Success by Proxy: The Role of Patents in Canadian Adaptation

by

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Introduction

Researchers studying Canadian innovation during the early twentieth-century can be divided into two distinct groups. The first, often referred to as nationalists, argue that Canadian industrialists passively received American or European technology whether or not it was appropriate to the Canadian environment.[1] According to this view, Canadians did not adapt foreign technology to Canadian conditions. Nationalists envision a Canadian manufacturing sector that was technologically dependent, inefficient and backward. The second group, continentalists, argue that foreign technology was not passively received but actively adapted to improve Canadian productivity and competitiveness (Wylie 1989, pp. 572).[2]

The nationalist-continentalist debate was an important feature of the twentieth-century literature on Canadian productivity; however, some recent rigorous empirical work, notably by Peter Wylie and Ian Keay, has quieted this debate. By applying formal product and cost functions, Wylie (1989) and Keay (2001) have provided strong evidence of the innovative nature of Canadian industrialists. Their results have firmly supported, if not confirmed, the continentalist view that Canadian manufacturers used a different technology than U.S. firms by adapting U.S. technology to domestic conditions. A central work on this topic is Wylie's 1986 doctoral dissertation, and his related articles, on technological adaptation. More recently, Ian Keay has enhanced our knowledge on Canadian innovation. However, there are still facets of the debate that have remained unexplored.

The purpose of this essay is to further our understanding of Canadian inventiveness by focusing on patent records. This approach represents a departure from past work on technological change, certainly in the Canadian context. The techniques utilized in previous work have never attempted anything more than a superficial pass through patent records. Wylie

[1] Nationalist writers include: Naylor (1975), Williams (1982), Watkins (1970), and Levitt (1971).

[2] Continentalist writers include: Mackintosh (1933), Johnson (1962), Chambers and Gordon (1966), Aitken (1962) and Dales (1966). Wylie (1986) and Keay (2001) have recently analyzed the debate; their results tend to support the continentalist view

(1986), who is one of the only continentalist authors to mention patents, dismisses patents without any exploration of the data. Naylor (1975) uses patent evidence to support the nationalist argument but presents only limited evidence.

While estimates of production functions suggest that Canadian technology differed from that in the United States, it is unclear how Canadians were successful in altering U.S. technology to suit domestic conditions. Analysis of inventive activity reveals a very different story from that implied by Wylie. By looking at electricity-using inventions in both Canada and the United States, I find that Canadians, at least in the realm of patented inventions, had very little involvement in adapting technologies to fit their resource endowments. Instead it appears nearly all the inventive activity took place in the U.S. and Europe. This foreign technology was brought to Canada and, if continentalists are correct, adapted to the Canadian environment by American inventors. Thus, foreign inventors may have been inventing to suit their own domestic economy while simultaneously making inventions available to Canadians. More specifically, foreigners were making available a pool of technical knowledge that may have advanced the process of cost minimization in Canadian manufacturing.

The Nationalist-Continentalist Debate

The nationalist-continentalist debate is an important aspect of the economic history of Canada in the early twentieth-century. Nationalists have proposed that industrialization in Canada occurred in the absence of indigenous technological change, relying on foreign technologies that were at times inappropriate to local conditions. According to this view, institutional constraints limited the development of indigenous innovation and fostered dependence on foreign technology (Wylie 1989, p. 572). The transplantation of technology into Canadian manufacturing was cost inefficient. Naylor (1975, p. 38) describes the evolution of Canadian industrialism as, "inefficient, non-innovative and backward...with a penchant for dependence on foreign techniques."

Nationalists argue that foreign control of Canada's industries reduced the capacity of domestic producers to adapt imported technology to local conditions. They suggest that government deficiencies, insufficient research funding, and a weak capital goods sector promoted the importation of technology that was domestically inappropriate, while limiting the ability of Canadians to adapt this technology (Wylie 1989, p. 572). The high level of foreign ownership in Canadian manufacturing, the ability of foreign industrialists to obtain patents for technology that was engineered for foreign conditions, and the low percentage of industrial machinery produced in Canada all support the nationalist view. Other evidence, however, paints a very different picture.

Continentalists hold that industrialization in Canada was successful due to the early emergence of a domestic technical capability. They argue for indigenous adaptation and the successful application of foreign technology (Wylie 1989, p. 572). According to Wylie, "The course of Canadas industrial history was directed by the degree of indigenous technological change, the installation of new imported technology, and especially the utilization of imported technology under local conditions." In effect, foreign technology, developed under foreign factor prices, was imported into Canada and reshaped by incremental adaptive changes.

Evidence of the continentalist view is present throughout economic and business literature. Wylie, Keay, and others, have attested to the adaptive nature of Canadian industry in the early twentieth-century.[3] Contemporary government reports, as well as business and engineering publications, have confirmed the significance of foreign technical knowledge and its subsequent adaptation and absorption within Canadian firms (Wylie 1989, p. 573). However, both theoretical and empirical evidence is needed in order to understand the tech-

[3]See Wylie (1989), Keay (2000), Mackintosh (1933), Johnson (1962), Chambers and Gordon (1966), Aitken (1962) and Dales (1966).

nological adaptability of Canadian industrialists. The literature on induced innovation forms the framework necessary to approach the debate over Canadian technological development.

Induced Innovation and Biased Technical Change

The theory of induced innovation has been an integral tool in the debate surrounding Canadian adaptability. The induced innovation approach takes technical change as endogenous to the economic system (Wylie 1986, p. 51). According to the theory of induced innovation, changes in factor prices can induce specific changes in the pattern of inventive activity. In a sense, relative factor prices are a determining force in the process of innovation. If continentalists are correct, the process of induced innovation must have played a key role in the technological development of Canadian industry. Alternatively, if nationalists are correct, induced innovation was not part of the Canadian manufacturing experience.

Figure 1 displays a simple induced innovation mechanism for technical change.[4] In this figure the firm produces a level of output given by its production isoquant f_{11}. Underlying this isoquant is a menu of production technologies given by the Fundamental Production Function F_1.[5] The Fundamental Production Function depicts a "range of alternatives derived from all possible designs from the huge body of existing relationships that make up the stock of existing knowledge."[6] Thus, a movement from one point on the current Fundamental Production Function to another point on the same FPF does not require any advancement in existing knowledge. Alternatively, a movement from one point on the current Fundamental Production Function to another FPF must involve the attainment of knowledge. An Induced change in technology can be depicted as the movement from one isoquant on the FPF to

[4] All figures in this thesis are derived from, but not copies of, materials presented in Wylie (1986), Wylie (1989) and Ahmad (1966).

[5] The Fundamental Production Function is also referred to as a Metaproduction Function or an Innovation Possibilities Curve. This thesis will use the term Fundamental Production Function (FPF) in order to conform to Wylie (1986).

[6] Salter 1960, p. 15

another. This movement, however, does not require an increase in the pool of knowledge.[7]

In contrast to induced innovation, factor substitution is the movement from a point on an isoquant to another point on the same isoquant. This type of substitution represents the cost minimizing response to a change in factor prices. In Figure 1 this is shown to be a movement from point A to point B, in response to a change in the factor price ratio from P_1 to P_2. Induced innovation is shown to be a movement from point B to point C, in response to the same change in the factor price ratio.[8] Therefore, induced innovation requires the movement from isoquant f_{11} to a new isoquant.[9] Thus, the theory of induced innovation stresses a theoretical, rather than empirical, distinction between a movement along the short run production function and a shift to a new short run production function on the FPF. This process is represented using a cost minimizing neoclassical framework.

Induced innovation initiates a process of technical adjustment that goes beyond factor substitution. Such innovation tends to save on factors whose relative prices have risen and exploits factors whose relative prices have fallen (Wylie 1986, p. 56).[10] While the movement to a new isoquant reduces costs by optimizing the mix of factor inputs, the process of technological development is not costless, as it requires the development of new production technologies. Although the existing knowledge allows for the development of new technology, it does not imply that new technology is contemporaneously available in a usable form. As pointed out by Wylie, "each new process on the FPF requires resources be spent in process engineering to the point when the process can be used (Wylie 1986, p. 57)." One can imagine

[7]Salter has raised concerns over this definition of induced innovation. According to Salter (1960), induced innovation requires the movement to a new FPF, in addition to the movement to a new isoquant. Therefore, Salter considers induced innovation to be a type of technical change rather than a unique adaptation. This thesis will follow the assumption of Wylie (1986), that induced innovation is the movement to a new production isoquant.

[8]The movement from F_1 to F_2 involves technical change or invention rather than technical adaptation alone

[9]The timing of the movement from both A to B and B to C is not specified.

[10]Salter (1960) refers to this process as long-run factor substitution and not induced innovation. This thesis will follow Wylie (1986) who refers to this process as induced innovation.

that the expense of time and resources on technical adaptation or induced innovation will occur until the last dollar spent on innovation equals the last dollar saved in total cost. In other words, induced innovation will persist until the marginal benefit of innovation equals the marginal cost.

The theory of induced innovation is incomplete without some consideration of biases to innovation. The advancement of technical knowledge can be represented by an inward shift in the fundamental production function. In Figure 1 this movement would take the FPF from F_1 to F_2. The movement from an isoquant on F_1 to an isoquant on F_2 may involve both biases to innovative change and induced innovation in the presence of changing factor prices.

In order to explain the process of biased innovation, it is convenient to restrict the change in factor prices. Consider the illustration of innovative change in Figure 2. Figure 2 (a) describes the process of biased and unbiased innovative change. Neutral innovation occurs when an increase in the available pool of knowledge shifts the Fundamental Production Function from F_1 to F_2. The result is a movement from point A to point B, since both are tangent to the price ratio P_1. At the original price ratio P_1 there is no change in the relative mix of factor inputs when innovative change is unbiased toward one particular factor. Figure 2 (a) also describes two cases of biased innovative change in the absence of factor price changes. The movement of the FPF from F_1 to F_3 indicates that innovation is biased toward the use of factor 2. The movement of the FPF from F_1 to F_4 indicates that innovation is biased toward the use of factor 1.

An example of innovative change in the presence of changing factor prices is illustrated in Figure 2 (b). A shift in prices from P_1 to P_2 will result in factor substitution from point A to point B. Eventually an increase in the existing pool of knowledge will shift the FPF from F_1 to F_2. In the figure, the innovative change, represented as the inward movement of the FPF, is unbiased. If factor prices had remained fixed (at P_1) and the innovative change was unbiased, the firm would move from point A to point C. The change in the relative factor price ratio from P_1 to P_2 is what promotes induced innovation. Induced innovation results in the movement from point B to point D, where the new price ratio is tangent to the new FPF. Overall, technical change is biased toward the use of factor 1. This type of technical change is considered factor 2-saving (factor 1-using), as the relative input mix will use less of factor 2 and more of factor 1. Note that the bias to technical change could also have been impacted by biases to innovative change. If innovative change is biased towards the use of factor 1, and the price of factor 1 falls relative to factor 2, both of these effects serve to increase the use of factor 1. If innovative change is biased towards the use of factor 2, and the price of factor 1 falls relative to factor 2, these effects act in opposite directions. Thus, induced innovation is responsible for only a portion of the change in relative factor use.

Ahmad (1966) has provided a slightly different interpretation of induced innovation. According to Wylie (1986, p. 55), inventive activity could be the movement to a new isoquant on the same Fundamental Production Function or a movement over time to a new Fundamental Production Function. Wylie assumes that numerous technologies are available (Wylie 1986, p. 55). In the very short run, firms are stuck on their technology isoquant and movement is only possible on the current isoquant.[11] In the short run, it is possible to utilize the existing pool of knowledge to move to a new technology isoquant on the FPF. In the long run, the existing pool of knowledge is expanded and movement to a new FPF is possible. Alternatively, Ahmad makes the simplifying assumption that the cost and time required in moving from one isoquant to another isoquant, belonging to the Fundamental Production Function of the same period, is equal to that required in moving to the Fundamental Production Function of the next period, which is always nearer to the origin than the FPF of the current period (Ahmad 1966 p. 347). Ahmad requires that a single technology be

[11] The term 'very short run' is not used to indicate that all inputs are fixed, as is commonly implied. Instead the term 'very short run' refers to the fixed nature of technology.

chosen in each period. Technology in the current period is fixed and cannot be altered until inventive activity makes new technologies available. Induced innovation is linked directly to the advance in technological knowledge and the inward movement of the Fundamental Production Function.

Figure 3 illustrates Ahmad's perspective on induced innovation over time. The shift to a new isoquant on a new Fundamental Production Function is needed in order to argue that induced innovation has occurred. Changes in factor prices will have no effect on the current isoquant and the firm will be forced to choose an alternative point on the same isoquant that provides a lower cost alternative (given the new factor prices). This adjustment in the factor combination indicates the simple case of factor substitution, rather than the more complex case of induced innovation. In Figure 3 factor substitution is represented by the movement from point A to point B on isoquant f_{11}. The nature of future invention and the increase in technical knowledge is what determines the presence of induced innovation. According to Ahmad, the isoquant chosen in the next period will not be the same as the isoquant chosen in the initial period (given that there was a relative change in factor prices). In Figure 3 this is indicated by the movement from point B to point C. Figure 3 depicts a relative decrease in the price of factor 1, thus the process of induced innovation leads to the development of technology that economizes on the use of factor 2 and capitalizes on the price advantage in factor 1. The convexity of the Fundamental Production Function ensures that innovation occurring in response to a relatively higher price of a given factor would use less of that factor. In other words, a rise in the relative price of factor 2 tends to result in an innovation which is factor 2-saving. If the process of invention is biased, the final mix of factors used will be altered by the direction and degree of the bias to innovation.

Wylie has utilized the theory of induced innovation to address the nationalist-continentalist debate. The induced innovation literature implies that invention can be influenced by factor prices. As a result, induced innovation in one country produces technology that is not suit-able for use in economies with different factor prices. Furthermore, the theory of induced innovation has significant implications for small nations due to their greater reliance on borrowed technical knowledge. This was particularly important for Canada as it relied more heavily on borrowed technology for its productive infrastructure (Wylie 1989, p. 569). This borrowed technology came primarily from the United States where labour, capital and energy prices differed. Canadian growth, during the second industrial revolution, was concentrated in new technologically sophisticated industries such as chemicals, electrical apparatus, metallurgy, mineral products, machinery, and transportation equipment, all of which relied heavily on the availability of cheap electricity. Canada benefitted from a significantly lower price of electricity, compared with the United States, predominantly due to its use of large-scale hydroelectric power installations. According to Dales, "Hydroelectricity has been a prerequisite to central Canada's industrial growth (Dales 1953, p. 184)." Coal prices were higher in Canada than in the United States, due to higher tariffs and transportation costs (Wylie 1989, p. 585). Table 1 displays electricity rates for several United States and Canadian cities in 1922.[12] The rates were considerably lower in Canadian cities than in Buffalo and Detroit. For example, the rate of power (large load) was 1.33 cents per kilowatt hour in the most expensive Canadian city, Montreal, and 1.54 cents per kilowatt in the cheapest U.S. city, Buffalo. The Canadian cities had lower electricity rates in commercial light, domestic light and power (small load) as well.

If Canada imported unaltered American technology, as nationalists have claimed, the differences in energy factor prices would have made American technology inappropriate for Canadian manufacturers. If continentalists were correct, Canadian manufacturers adapted this foreign technology to suit Canadian factor prices. This technical adaptation was a form

[12]The per kilowatt hour rates are expressed in Canadian dollars and adjusted for the Canadian-U.S. exchange rate.

of induced innovation.[13] Therefore, induced innovation and biased innovative change (consistent with Ahmad or Wylie) by American manufacturers must have been followed by induced innovation on the part of Canadian manufacturers.

