and Co.)

Maddison, Angus (1995) *Monitoring the World Economy*, *1820-1992* (Paris: OECD).

Mann, Charles (1918) *A Study of Engineering Education* (New York: National Engineering Societies).

McHugh, Jeanne (1980) *Alexander Holley and the Makers of Steel* (Baltimore: Johns Hopkins University Press).

McInnis, Marvin (1994) "Immigration and Emigration: Canada in the Late Nineteenth Century," Ch. 7 of Timothy J. Hatton and Jeffrey G. Williamson, eds, *Migration and the International Labor Market, 1850-1939* (London: Routledge).

Mitchell, Brian (1998) *International Historical Statistics: Europe,* 4th edn (London: Macmillan)

Nelles, H.V. (1974) *The Politics of Development: Forests, Mines and Hydroelectric Power in Ontario, 1849-1941* (Toronto: Macmillan of Canada).

Prados de la Escosura, Leandro (2000) "International Comparisons of Real Product, 1820-1990: An Alternative Data Set," *Explorations in Economic History*, 37, pp. 1-41.

Rosenberg, Nathan (1998) "Chemical Engineering as a General Purpose Technology," Ch. 7 of E. Helpman, ed., *General Purpose Technologies and Economic Growth* (Cambridge, MA: MIT Press).

Urquhart, M.C. (1993) *Gross National Product, Canada, 1870-1926: The Derivation of the Estimates* (Kingston and Montreal: McGill-Queen's University Press).

Who's Who in Engineering (1925) 2nd ed. (New York: Who's Who Press).

Wylie, Peter (1989) "Technological Adaptation in Canadian Manufacturing, 1900-29,"*Journal of Economic History*, 49, pp. 569-91.

Young, C.R. (1958) *Early Engineering Education at Toronto, 1851-1919* (Toronto: University of Toronto Press).

Tables

Table X.1 Comparative Real Per Capita Income Growth, Selected Industrialized Countries
(Average annual rates of growth)

	1897-1907	1897-1913
Canada	4.43	3.63
Australia	3.05	2.58
Belgium	0.96	1.02
Denmark	2.01	1.97
Finland	1.23	1.65
France	1.52	1.75
Germany	1.62	1.74
Italy	3.85	3.22
Japan	2.24	1.68
Netherlands	- 0.44	0.37
New Zealand	3.05	1.67
Norway	0.91	1.66
Sweden	2.28	2.29
United Kingdom	0.93	0.90
United States	3.00	2.15

Source: Sweden, unpublished revised estimates from Lennart Schön; all other countries, Maddison (1995)

Table X.2 International Comparative Growth of Industrial Output
(Average annual rates of growth)

	1897 - 1907			1897 - 1913		
	I*	Pop	Ipc	I*	Pop	Ipc
Canada	8.02	2.27	5.75	6.29	2.52	3.77
United States	6.68	1.88	4.80	5.76	1.88	3.88
Austria	4.00	1.03	2.97	3.33	0.99	2.36
Germany	4.07	1.47	2.60	4.06	1.41	2.65
France	1.75	0.15	1.60	2.57	0.17	2.40
Italy	5.45	0.74	4.71	4.06	0.74	3.32
Sweden	4.75	0.72	4.03	3.45	0.75	2.70
Japan	3.11	1.13	1.98	4.05	1.21	2.84

I* Industrial production
Pop: population
Ipc: industrial production per capita

Source: Canada, calculated from M.C. Urquhart (1993); all other countries from Mitchell (1998)

Table X.3 Growth Rates of Industrial Sectors in Canada, 1897-1907

	Average Annual Growth Rate	Percent of Manufacturing Output
Technologically Impacted Industries		
Rubber products	9.64	0.81
Paper	8.25	2.44
Iron and steel	16.70	21.71
Non-ferrous metals	15.80	5.56
Electrical apparatus	19.30	1.44
Chemicals	10.30	2.77
Industries Little Affected		
Primary textiles	1.68	3.37
Clothing	6.17	9.61
Leather products	- 0.84	4.93
Wood and wood products	7.10	16.78
Printing and publishing	3.00	3.05

Source: Calculated from Urquhart (1993)

Table X.4 Engineering Graduates of Canadian Universities, 1891-1914

Year	Total	McGill	Toronto	EP*	Queen's	Other
1891	14	11	-	3	-	-
1892	22	17	1	3	-	1
1893	41	18	10	7	-	6
1894	41	23	12	2	-	4
1895	43	30	11	-	-	2
1896	48	33	9	5	-	1
1897	50	41	5	-	2	2
1898	81	42	9	25	3	2
1899	65	41	6	14	1	3
1900	58	36	10	4	4	4
1901	86	40	20	22	3	1
1902	72	30	15	7	14	6
1903	96	41	16	17	18	4
1904	105	53	19	13	14	6
1905	117	43	24	16	21	13
1906	139	64	28	14	19	14
1907	169	62	31	28	35	13
1908	213	89	50	30	34	10
1909	229	82	67	31	43	6
1910	265	108	64	33	42	18
1911	294	100	99	43	42	10
1912	364	97	129	55	67	16
1913	354	106	106	63	59	20
1914	364	115	151	41	42	15
pre-1891	164	140	3	10	-	11
Total to 1914	3300	1322	892	476	433	177
Total to 1911	2218	1004	506	317	265	126

* École polytechnique

Source: Harris (1976)

Table X.5 Summary of Evidence on Engineers in Canada in 1911

X.5.1 Period of Birth

Pre - 1865	9.7%
1865-1874	18.2%
1875-1885	49.1%
1886 +	23.0%

X.5.2 Country of Birth

Canada	69.7%
Britain	16.1%
United States	11.9%
Other	2.3%

X.5.3 Training

Britain	12.9%		
United States	13.2%		
Canada	72.1%		
		McGill	31.0%
		Toronto	29.3%
		Queen's	8.6%
		École polytechnique	8.3%
		RMC	4.8%
		Other universities	8.2%
		Non-university	9.7%

X.5.4 Branch of Engineering

Civil	47.0%
Electrical	20.7%
Mining	16.9%
Mechanical	10.1%
Forest	2.0%
Other	3.3%

X.5.5 Employment in 1911

Private practice	19.0%
Railways	16.7%
Electrical Utilities	9.7%
Government	19.2%
Other	35.4%

Source: Tabulated from *Who's Who in Engineering*, 2nd ed. (New York: Who's Who Publications, 1925).