The distinction between the nationalist and continentalist positions is described in Figure 4.[14] The initial price ratio facing U.S. and Canadian manufacturers is given by P_1. As the price of electricity in Canada falls, the relative price ratio shifts from P_1 to P_2.[15] In the very-short-run only factor substitution from point A to point B is possible. Over time, an advance in the available pool of knowledge shifts the Fundamental Production Function from F_1 to F_2.[16] Nationalists argue that Canadian manufacturers did not adapt U.S. technology. According to nationalists, Canadian manufacturers operated on the U.S. technology isoquant f_{21} in Figure 4 and were unable to take full advantage of Canadian factor prices. In other words, Canadian manufacturers cost minimized on the American isoquant according to relative factor prices in Canada, moving from point C to point D. The movement from C to D, following the innovative change in technology, involved only factor substitution on the part of Canadian manufacturers.[17] Figure 4 also illustrates the continentalist theory that Canadian manufacturers were successful in adapting American technology in order to suit relative factor prices in Canada. If Canadian manufacturers adapted American technology, they would have been able to operate on a lower cost technology isoquant, f_{22}, at point E. This implies Canadian manufacturers were able to cost minimize over the entire Fundamen-

[13] Adaptation using the existing pool of knowledge is consistent with Wylie's definition of induced innovation.

[14] The United States had an electricity-saving bias that resulted from the reduced use of electricity inputs relative to coal, despite the fall in electricity prices from 1900-1929 (Wylie 1986, p. 85). This Figure simplifies the situation by displaying innovative change as unbiased.

[15] The price of electricity fell in both countries over the early twentieth-century, however, the fall in the price of electricity was more dramatic in Canada. This figure avoids a relative change in United States factor prices to simplify the argument.

[16] The innovative change shown in this figure is unbiased but the analysis can easily be altered in the presence of biases to innovation.

[17] The unbiased innovative change that shifted the FPF inward was made possible by innovation on the part of American inventors.

tal Production Function F_2 and not simply over the American technology isoquant, f_{21}, as proposed by nationalists.

Estimates and Evidence

In order to resolve the nationalist-continentalist debate we need to analyze Canadian adaptability empirically. Specifically, we would like to determine whether or not Canadian industrialists were using U.S. technologies. According to the nationalist view, factor biases to technical change in Canadian and U.S. manufacturing were the same, any difference in Canadian and American factor shares being the result of substitution along the American technology isoquant (Wylie 1986, p. 91). In the continentalist view, technical change in Canada was more using of factors whose relative price fell in comparison with the United States and more saving of factors whose relative price rose. Thus, biases to technical change in Canada and the U.S. would be expected to differ significantly and in a predictable manner. In particular, technical change in Canada should have been more electricity-using and less coal-using than technical change in U.S. industries, for the continentalist view to hold.

In order to test these opposing views, Wylie (1986, p. 92) estimated the value added shares of electricity and coal, and their respective physical inputs and factor prices for seven manufacturing sectors in Canada and the United States. Wylie estimated translog production functions, and used the technological substitution parameters to separate the influence on factor shares of changes in relative factor prices from biases to technical change.[18] Changes in factor shares were assessed in order to determine the influence of factor substitution and

[18]Translog substitution parameters and elasticities of factor substitution are presented in Wylie (1986) p. 92.

biased technological change. The equation used to decompose share changes is given by:

$$dBS_i = dS_i - \sum_j b_{ij} d \ln X_i \tag{1}$$

where dBS_i is the change in the share of factor i due to biased technical change, S_i is the share of factor i, X_i is the physical quantity input of factor i, and b_{ij} are the translog own- and cross-price substitution parameters for factors i and j (Wylie 1986, p. 92). In effect, the change in the factor share due to biased technical change can be found by subtracting the share change attributable to changing input levels in response to changing factor prices, for a given production function, from the actual share change. Use of this method imposes the same underlying shape of the isoquant on Canadian and American industries, allowing the theoretical comparison of patterns of bias. If Canadian firms substituted only within available American technology, according to the elasticities of substitution embodied in that technology, differences in factor share movements over time would be explained entirely by factor substitution in response to factor price movements (Wylie 1989, p. 587). Alternatively, if Canadian factor share movements differed over time from those of the United States, where this could not be attributed to the opportunities for substitution within available U.S. technology, this would indicate a different technology was employed in Canada.

Table 2 decomposes the change in electricity shares into changes in input levels in response to changing relative factor prices and changes to biased technical change, in seven key manufacturing sectors. Notice that the change in actual factor shares from 1910-1929 is calculated as the sum of the factor substitution and biased technical change effects. For example, in the chemicals industry the change in the electricity share is 0.029. This can be decomposed into the change due to factor substitution of 0.013 and the change due to biased technical change of 0.016. Changes due to price-induced factor substitution explain most of the share change in all industries except for the chemicals and transportation equipment industries.

The evidence on electricity shares appears not to support the argument that industries moved to purchased electricity by specifically developing technologies to be electricity-using. This observation, however, is misleading without a comparison of factor share changes in the United States. In contrast to electricity, the change in coal shares was due predominantly to price induced factor substitution in only four of the industries: chemicals, petroleum and coal, non-ferrous metals and machinery. In the other three industries, stone, clay, glass, iron and steel, and transportation equipment, the share change was mostly due to biased technical change. In these industries, manufacturers were responding to price changes by developing coal-saving technology. This implies a more balanced split between the sources of factor change.

Table 3 compares the biases to technological change in Canada and the United States for the same manufacturing industries.[19] In the chemicals industry, Canada's factor share change due to biased technical change (dBS_i) in electricity was 0.016 over the period 1909-1929. In the United States the bias was -0.010. In the chemical industry, technological change was electricity-using in Canada and electricity-saving in the United States. In the transportation and equipment industry, the biases were 0.006 in Canada and 0.002 in the United States. In both countries technological change was electricity-using, however, in Canada it was more electricity-using than in the United States. For all other industries technological change was electricity-saving in both countries, however, in Canada it was less electricity-saving than in the United States. Overall, technological change in Canada was biased toward the use of electricity relative to the United States.

The findings regarding coal are more varied. In petroleum and coal, stone, clay and glass, and non-ferrous metals, Canada was more coal-using or less coal-saving. In the iron and steel,

[19] Wylie (1989) also displays the factor share changes due to biased technical change for capital and labour. These have been excluded from this discussion due to the focus here on electricity.

machinery and transportation equipment industries, the United States was more coal-using or less coal-saving than Canada. These results indicate that early twentieth-century Canadian manufacturing displayed a substantial degree of indigenous technological adaptation to domestic factor prices. Canadian technological change differed from that of the United States, and in a manner that was consistent with Canadian factor endowments. The smaller electricity-saving biases measured in Canada and the electricity-using biases in the chemicals and transportation equipment industries demonstrate, if viewed in an induced innovation framework, that Canadian industries pushed harder to adapt and develop electricity-using technologies than their U.S. counterparts, a result consistent with the induced innovation hypothesis (Wylie 1986, p. 98). This evidence contradicts the nationalist argument and supports continentalist claims regarding Canadian adaptation of foreign technology.

More direct tests of the induced innovation model of technical change and Canadian adaptation have been performed by Wylie (1986) and also by Keay (2000). Wylie tested the theory of induced innovation by estimating three separate translog models for several manufacturing sectors. He estimated an unrestricted translog cost function model of technological bias and induced innovation against two restricted models; the first restricted model hypothesized no factor input biases to technical change while the second restricted model hypothesized the absence of price-induced innovation. The significance of restrictions in each model was tested with likelihood ratio tests. The test statistics and critical values are presented in Table 4.[20] The test statistics are obtained by taking twice the log of the maximum restricted likelihood function (one of the two restricted translog cost functions) over the maximum unrestricted likelihood function (the unrestricted translog cost function). These test statistics are distributed as a chi-square variable with degrees of freedom equal to the number of independently imposed restrictions (Wylie 1986, pp. 137-138).

[20] Wylie included only four of the major manufacturing sectors (metals, machinery, non-metallic metals and chemicals) in the translog estimation and testing as opposed to the seven industries discussed earlier

Given no input bias restrictions, the test statistic for the metals industry is 36.97, the machinery industry is 39.79, the non-metallic minerals industry is 11.77 and the chemicals industry is 32.00. If the test statistic is greater than the chi-square critical value of 21.66 then the null hypothesis can be rejected at the 1% level of significance. The no factor input bias restrictions can be rejected at the 1% level of significance in all sectors except non-metallic minerals processing. Therefore, technical change appears to have been biased in its use of factors in most industries. The same process can be repeated to test the restriction of no price induced input biases. The hypothesis of no price induced input bias (induced innovation) can be rejected at the 5% level of significance in all sectors except non-metallic minerals processing, where it can be rejected at the 10% level. Thus, in the sectors considered, Wylie's findings confirm the hypothesis of induced innovation in Canadian manufacturing and the continentalist view of Canadian adaptation.

Using the parameter estimates from input demand systems, Keay (2000 p. 235) tested to see whether Canadian industries were utilizing domestically unique technology or unaltered U.S. technology. Table 5 displays the common technology Wald statistics used to perform this test.[21] Any Wald statistic greater than 21.03 (given the 12 degrees of freedom) indicates a rejection of the common technology null hypothesis. For example, since the Wald statistic for the common technology test in the steel industry is 844.280, it is possible to reject the null hypothesis of a common technology between the United States and Canada. As each Wald statistic is over 21.03, all nine Canadian industries in Keay's sample were employing domestically unique technology. In other words, Canadian industrialists were operating with altered or unique technology.

Keay also tested whether Canadian and American firms exhibited the same biases to technological change. The Wald statistics for common technology bias testing must be greater than 7.82 (given 3 degrees of freedom) in order to reject the null hypothesis of common

[21] Notice that Keay uses nine industries that differ from Wylie but the conclusions are generally comparable

technology biases. The common technology biases Wald statistics used to perform these tests have been included in Table 5. All of the Wald statistics are greater than the critical value of 7.82. Therefore, for each industry Keay rejected the hypothesis that Canadian and American manufacturers shared common biases to technological change. Keay's results reveal that Canadian firms were employing domestically unique technology while displaying domestically unique technological biases, implying that the responsiveness of Canadian firms must have been partly attributed to induced technological innovation on their part. Canadian manufacturers could not have been using unaltered U.S. technology. These findings are consistent both with Wylie and the continentalist view.

In order to determine the adaptability of Canadian manufacturers, Wylie (1986) estimated elasticities of factor substitution for Canada and compared these with elasticities for the United States. Focussing on the relationship between electricity and coal, Table 6 presents Wylie's estimates of partial elasticities of substitution and own-price elasticities of demand for these factors.[22] In Canada, the elasticities of substitution between electricity and coal in the Metals and Minerals industries are -10.85 and -7.81 respectively. The negative elasticities of substitution between electricity and coal indicate the relationship to be one of complementarity. The elasticities of substitution between electricity and coal in the Machinery and Chemicals industries are 19.69 and 33.85 respectively. The positive elasticities of substitution between electricity and coal indicate the relationship to be one of substitutability. Canadian manufacturers in the Machinery and Chemicals industries substituted away from coal, which became relatively expensive, and moved towards the use of electricity. In the United States, the elasticities of substitution between electricity and coal are 4.65, -10.98 and 4.49 in the Metals, Machinery and Chemicals industries respectively. Electricity and coal are complements in the machinery industry and substitutes in the Metals and Chemicals

[22]Results presented in Table 6 assume a constant returns to scale translog estimation process. For results using a variable returns to scale specification see Wylie (1986, p. 146)

industries.

The own-price elasticities of demand for electricity in Canada indicate an elastic demand response for electricity in all sectors except Machinery. The Chemicals industry displays the most elastic demand for electricity with an own-price elasticity of -3.02. In terms of coal, the own-price elasticities of demand indicate an elastic demand in the Metals and Machinery sectors.[23] In the United States, the elasticities of demand in all industries illustrate an elastic demand for electricity. The demand for coal is elastic in the Metals and Chemicals industries.[24] Compared with U.S. manufacturers, Canadian manufacturers in the Chemicals industry were more able to substitute electricity for other factors in response to the falling price of electricity. Overall the demand for electricity was elastic in most industries, allowing Canadian manufacturers to exploit the relatively low price of electricity.

Keay (2000) has undertaken several empirical tests of Canadian adaptability that are consistent with Wylie's findings. According to Keay, if Canadian manufacturers were responding to their domestic market conditions, they would be expected to substitute among inputs in response to changes in input prices. This movement along a given isoquant would indicate the degree of factor substitution resulting from a change in the slope of a firm's isocost function (Keay 2000, p. 222). This behaviour is ensured by the firm's incentives to cost minimize. Responsive manufacturing firms should make adjustments to the technology they employ, or adopt new technology, in order to take advantage of input price movements that appear to be permanent.

The ability of Canadian manufacturers to adapt to changes in factor prices is reflected in the elasticities of substitution estimated by Keay. Table 7 displays the elasticities of substitution between labour (L), capital (K) and intermediate inputs (M). For example, the elasticity of substitution between capital and labour in the steel industry is 0.827 in Canada

[23] In the Minerals and Chemicals sectors coal an inferior input.
[24] In the Machinery industry coal is an inferior input.

and 0.158 in the United States, indicating labour and capital were substitutes. The degree of substitutability between these factors was stronger in Canada than the United States.

Contrary to the entrepreneurial failure hypothesis of the nationalists, the elasticities of substitution show no evidence of inflexibility on the part of most Canadian manufacturers. The elasticities of substitution indicate that Canadian industries had greater elasticities than the American industries in 17 of 27 cases (Keay 2000, p. 232). According to Keay, "In general, the Canadian producers were substituting among their inputs and/or adapting their technology in response to changes in their input prices, and this flexibility compared favorably with that of the American producers (Keay 2000 p. 232)."

Keay also investigated the relative responsiveness of Canadian producers by calculating own-price elasticities of demand.[25] Table 7 displays the own-price elasticities of demand for labour, capital and intermediate inputs. For example, the own price elasticities for labour in the steel industry are -0.092 for Canada and -0.033 for the United States. The larger absolute value of the Canadian own-price elasticity indicates that Canadian steel manufacturers were responsive to changes in the price of labour. Overall, the own-price elasticities of demand indicate that all of the Canadian industries selected were more responsive than U.S. industries to changes in an input's own price, for at least one input. The Canadian industries had greater own-price input demand elasticities than the American industries in 21 of 27 cases (Keay 2000, p. 233). Thus, the own-price elasticities of demand suggest that Canadian manufacturers were flexible and responsive to movements in the price of inputs they employed, even in comparison with U.S. producers.

Keay's findings indicate that Canadian producers responded to changes in relative input prices by altering their use of inputs in a manner consistent with cost minimization (Keay 2000, p. 225). These domestic price changes were not explained by changes in United States relative input prices. Therefore, his evidence places in doubt the nationalist argument that

[25] For a more detailed description of this calculation see Keay (2000) p. 230

Canadian entrepreneurs were unable to alter their use of inputs or adapt their technology to suit domestic conditions. The evidence suggests rather that Canadian firms were responsive to changes in domestic input prices.

Patents and Technological Change

If Canadian manufacturers were induced, by factor prices, to adapt foreign technology, the patent records should reflect this. Alternatively, if Canadians were engaging in factor substitution and were unable to adapt foreign technology, the patent records should indicate this as well. The intent of this work is to make use of patent records to explore the question of induced innovation and biased technical change. By examining the patent records of the United States and Canada this paper provides another approach to the issue of Canadian adaptation of technology.

Patent records may be a key element in our understanding of the success of Canadian industrialists. Wylie, however, has questioned the relevance of these records. According to Wylie, Canadian adaptation and innovation occurred at the firm level and on the factory floor (Wylie 1989, p. 574). Therefore, much of the technical adaptation was happening in an informal setting, bypassing the process of patented invention. But, this claim seems unconvincing given the scale and the significance of inventive activity during this period of electrification. Moreover, authors such as Sokoloff (1988), Khan (1993), Lamoreaux (1999), Moser (2007), and Lanjouw, Pakes and Putnam (1998) have supported the use of patent data to measure inventive activity.

Sokoloff and Khan have been instrumental in connecting patents to the process of technical change. According to Sokoloff, patents are a gauge of the use of resources to develop new technologies (Sokoloff 1988, p. 817). Khan and Sokoloff (1993) illustrated the relationship by gathering data on 160 early-nineteenth-century ‘great inventors’. Their research reveals that all 160 of these inventors made use of the patent system as the means to appropriate returns from their efforts. In addition, patenting of the 160 selected inventors exhibited cyclical patterns that mirrored the patenting patterns of 'ordinary' patentees (Khan and Sokoloff 1993, p. 290). In other words, Sokoloff and Khan's results indicate that inventions (especially the more significant ones) were likely picked up in the patent records.

Petra Moser (2007) has argued that scientific breakthroughs tend to increase inventors' propensity to patent. Moser collected data on 7,219 British and American innovations, with and without patents, which appeared at four world's fairs between 1815 and 1915. According to Moser, the data show that the ability to keep innovations secret is a key determinant of patenting, and that inventors' propensity to patent increases in response to scientific progress (Moser 2007, p. 2). As electricity related invention was at the forefront of scientific advance during the second industrial revolution, this supports the connection between patents and inventive activity.

Lanjouw, Pakes and Putnam (1998, p. 406) found that the unique combination of detail and coverage found in patent data make them particularly well suited to studies of technology or externalities in the knowledge process. They argue that the main problem with using patent data to measure innovation stems from the fact that the importance of inventions varies widely. Issues of this nature are common in the patent literature, however, the use of patent data in this study should be largely unaffected by these problems. My approach is to compare the scope of patenting in well-defined categories across countries. In other words, since many of the same patents are identifiable across countries and the categories are specific to a given type of invention, the issue of the importance of different patents to productivity is not as serious. If different patent categories tend to produce inventions of differing technological significance, a comparison of the same categories across countries will be acceptable even when a comparison across categories is not. Once one accepts that patent records are a valid measure of the degree of inventive activity then the use of patent data to address the nationalist-continentalist debate over Canadian adaptation is entirely reasonable.

Patents in Canada and the United States

Despite the extensive theoretical evidence brought forward to support the continentalist argument there has been little done to address the 'circumstantial evidence' of non-adaptation in the nationalist literature.[26] One of the main nationalist arguments is based on the patent record in Canada. According to the nationalists, statistics on country of residence of the patentee demonstrate a U.S. dominance in the 1900-1914 period. Table 8 illustrates the relative lack of Canadian inventiveness as perceived by nationalist writers. Naylor (1975), one of the predominant voices for the nationalist view, has argued that indigenous Canadian technical capability, in the process of innovation, was limited by the American dominance in industrial technology. There are several reasons why American inventors dominated the field of invention. Cole (1973) proposed that a larger population can stimulate the growth in invention by increasing both the supply and demand of inventive activity. According to this argument, the relatively large population of the United States would have helped American inventors dominate Canadian inventors in the supply of new invention by generating a larger market for ideas.

Others have argued that immigration may increase inventive activity, by augmenting a nation's incoming flow of knowledge (Musson and Robinson, 1978). In this context, a high level of immigration was a source of skilled individuals, who raised the degree of inventiveness. Although Canada benefitted from substantial immigration during the early twentieth-century there was likely a lag in the relationship between the arrival of skilled individuals and an increase in the supply of invention. If this was the case then the large

[26] Wylie (1986) p. 41 refers to nationalist evidence on non-adaptation as circumstantial

immigration flows to the United States in the late nineteenth-century had a greater effect on the level of American inventiveness than was the case for Canada.

The dominance of American inventors could also have been the result of larger and more developed American markets. Detailed investigation of patent records indicates that patenting takes place mainly in urban areas (Phillips 1992, p. 389). Given its relatively small urban centers, it is not surprising that Canada generated few patents. Another line of argument proposes that Canadian manufacturers may have lacked the technical capability to adapt or even fully comprehend imported American technology (Naylor 1975, p. 57). Naylor argues that this inability may have been the result of an exodus of skilled labour from manufacturing into commercial services during the early twentieth-century.

Evidence from Patent Records

The patent data described in this paper are drawn from both Canadian and American sources. The Canadian records have been gathered from the public use database of the Canadian Intellectual Property Office. The American patents are drawn from the public use database of the United States Patent and Trademark Office. Both the Canadian and American patent records from 1880-1929 identify the inventor, the name of the invention, the category of the invention and the issue date of the patent. Prior to 1919, the Canadian patent data can be used to identify the inventor's country of origin and the owner's country of origin. The data has been organized and presented by year.[27]

Figure 5 displays the total yearly patents issued in Canada and the United States, and the relative number of patents issued. There was an upward trend in the number of patents throughout the 1880-1929 period, which was more pronounced beginning in 1900. From 1880-1900 the trend was 108.9 patents per year in Canada and 328.4 per year in the United

[27] The results can also be generated monthly.

States.[28] After 1900 the trend increased to 195.5 patents per year in Canada and 662.3 per year in the United States.[29]

A comparison of the total number of patents issued in Canada and the United States seems to support the nationalist claim. The United States issued significantly more patents. These results are consistent with patent literature that argues population growth, immigration and market size affected the process of invention. At most, over the period 1880-1929, Canada issued one third the number of U.S. patents, and the average was just one fifth. However, the gap was closing, especially in the late nineteenth century. Over the period 1900 to 1929, the relative number of Canadian patents increased less rapidly. The reason was less a decline in Canadian patenting than the boom in American patenting that occurred after 1900.

Figure 6 displays the total yearly patents issued per 1000 people in Canada and the United States.[30] Starting from a situation of relative equality in 1880, Canada was issuing a differentially rising number of patents, per capita. This finding, however, does not take into account the origin of the inventor, and so, one should be wary about drawing conclusions from it. Regardless of the origin of inventors, there was clearly an infrastructure in place within Canada to handle the patenting of technical innovation.

Electricity-Using Invention in Patent Records

Wylie argued that in the period 1900-1929 Canadian manufacturing firms were adopting electricity-using technologies in comparison to those in the United States. As Wylie puts

[28] Regression results from 1880-1900: $\hat{Can} = 1,613 + 108.9 * \Delta Year$ $\hat{U.S.} = 18,574 + 328.4 * \Delta Year$.

[29] Regression results from 1901-1929: $\hat{Can} = 4,876 + 195.5 * \Delta Year$ $\hat{U.S.} = 28,965 + 662.3 * \Delta Year$.

[30] Canadian patent records have been compiled using the Canadian Intellectual Property Office Database. United States patent records have been compiled using the United States Patent and Trademark Office Database. Population statistics for the United States were obtained from the Historical Statistics of the United States (Table Aa6-8). Population statistics for Canada were obtained from the Historical Statistics of Canada (Table A1)

it, “The industrial transition based on electrification which occurred in Canada in the first three decades of the twentieth century provides an ideal historical episode in which opposing nationalist and continentalist views on choice of technology can be tested (Wylie 1986, p. 23).” Canada’s low electricity prices should have made electricity a prime area for Canadian inventors. Unfortunately, there is no way to isolate the patent records to account for all of the electricity-using patents issued during the early twentieth century. However, an examination of several key electricity-based patent categories (identical between the United States and Canada) should proxy for the overall pattern of electricity-using invention.

Table 9 displays the eight electricity-based categories that are identically defined in the U.S. and Canadian patent records. Inventions listed in categories 310 and 320 are directly related to the generation of electricity. Dynamo electric generators, electro-motors, electro-magnets, and alternating current motors make up the majority of patents in this category. Inventions listed in category 340 are related to communication technology. Examples from this category include telegraphic relays, electric telegraph systems, submarine telegraphy, electrical relays, electrical signal systems, and electrical alarms. Inventions in the remaining categories facilitate or improve the use of electricity, from the measuring and testing of electricity to the development of batteries, conductors and circuits used in electrical devices. Examples of patents from these categories include insulating systems, electrical cables and wires, electric terminals, electric conductors, electric heating systems, circuit controllers, circuit breakers, electric switches, and electric indicators.

Including all electricity categories to proxy the overall degree of electricity-using invention risks that some were characterized by electricity-saving inventions. The electricity categories used in this paper have been chosen to be indicative of electricity-using invention. For example, electricity generating systems are certainly electricity-using inventions and represent the patented inventions in two of the categories chosen. Essentially all of the inventive activity within these categories tended to promote an increased use of electricity. The inventions in these categories extended the scope of electricity-using devices and increased, rather than decreased, the level of electricity utilized in production. Therefore, if Canadians were exploiting their advantage in electricity prices, the eight categories chosen should indicate innovation in the appropriate area.

Figure 7 shows the total yearly patents issued in Canada and the United States in the eight electricity categories from 1880 to 1929.[31] Both Canada and the United States exhibited substantial increases. A comparison of Figures 5 and 7 reveals that patenting in electricity was closely related to the overall pattern of patenting during this period. The correlation between the overall patent series and electricity patent series from 1880-1929 is 0.9356 in Canada and 0.9639 in the United States. Many more electricity patents were issued in the United States than in Canada. This is not surprising given the dominance of the United States in overall patenting during this period.

Although the pattern of electricity patenting was very similar between the two countries there was a slight divergence in the 1920's. In the United States there was a decline in electricity patenting during the late 1910's, followed by a strong recovery in the late 1920's. The fluctuation in patenting was likely related to the timing of the U.S. involvement in WWI. By comparison, electricity patenting in Canada seems to have fluctuated around a new higher average throughout the 1920's. In both countries there was an upward trend in the level of electricity patenting. Figure 8 displays the relative number of Canadian to American patents issued in electricity and all categories of patents. Through the period 1880-1929 Canada was issuing far fewer patents than the U.S., but more importantly, the relative number of electricity patents being issued was even less than the average for all patents. In the 1920's, though, the gap was reduced.

In general, there was a rising trend, usually after 1900, in the number of electricity patents issued. This indicates that electricity patenting was increasing over the period 1880-1929.

[31]The combined electricity categories will be referred to as the electricity categories

In the United States, the largest fluctuations in patenting were closely related to WWI. In Canada, fluctuations in patenting were common due to the small number of electricity patents each year. All of the categories show an American dominance in the number of patents issued. Most categories show very few patents issued in Canada during the period prior to 1900. In other words, the empirical evidence seems to support the argument that the United States was responsible for the majority of the inventive activity occurring in the early twentieth century, even in terms of electricity related invention.[32]

Development and Diffusion of Technology

While it is clear that the United States generated significantly more patents than Canada, the question remains whether Canadian inventors were successful in adapting American technology or developing their own technology. Figure 9 presents patents by country of residence of the inventor. It reveals a dominance of American inventors in the number of electricity patents issued within Canada from 1880 to 1919.[33] Prior to 1900, Americans took out nine patents in Canada for every patent issued to a Canadian inventor. After 1900, during the so called 'second industrial revolution', this pattern became even more pronounced with an average of ten patents issued to American inventors for every one issued to a Canadian. These results support Naylor's observation of the general trend in patenting within Canada over this period. In other words, Canadian inventors were patenting far less within Canada than American inventors, and less than inventors from other countries as well.

The evidence on country-of-residence seems to support the nationalist theory that Canadian manufacturers did not adapt foreign technology to suit Canadian factor prices. In many of the electricity categories, little patenting occurred in Canada from 1880 to 1929

[32] See the Appendix for a comparison of patents issued in Canada and the U.S. for each individual electricity category.

[33] In the case of multiple inventors, patent origin is defined by the first or primary inventor.

by Canadians. However, it remains possible that Figure 9 is consistent with the continentalist argument. Although Canadian inventors may not have been successful in patenting electricity-using technology, in order to exploit Canada's cheap electricity prices, Canadian manufacturers may have been able to aquire the appropriate innovations directly from foreign inventors. In terms of figure 9, foreigners (typically Americans) may have been making the entire Fundamental Production Function available to Canadians.

American inventors may have been generating a pool of knowledge that was appropriate not only to factor prices in the United States but also to factor prices in Canada. Canadian manufacturers could then pick and choose the most appropriate technology from this pool. Thus, Canadian manufacturers were able to, in a relatively costless manner, move to the cost minimizing point on the Fundamental Production Function rather than being forced to use the American technology isoquant. In other words, technical adaptation was less costly for Canadian manufacturers who were able to benefit from technical advances made by American inventors. As continentalists have shown, Canadian manufacturers were operating on the cost minimizing point of their FPF, using appropriate technology and exploiting relative factor prices in Canada. However, this success may have had less to do with the process of induced innovation on the part of Canadian manufacturers and more to do with the nature and scope of American invention.

An analysis of Canadian ownership versus Canadian invention in electricity further supports the success of Canadian manufacturers in acquiring appropriate technologies. Figure 9 shows the number of electricity patents issued to Canadian owners.[34] Note that more Canadians were owners, rather than inventors, of electricity-related technology. Canadian ownership of electricity patents increased rapidly throughout the 1900's, reaching about 70 percent of American ownership by 1919. This result suggests Canadian manufacturers were

[34] Owner refers to the owner listed on the patent. In the case of multiple owners the first or primary owner is used to determine origin.

acquiring American inventions that they could apply in their own production processes.

If American inventors were making the entire FPF available to Canadian manufacturers, inventive activity should have shown up first in the United States and then in Canada. Table 10 displays the correlation between the lagging and leading United States electricity patent series and the Canadian electricity patent series.[35] The positive coefficient between the Canadian series and the first lag of the American series is consistent with this hypothesis. No other lead or lag of the American series is statistically significant, indicating the American patents tended to lead Canadian patents by about one year. In other words, the fluctuations in the number of electricity patents in the United States tended to lead the fluctuations in the number of electricity patents in Canada. Thus, after a one year lag, American inventors appear to have influenced the pool of inventions available to Canadian manufacturers.

The timing of patenting in Canada and the U.S. can also be examined with a vector autoregression model. Table 11 shows the results where the dependent variable is the natural log of the first difference of the number of electricity patents in Canada. The first lag of the United States series has both a positive and significant (at the 5% level) coefficient. This indicates that the United States electricity patent series led the Canadian series by approximately one year. These results support the view that electricity-using technology flowed from the United States to Canada, a process of diffusion that occurred with a one-year lag.

A more detailed look at the patent record reveals a similar pattern of technological diffusion. I have isolated specific electricity inventions from one of the eight patent categories. Category 320 (Battery/Capacitor Charging & Discharging) was chosen for tractability. A small number of inventions were patented in this category each year. Sixty-six patents were recorded in category 320 from 1880 to 1919 in Canada. Of these sixty-six, twenty-five can be directly identified in the patent records of the United States.[36] Table 12 presents the

[35]The patent series for both countries has been first differenced before calculating correlation coefficients.

[36]Some of the patents listed represent identical inventions but with slightly different names. In these cases the Canadian name has been used.

patents that are in both the Canadian and American records. The twenty-five patents are listed chronologically according to their date-of-issue in Canada. Two conclusions about the diffusion of this technology can be drawn. First, American inventors issued their patents in Canada, on average, 10.28 months later than in the United States. For example, Eli Starr & William Peyton took out a Canadian patent on a system of electric lighting 19 months after it was patented in the United States, William Kookogey patented an apparatus for charging and discharging storage batteries 14 months earlier in the United States, and William Bliss patented an electrical distribution system 3 months earlier in the United States.

If one assumes that the pattern of patenting closely approximates the pattern of invention, these results indicate invention in electricity-related technology was transferred from the United States to Canada, following a roughly one-year lag. This is evidence that the United States was making a pool of knowledge available to Canadian manufacturers by taking out electricity patents in Canada shortly after patenting their inventions in the United States. In effect Canadian patents were a sample of the American patent menu. Note, however, in the case of the United Kingdom, patents tended to be issued in Canada before the United States, possibly indicating that Canadian manufacturers had closer ties to Britain.

Electricity Patents and Canadian Invention

The United States generated more patents in each of the eight electricity-related categories. At the same time, the total number of patents in all areas of invention were much higher for the United States. Thus, the mix of patents in electricity as a fraction of the total number of patents is a better indicator of the relative success of Canadian manufacturers to adopt electricity-using technology. Figure 10 displays the share of electricity patents in the United States and Canada. The results indicate that the United States issued a larger share of electricity patents than Canada. The figure also confirms that electricity patents were increasing as a share of overall patenting. This result is consistent with the hypothesis that electricity related invention was increasing in response to the falling relative price of electricity in both Canada and the United States.

The shares of patents in each of the eight electricity categories are illustrated in Figures 11 (A) to (H). In each category the pattern of invention is quite different. In category 306 (Circuit Makers & Breakers), the share of electricity patents increased rapidly over the 1880-1929 period (See Figure 11 (A)). By the mid 1920's, category 306 accounted for approximately 1.5% of all patents in each country. Canada caught up to the United States in the share of electricity patents during several brief intervals. The period surrounding WWI saw a reduction in the relative number of electricity patents in the United States and an increase in Canada. In both series there was little fluctuation, making the upward trend a prominent feature. In category 339 (Electrical Connectors) the share of patents issued in Canada and the United States also rose throughout the period 1880-1929 (See Figure 11 (G)). However, the upward trend was less steep in this category, especially prior to 1900. The United States issued a greater share of patents in this category until WWI. Following WWI, Canada's share of patents in category 339 exceeded or nearly matched the United States.

Both the Canadian and U.S. share of patents in categories 310 (Electrical Generators), 320 (Battery/Capacitor Charging & Discharging) and 337 (Conductors & Insulators) were relatively flat with no increasing or decreasing trend from 1880 to 1929 (See Figure 11 (B), (C) and (F)). In Category 310, the United States dominated Canada in the share of electricity patents. Before 1886, Canada issued a greater share of patents in this category; after 1886 the United States was dominant. Patenting in category 320 was sporadic with a large degree of variance around the average share of patents issued. This was related to the small number of patents issued. There was little to no upward trend in the share of patents issued in category 337. In this category Canada issued almost the same share of patents as the

United States over the period 1880 to 1929.

Category 340 (Electrical Communications) illustrates an increasing trend in the share of electricity patenting, for both Canada and the United States (See Figure 11 (H)). In this category, Canada issued a similar share of patents to the United States, especially after 1918. In contrast, there was a slightly decreasing trend in the share of patenting in Canada over 1880-1929 in category 322 (Single Generator Systems) (See Figure 11 (D)). This category is different from the others in that Canada issued a greater share of patents throughout much of the 1880-1929 period, as the share of patenting in the United States was almost flat.

When viewed individually, the electricity categories are diverse in their results. Some categories reveal a U.S. dominance in the share of electricity-related invention while other categories indicate, over intermittent periods, relatively more electricity-related invention in Canada. In general, Canada did not hold a relative advantage in the share of electricity patents. This result is surprising given the cheap price of electricity in Canada, and the conclusions of continentalists. In effect, the patent records are unable to corroborate the continentalist evidence. The United States produced a much larger pool of inventive knowledge, in the form of patents, than Canada. As a result, American inventors were responsible for the majority of inventive activity in electricity-related technology.

It is unclear why the Canadian patent record would indicate a menu of technology was available in Canada that was less electricity-using than in the United States. It is also unclear why Canadian and U.S. inventors patented fewer electricity-related inventions in Canada then in the United States as a share of total patents. However, if it is assumed that Canadian manufacturers were operating at their optimal point on the Fundamental Production Function, as continentalists suggest, there are several possible explanations that might shed light on this issue. Firstly, patent records may not be an appropriate measure of technological innovation and technical adaptation. Wylie has argued that Canadian adaptation of American technology was occurring in an informal setting. Specifically, Canadian technological mastery depended on the absorption of technical information, which had been disseminated by scientific and trade associations, machinery suppliers, and government research agencies. In addition, human interaction and organization on the factory floor at the development and engineering stages of technical advance facilitated the transfer of new ideas (Wylie 1989, p. 574). Thus, Canada's electricity related innovation could have sidestepped the patent process.

Secondly, electricity patents in Canada may have reflected cost efficient and fully employable inventions while electricity patents in the United States may have been more exploratory and unrefined. In other words, American inventors who chose to patent in Canada had adequately determined the usefulness of their inventions for the Canadian market, likely through an attempted introduction into the American market. Therefore, it is possible that many of the electricity patents issued in the United States did not generate employable inventions while most of those issued in Canada did. This explanation is consistent with the dominance of American inventors within Canada as well as the direction and lag in the diffusion of technological innovation between the two countries.

Lastly, there may have been a difference in the motives for invention within Canada and the United States with respect to electricity-using invention. Although the purpose of innovation in both countries was to generate electricity-using inventions that could take advantage of the falling price of electricity, inventions in Canada may have been more rudimentary. In essence, Canadian inventors may have had less motivation to invent complicated devices in order to maximize on the low cost of electricity, since even simple invention or adaptation of existing technology provided substantial returns.

Conclusions

The period from 1900 to 1929 was Canada's golden age of industrial development. As Wylie puts it, "The second industrial revolution, based on the commercial application of science, the internal combustion engine, the chemical transformation of materials, and new energy forms such as electricity, carried Canada into the industrial age (Wylie 1989, p. 570)." However, on the ability of Canadian industrialists to adapt foreign technology there exists disagreement among economic historians, usually referred to as the nationalist-continentalist debate. Did Canadian industrialists passively receive transferred technology or was the skillful application of imported technology one of the keys to Canadian productivity in the twentieth-century? Recent literature has tended to suggest that Canadian manufacturers were successful in adapting foreign technology. Application of formal product and cost functions has provided strong evidence of the innovative nature of Canadian industrialists.

Evidence from patent records, however, is unable to support the Canadian adaptation of American invention. Americans were largely responsible for the patents issued in Canada. Given the low price of electricity in Canada, the theory of induced innovation suggests that Canadians should have done more patenting in electricity-related areas. According to patent records, Canadians were patenting very few electricity-related inventions. Even as a share of total patents, the United States issued a greater number of electricity patents than Canada. Assuming patents are a reasonable proxy for invention, Canadian inventors appear not to have been responding to factor prices. Instead, Canadian manufacturers were benefitting from American technology, made available through the extent of American invention.

This paper has provided one look at the role of patents in the nationalist-continentalist debate. The findings have not settled the debate but rather given grounds for further investigation. Wylie dismissed the patent records, possibly because no full scale analysis of Canada's patent history had been attempted. In contrast, Naylor used patents to support the non-adaptation of American technology. This paper has shown, through a more detailed analysis of the patent records, that the mechanism by which Canadian manufacturers developed unique technologies merits further investigation.

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Figure 1: The Fundamental Production Function and Innovative Change

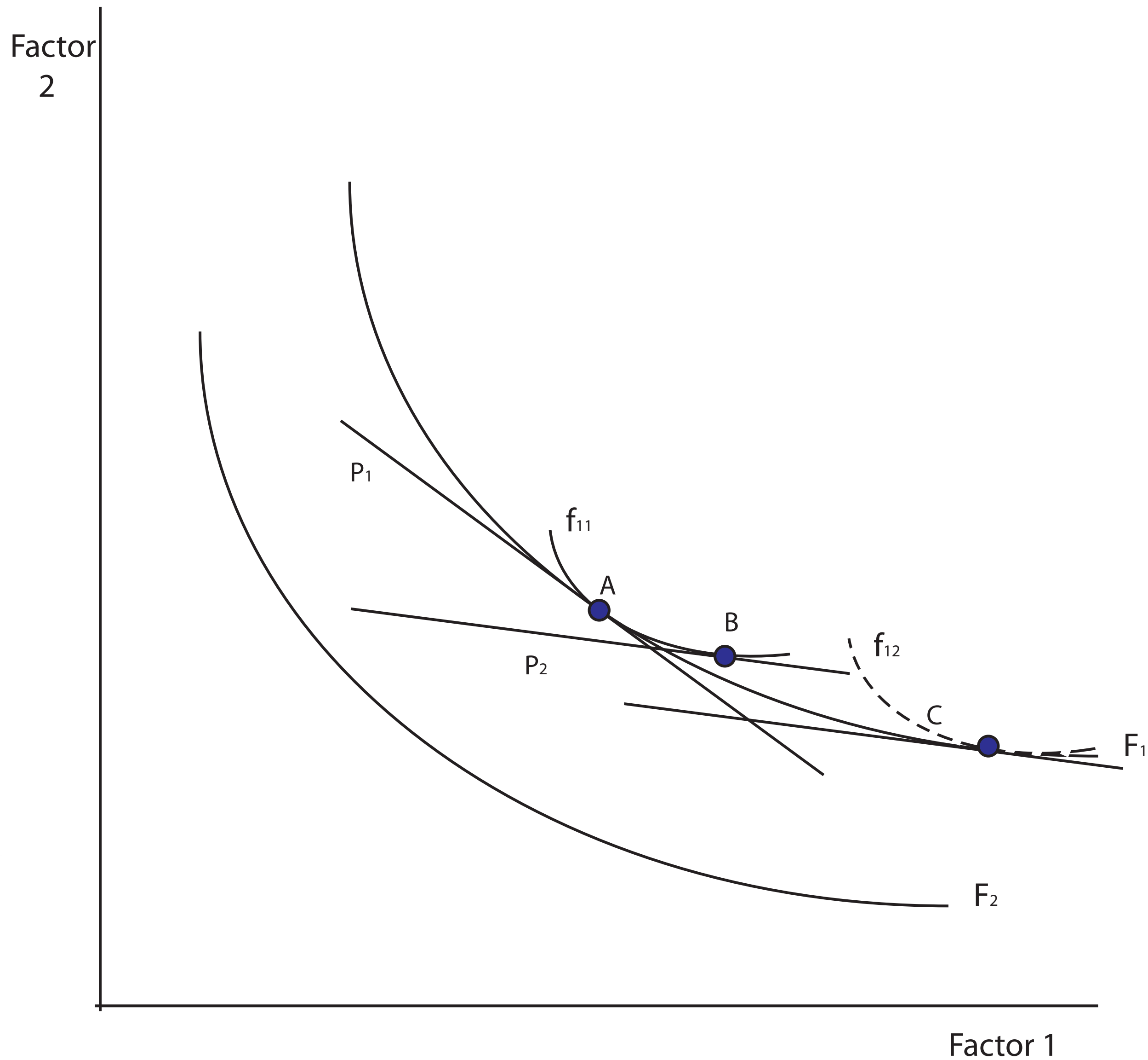


Figure 2: Biases to Innovation and the Fundamental Production Function

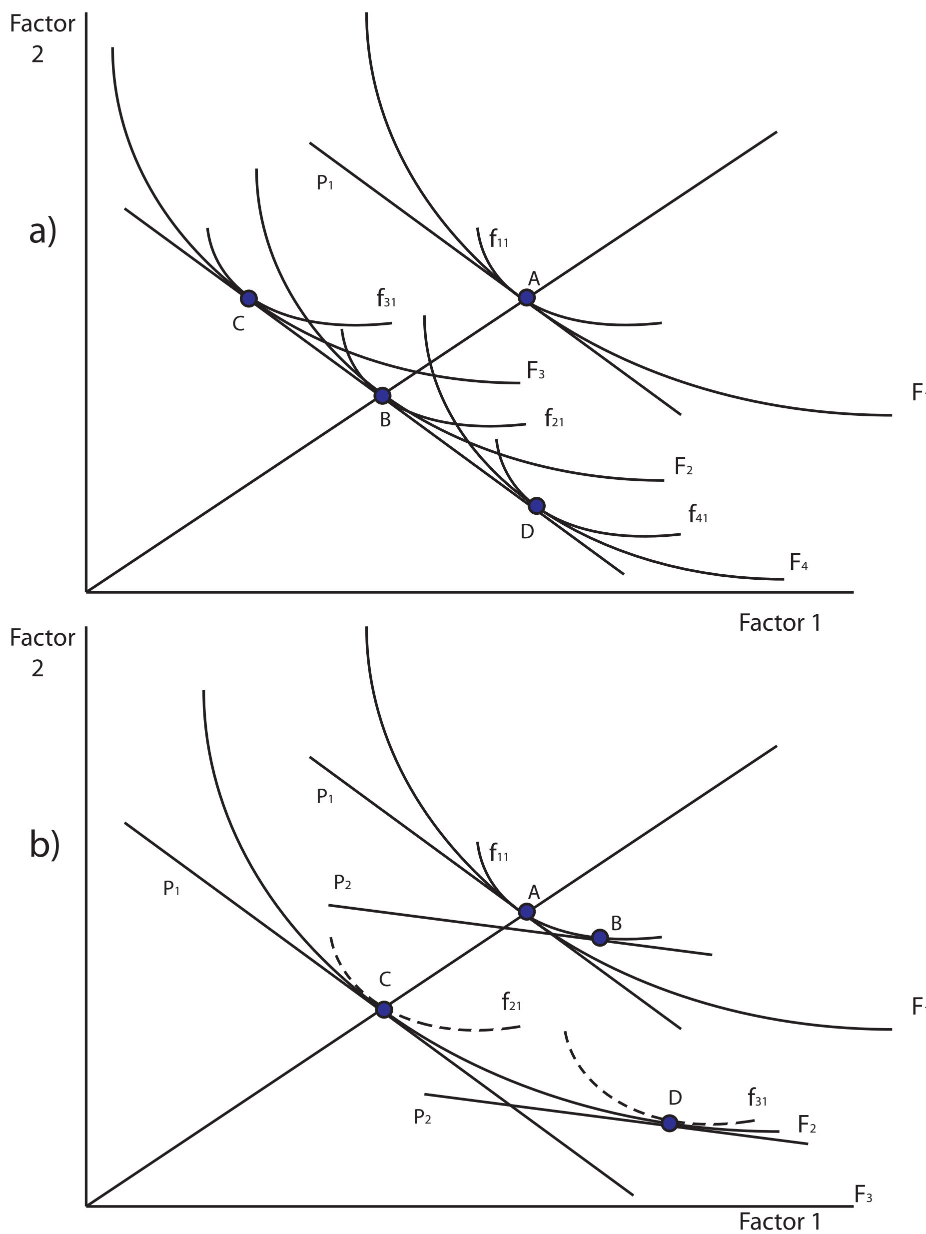


Figure 3: Ahmad's Theory of Induced Innovation

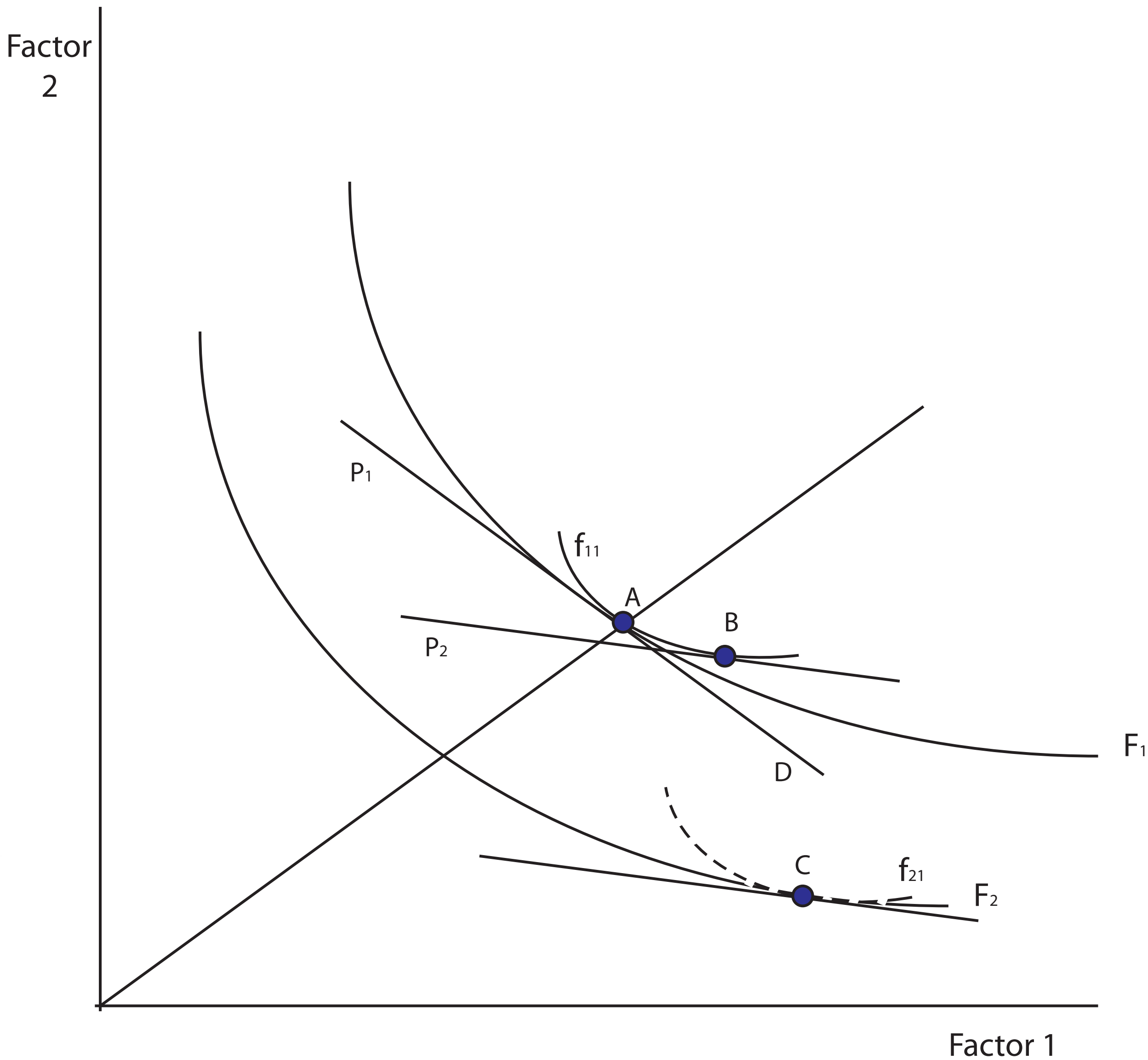


Figure 4: Induced Innovation and the Nationalist-Continentalist Debate

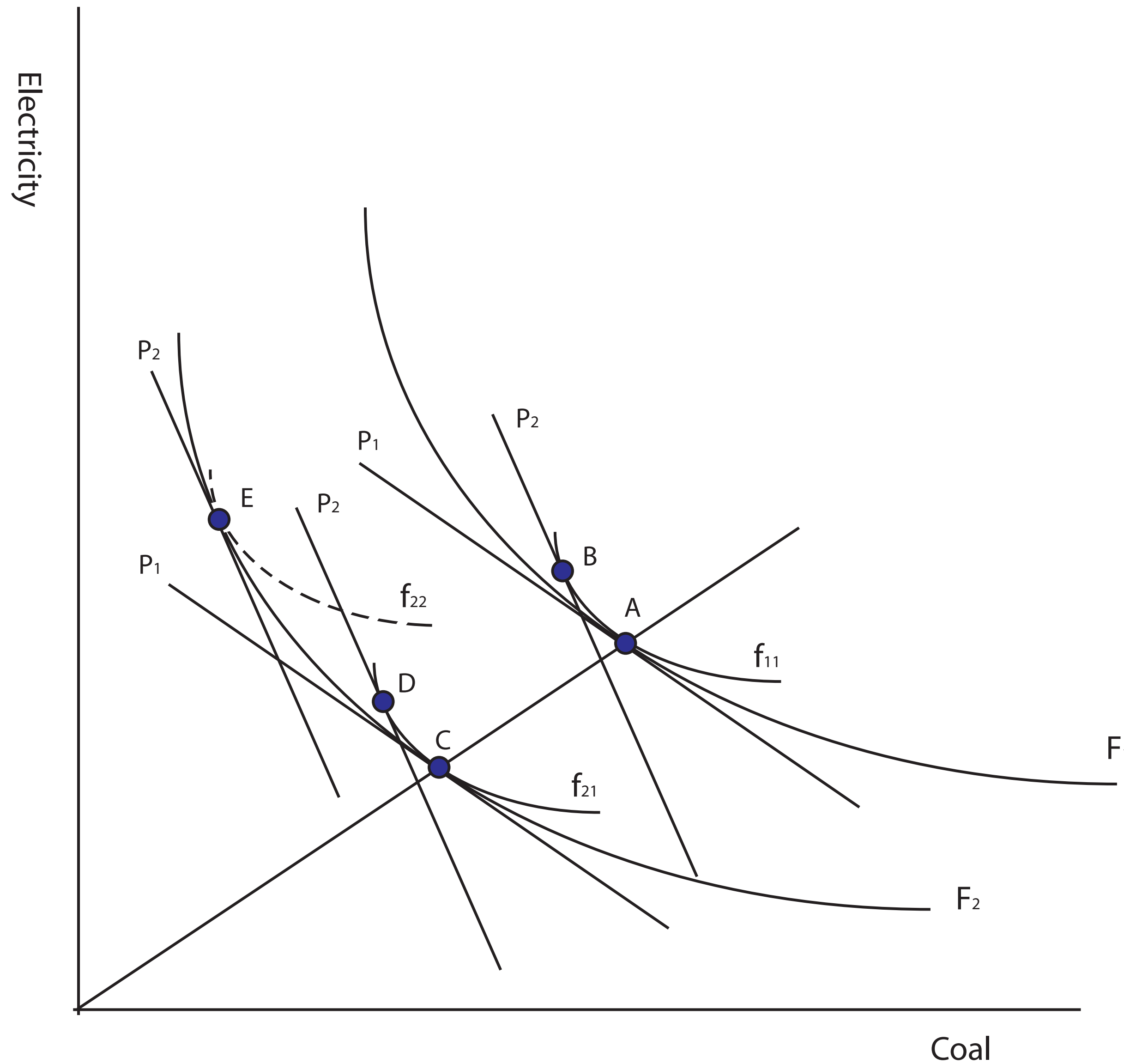
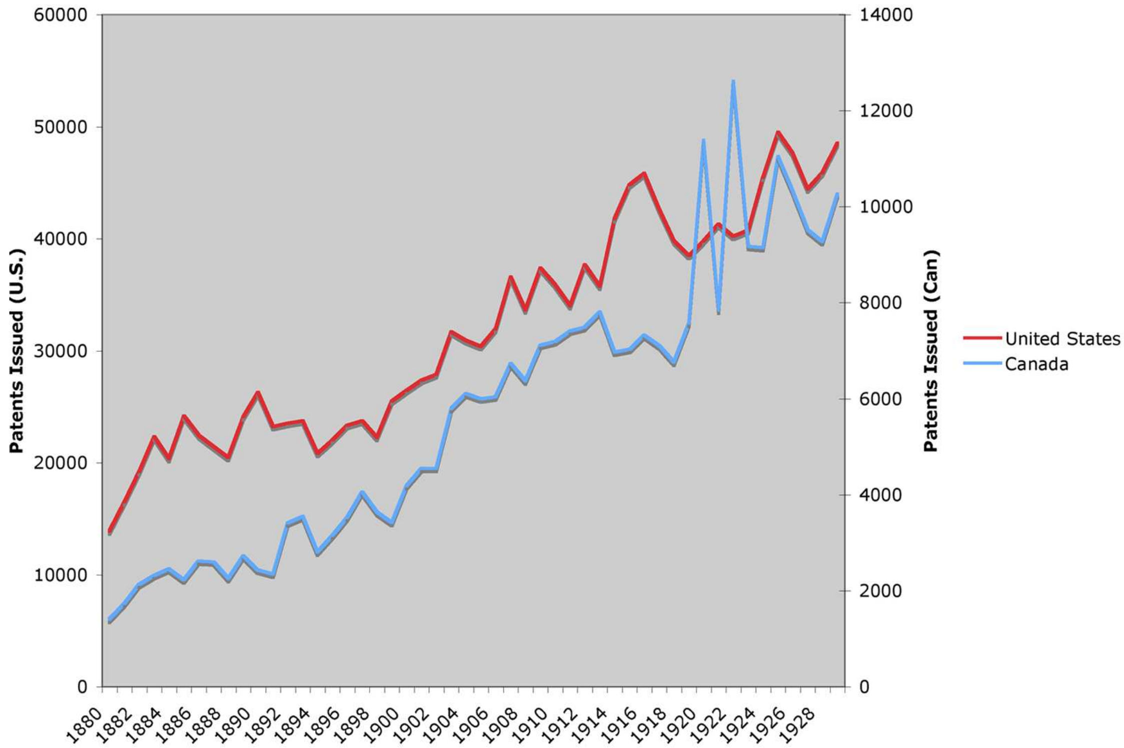


Figure 5: Total and Relative Patents: Canada and the U.S., 1880-1929



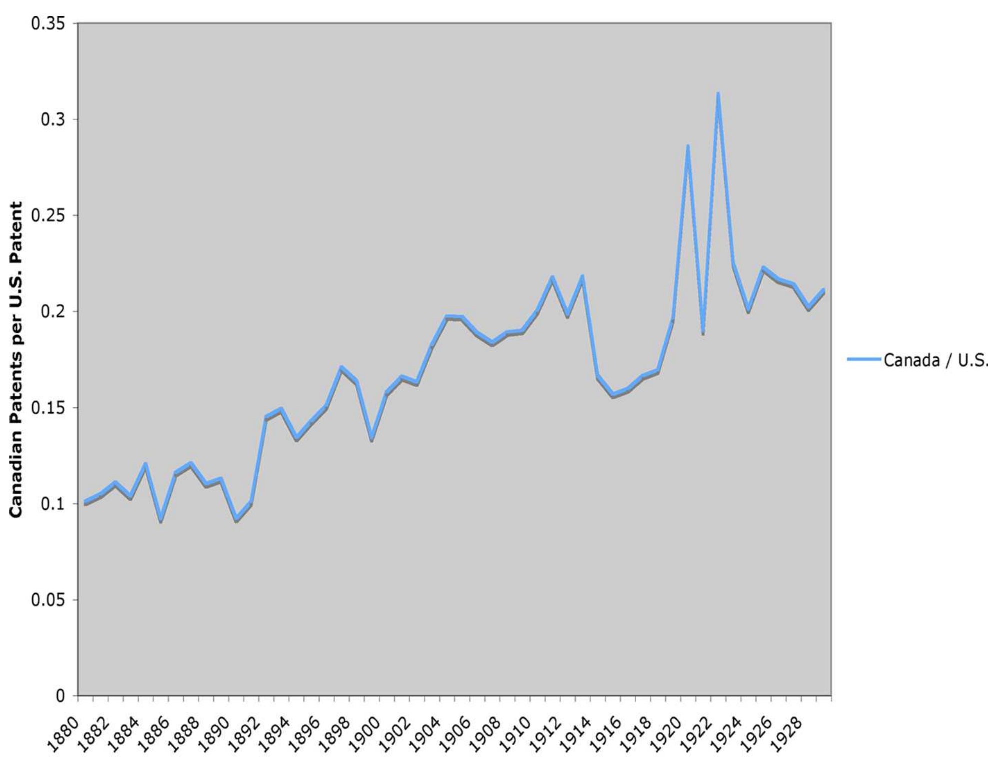


Figure 6: Total Patents Issued (per 1000 people): Canada and the U.S., 1880-1929

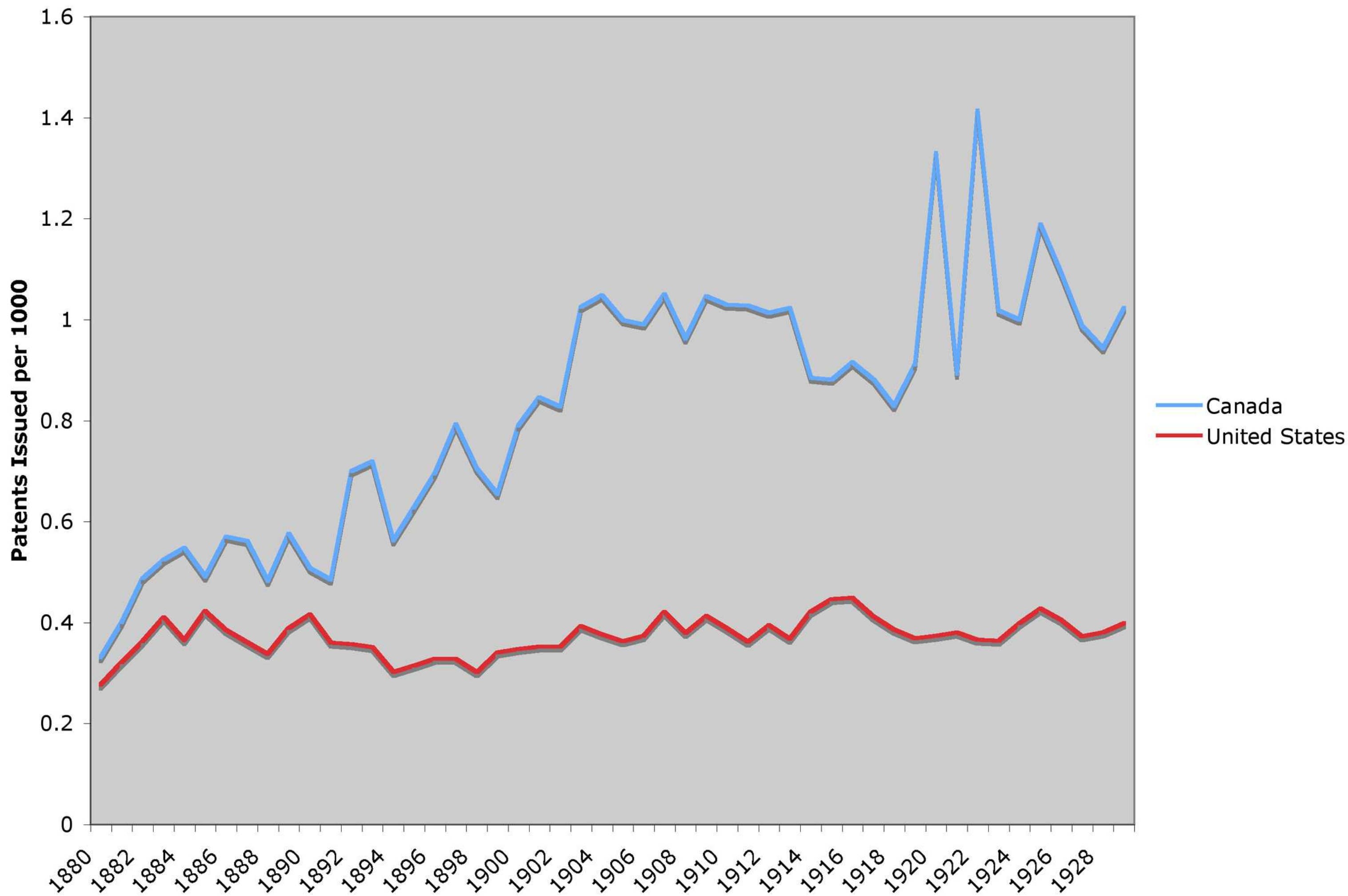
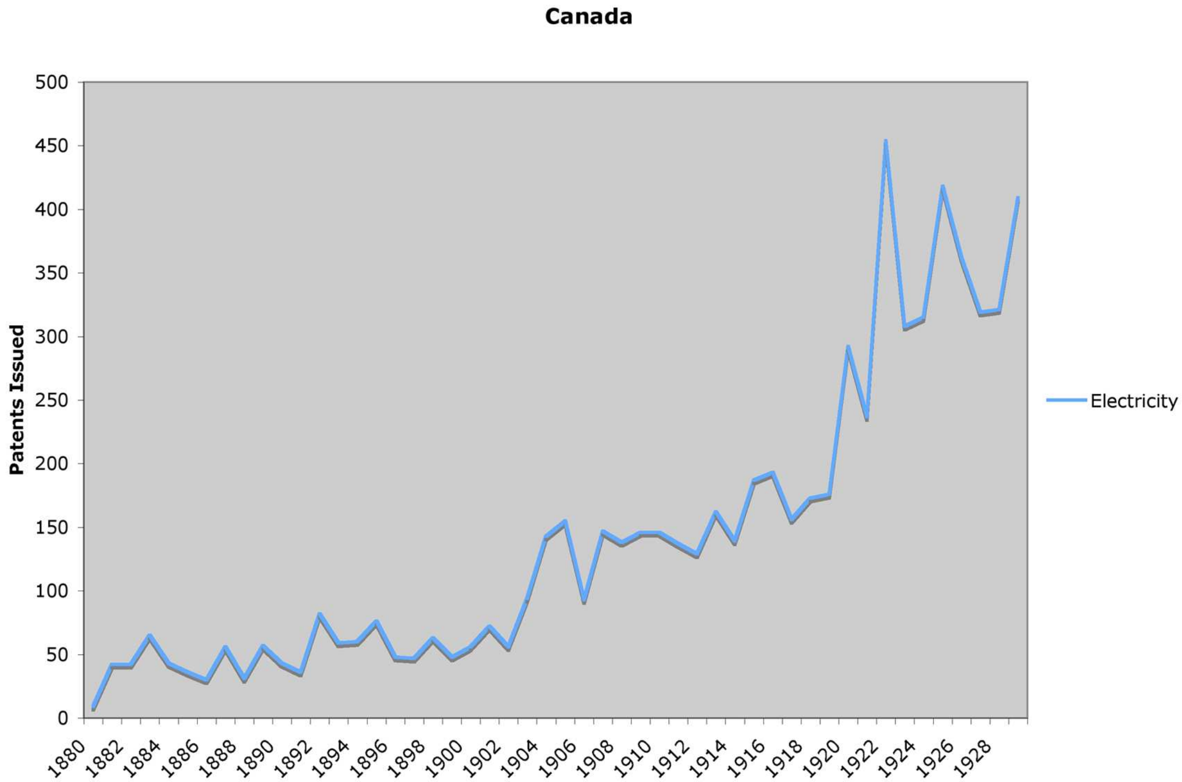


Figure 7: Electricity Related Patents: Canada and the U.S., 1880-1929



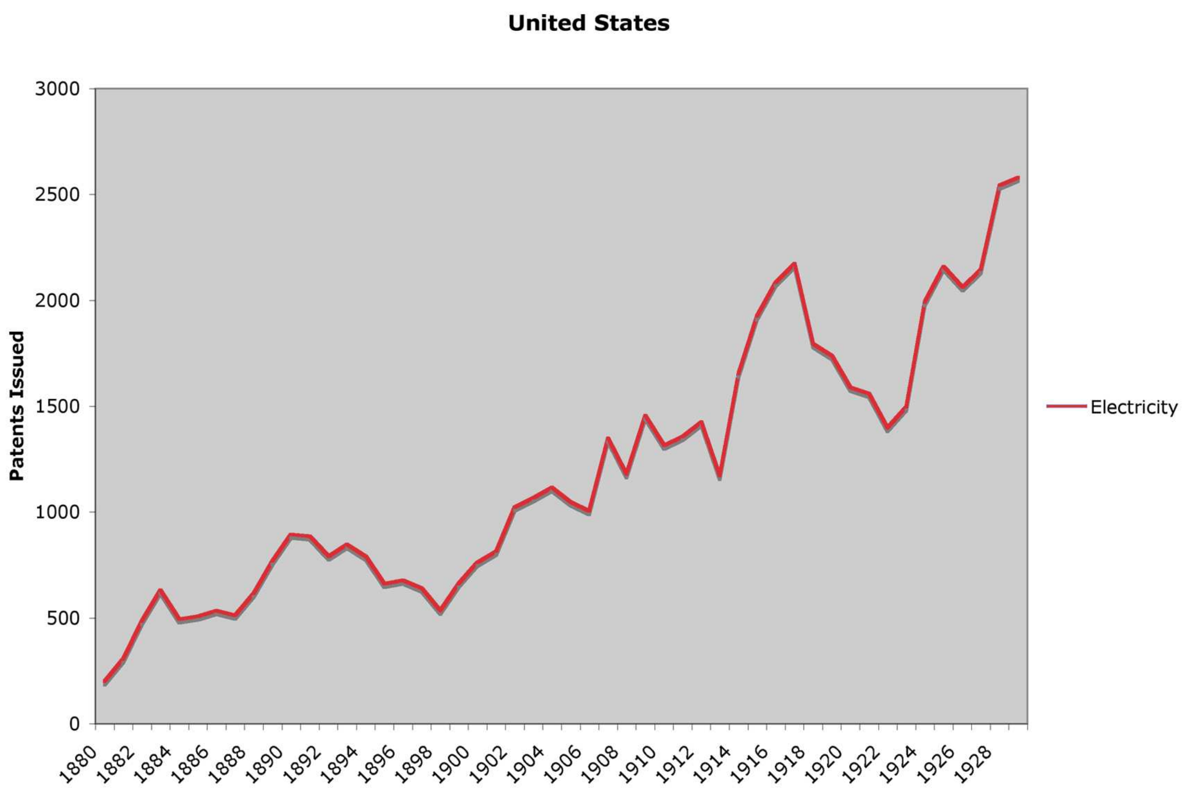


Figure 8: Number of Patents in Electricity and All Categories: Canada/U.S., 1880-1929

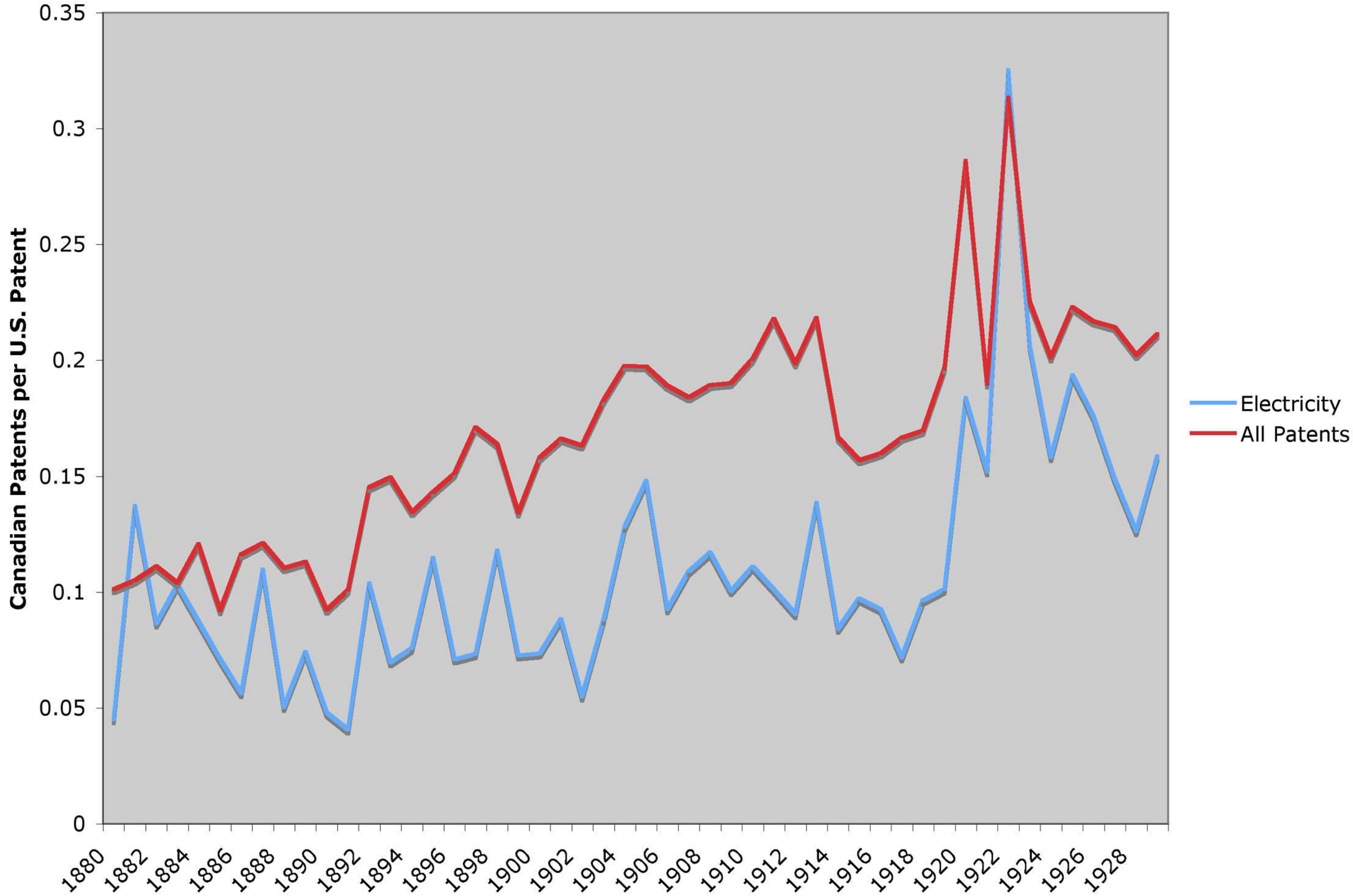


Figure 9: Electricity Patents in Canada by Origin of Inventors and Owners, 1880-1919

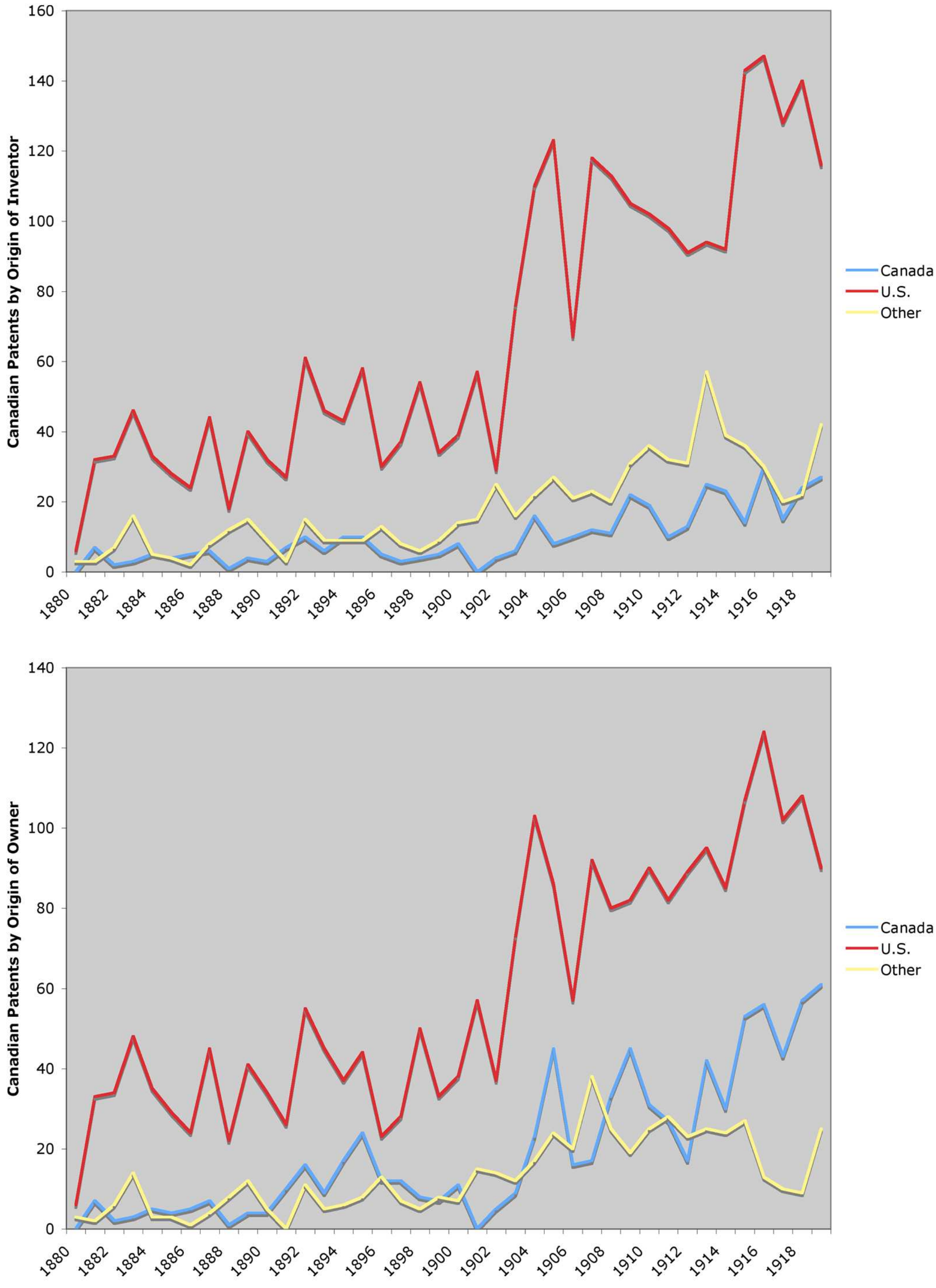


Figure 10: Electricity Patents as a Share of Overall Patenting: Canada and the U.S., 1880-1929

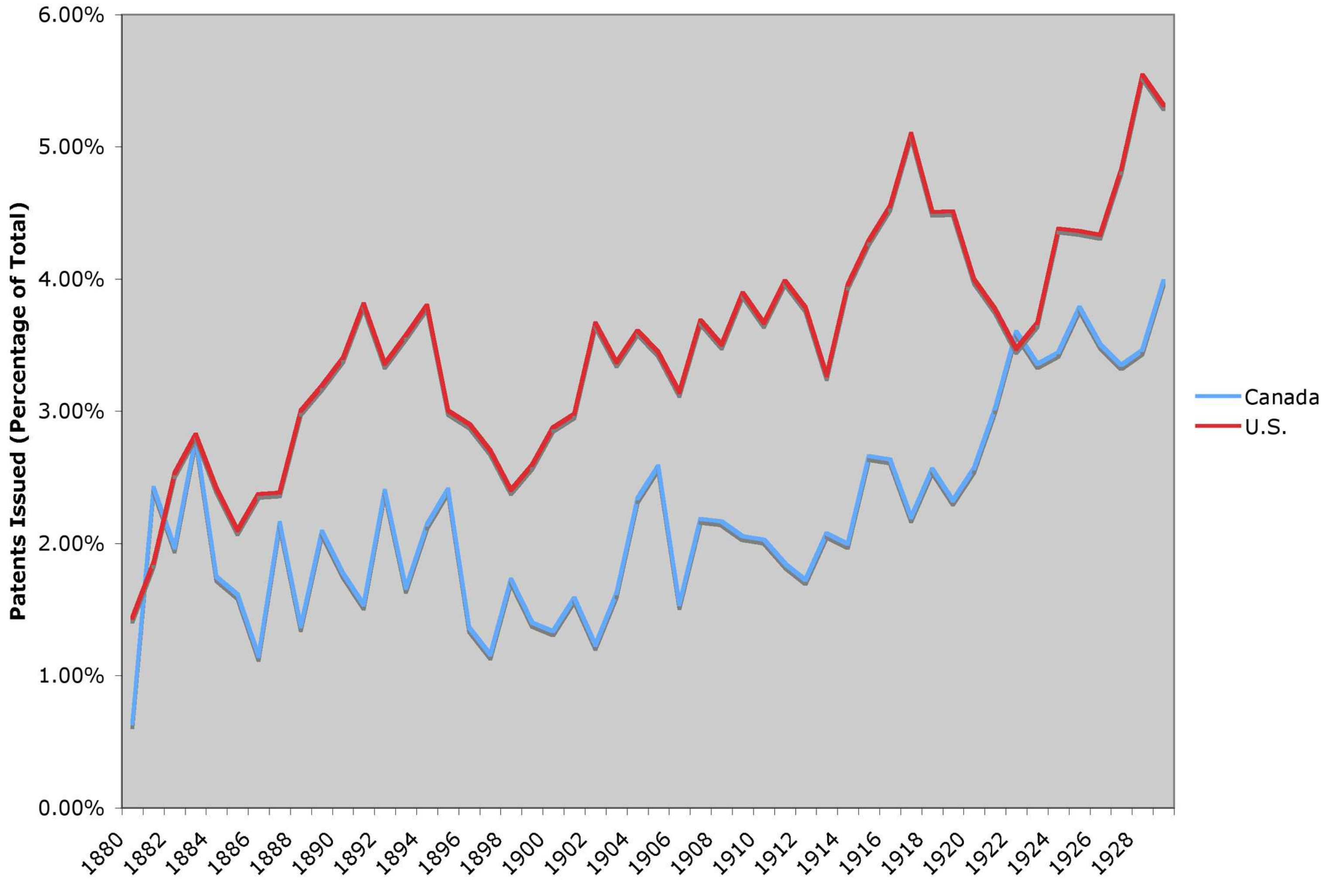
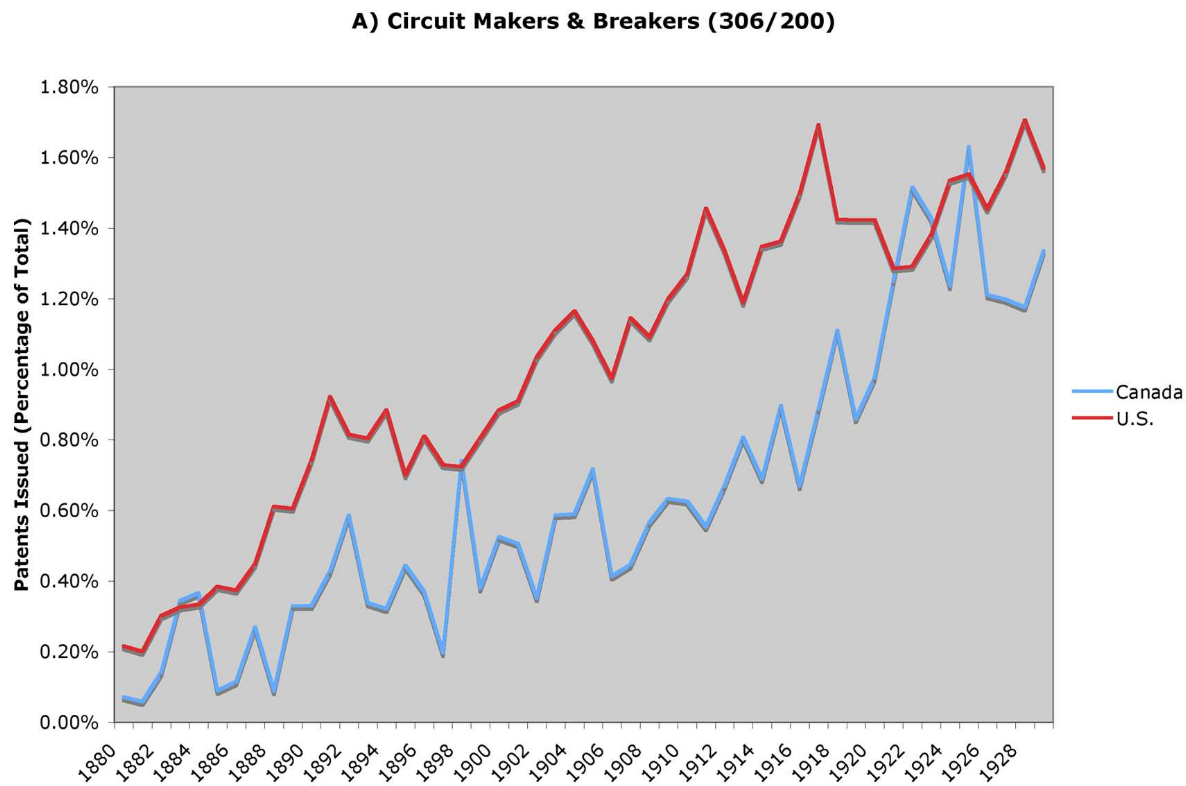
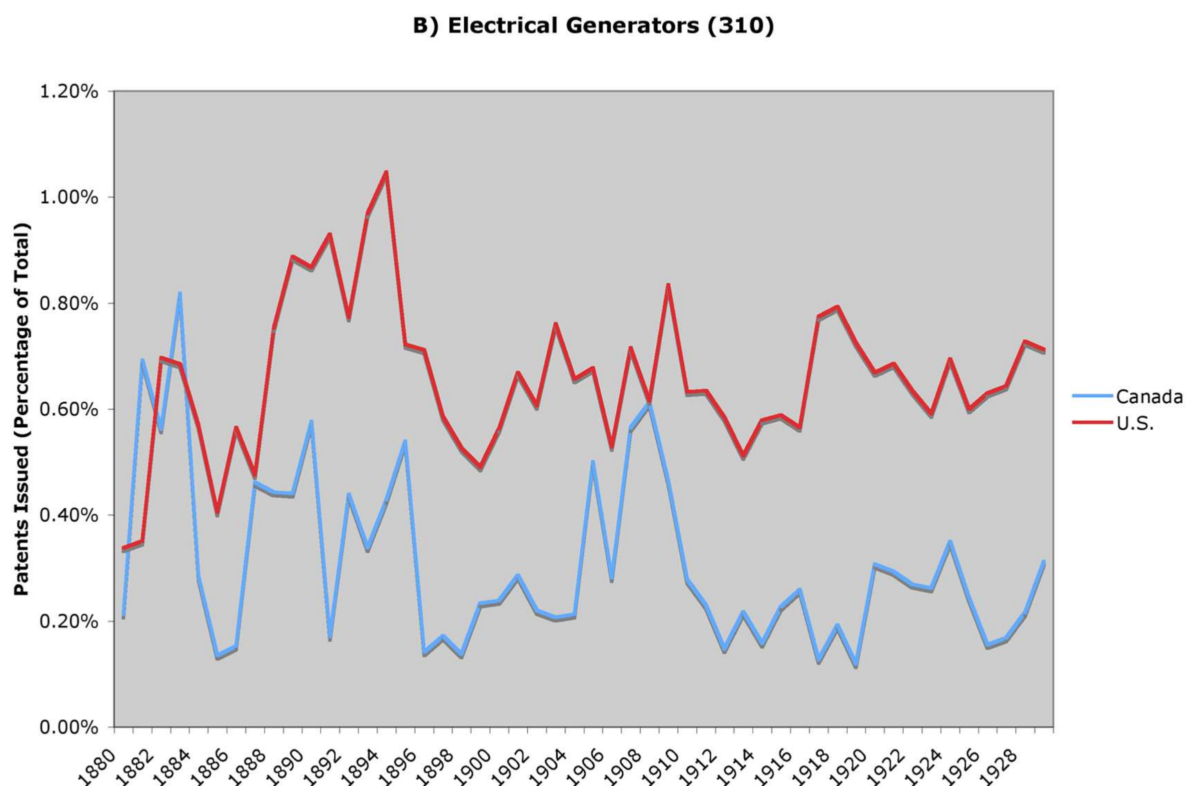
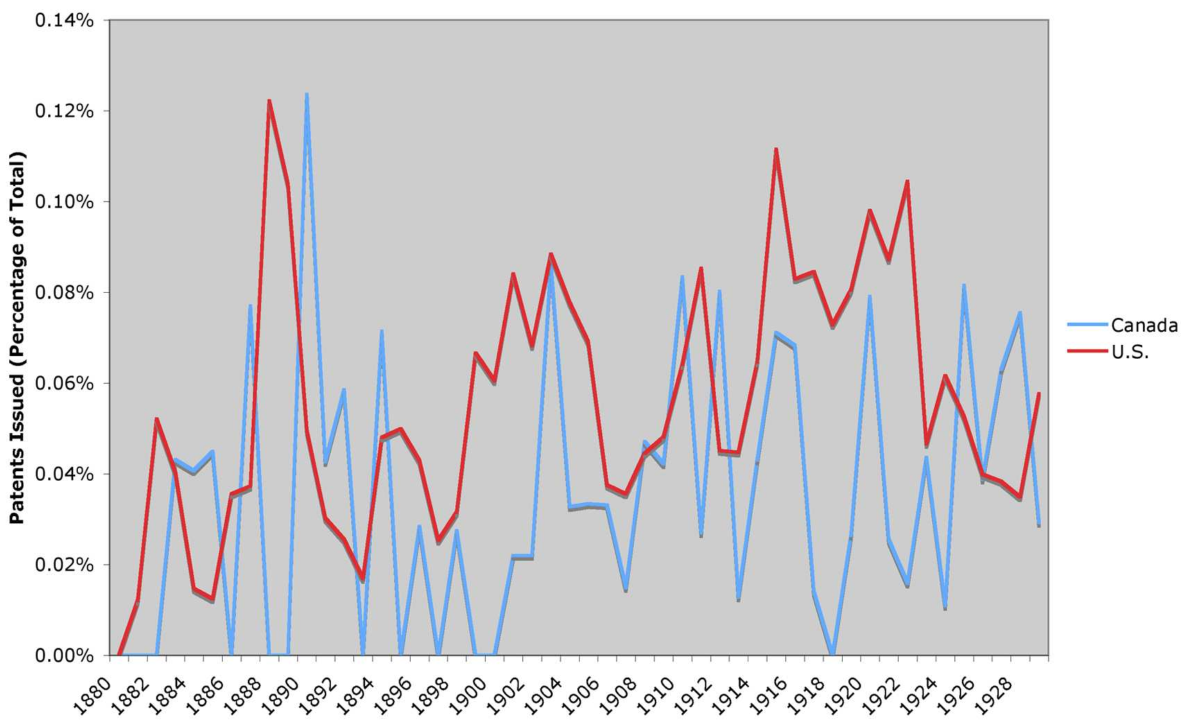


Figure 11: Electricity Patents by Category as a Share of Overall Patenting: Canada and the U.S., 1880-1929

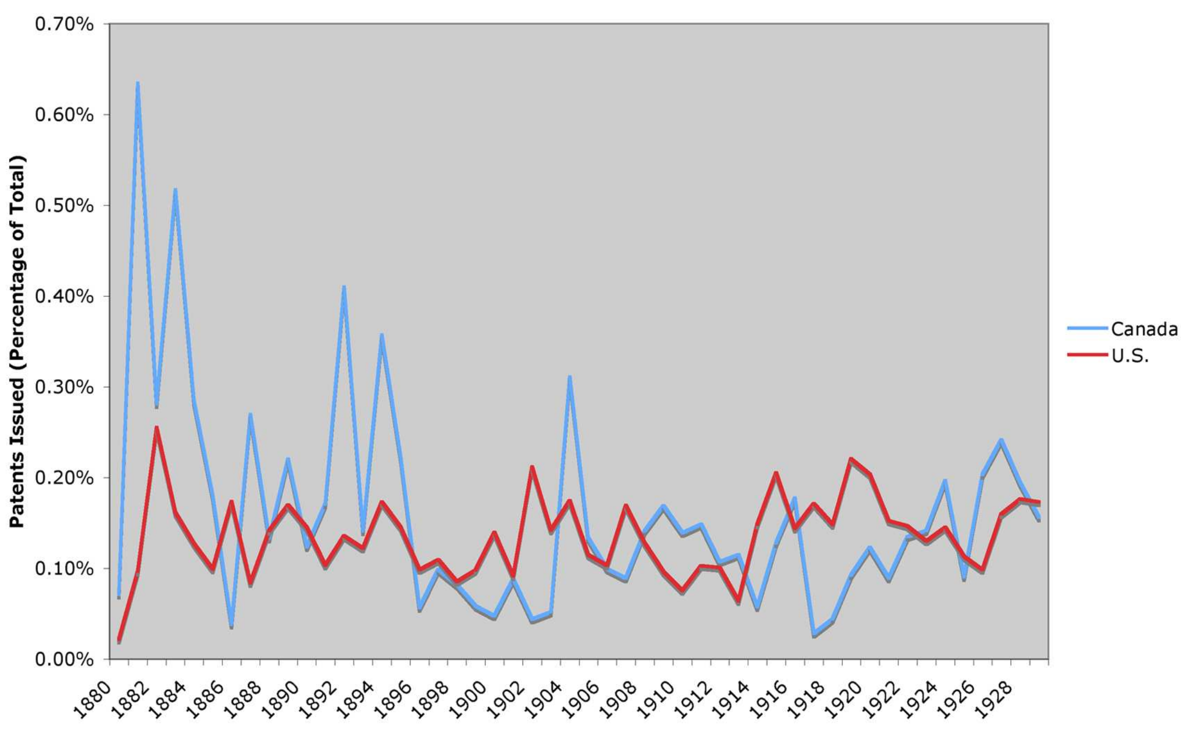


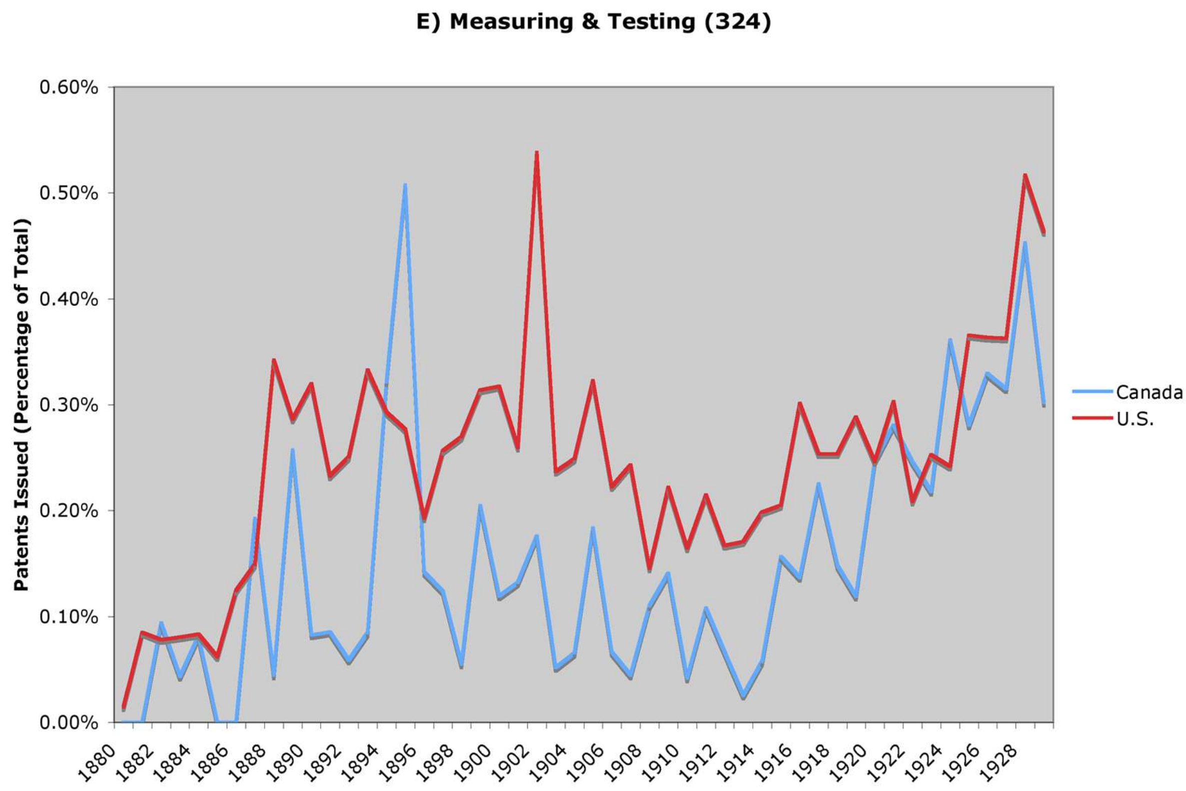


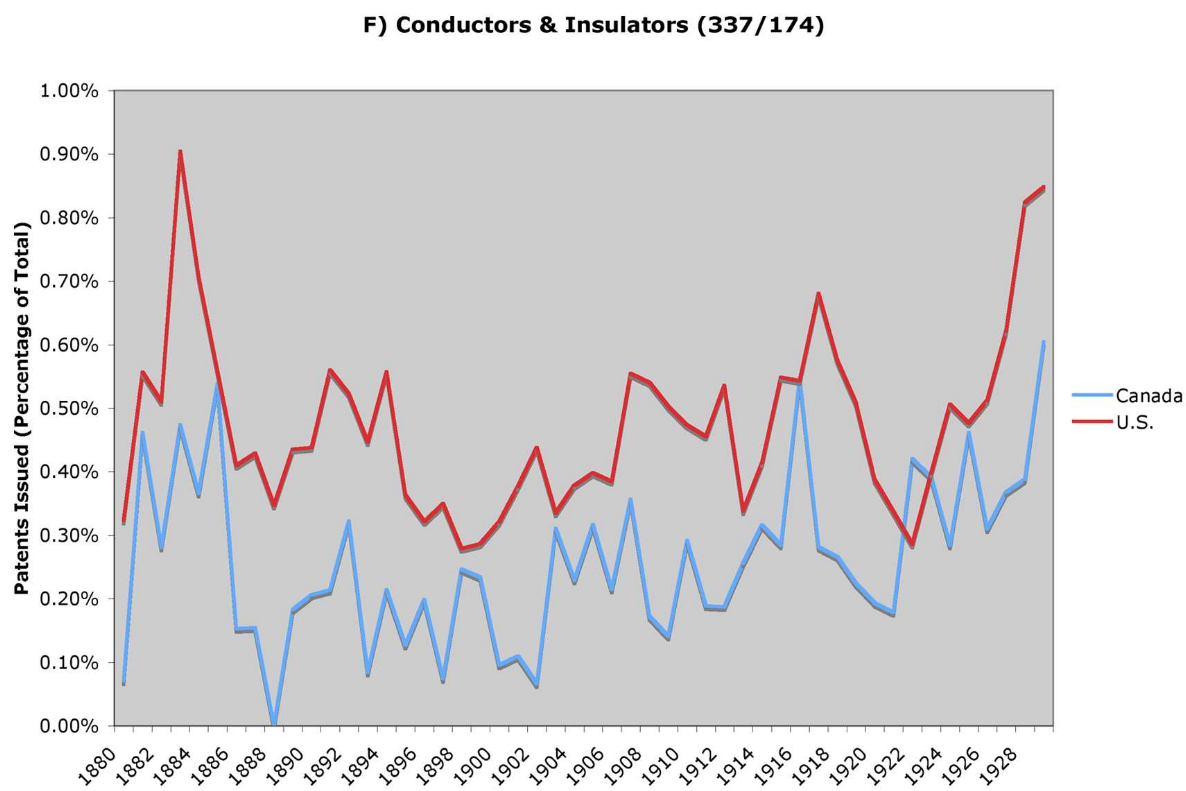
C) Battery/Capacitor Charging & Discharging (320)



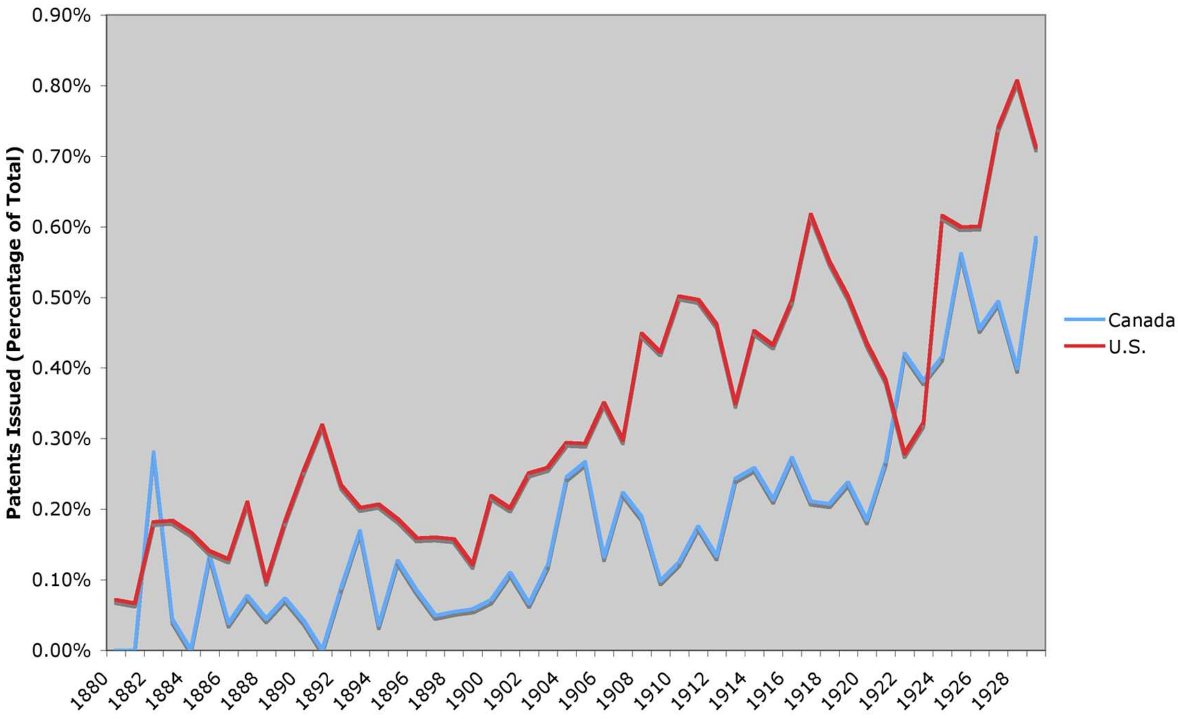
D) Single Generator Systems (322)




E) Measuring & Testing (324)
Patents Issued (Percentage of Total)
0.60%
0.50%
0.40%
0.30%
0.20%
0.10%
0.00%
1880
1882
1884
1886
1888
1890
1892
1894
1896
1898
1900
1902
1904
1906
1908
1910
1912
1914
1916
1918
1920
1922
1924
1926
1928
Canada
U.S.


F) Conductors & Insulators (337/174)
Patents Issued (Percentage of Total)
1.00%
0.90%
0.80%
0.70%
0.60%
0.50%
0.40%
0.30%
0.20%
0.10%
0.00%
1880
1882
1884
1886
1888
1890
1892
1894
1896
1898
1900
1902
1904
1906
1908
1910
1912
1914
1916
1918
1920
1922
1924
1926
1928
Canada
U.S.

G) Electrical Connectors (339/439)



H) Electrical Communications (340)

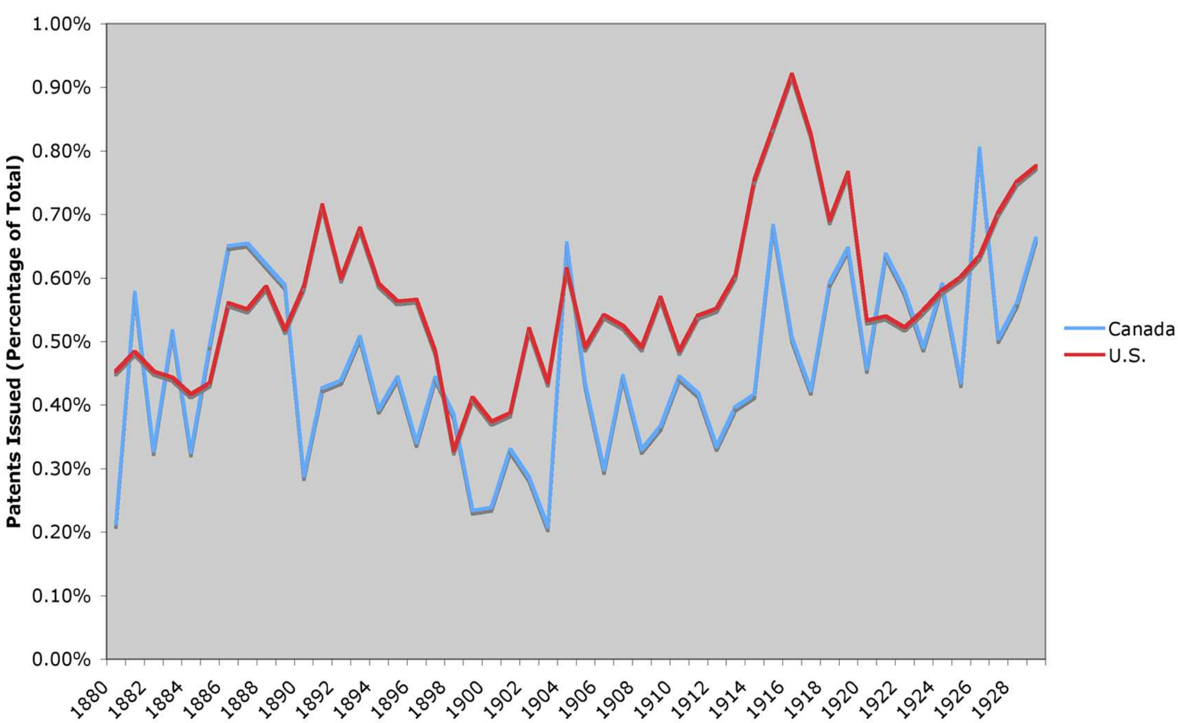


Table 1: Electricity Rates in Canadian and U.S. Cities in 1920

	Toronto	Hamilton	London	Montreal	Buffalo	Detroit
Domestic heat and light	1.53	1.53	1.53	2.56	5.80	4.14
Commercial light	3.88	2.45	3.00	4.87	7.00	7.49
Power, small load	2.93	1.83	2.21	3.55	5.25	7.14
Power, large load	1.00	0.63	0.76	1.33	1.54	2.78

Note: Rates are expressed in Canadian cents per kilowatt-hour

Source: Wylie (1989, p. 557)

Table 2: Electricity and Coal Shares in Canadian Manufacturing: Technological Biases, 1910-1929

	1910 Actual	1929 Actual	Change: 1910-1929 (dS_i)	Change due to factor substitution ($\sum_j b_{ij} dlnX_i$)	Change due to biased technical change (dBS_i)
Electricity Shares:					
Chemicals	0.005	0.034	0.029	0.013	0.016
Petroleum and Coal	0.004	0.011	0.007	0.047	-0.040
Stone, Clay, Glass	0.012	0.041	0.029	0.035	-0.006
Iron and Steel	0.008	0.019	0.011	0.022	-0.011
Non-Ferrous Metals	0.025	0.027	0.002	0.019	-0.017
Machinery	0.005	0.007	0.002	0.003	-0.001
Transportation Equipment	0.003	0.009	0.006	0.000	0.006

	1910 Actual	1929 Actual	Change: 1910-1929 (dS_i)	Change due to factor substitution ($\sum_j b_{ij} dlnX_i$)	Change due to biased technical change (dBS_i)
Coal:					
Chemicals	0.026	0.021	-0.005	-0.009	0.004
Petroleum and Coal	0.046	0.014	-0.032	-0.174	0.142
Stone, Clay, Glass	0.093	0.102	0.009	0.004	0.005
Iron and Steel	0.034	0.026	-0.008	0.002	-0.010
Non-Ferrous Metals	0.038	0.016	-0.022	-0.030	0.008
Machinery	0.019	0.009	-0.010	-0.007	-0.003
Transportation Equipment	0.030	0.016	-0.014	0.004	-0.018

Source: Wylie (1986, p. 97) and Wylie (1989 p. 586)

Table 3: Factor Share Changes Due to Biased Technical Change: Canada, 1910-1929, U.S., 1909-1929

Industry	Electricity Can	Electricity U.S.	Coal Can	Coal U.S.
Chemicals	0.016	-0.010	0.004	-0.016
Petroleum and Coal	-0.040	-0.104	0.142	0.018
Stone, Clay, Glass	-0.006	-0.035	0.005	-0.016
Iron and Steel	-0.011	-0.015	-0.010	0.002
Non-Ferrous Metals	-0.017	-0.020	0.008	0.002
Machinery	-0.001	-0.008	-0.003	0.004
Transportation Equipment	0.006	0.002	-0.018	-0.002

Source: Wylie (1989, p. 586)

Table 4: Specification Tests for Factor Input Biased Technical Change: Canada, 1910-1929

Industry	No Input Bias (Log Likelihood)	No Price Induced Input Bias (Log Likelihood)
Metals	36.97	18.19
Machinery	39.79	13.36
Non-Metallic Minerals	11.77	10.88
Chemicals	32.00	26.30
Critical Values of Chi-Square		
1 % level	21.66	16.81
5 % level	16.92	12.59
10 % level	14.68	10.65

Note: degrees of freedom are 9 and 6 respectively
Source: Wylie (1986, p. 144)

Table 5: Tests for Technological Bias: Canada vs U.S., 1907-1990

Industry	Null: Common Technology (Wald)	Null: Common Technological Biases (Wald)
Steel	844.280	31.109
Cotton	975.911	37.227
Silk	1612.585	84.537
Cement	6496.593	1093.509
Sugar	346.274	41.088
Oil	2411.012	643.809
Paper	1706.629	245.297
Wine	75413.982	6978.252
Spirits	6819.520	141.047

Note: degrees of freedom are 12 and 3 respectively
Source: Keay (2000, pp. 235-236)

Table 6: Elasticities of Substitution and Own-Price Elasticities of Demand (Electricity and Coal): Canada and the U.S., 1910-1929

	ϵ_{EE}		ϵ_{CC}		σ_{EC}	
Industry	Canada	U.S.	Canada	U.S.	Canada	U.S.
Metals	-1.19	-1.82	-1.80	-1.93	-10.85	4.65
Machinery	-0.88	-1.21	-1.06	5.99	19.69	-10.98
Minerals	-1.37	n/a	0.21	n/a	-7.81	n/a
Chemicals	-3.02	-1.36	0.64	-1.93	33.85	4.49

Note: Elasticities were calculated using the unrestricted translog model estimation referred to as model 1 in Wylie (1986)
Source: Wylie (1986, pp. 92, 146-149)

Table 7: Elasticities of Substitution and Own-Price Elasticities of Demand in Manufacturing: Canada and the U.S., 1907-1990

Partial Elasticities						
	σ_{KL}		σ_{ML}		σ_{KM}	
Industry	Canada	U.S.	Canada	U.S.	Canada	U.S.
Steel	0.827	0.158	1.300	0.294	-2.425	0.294
Cotton	0.685	0.614	1.214	0.834	2.420	-2.271
Silk	0.239	0.013	0.812	0.811	0.002	1.657
Cement	1.057	-2.801	1.069	5.293	-2.847	2.775
Sugar	0.450	-0.224	0.878	0.266	0.312	0.171
Oil	0.378	-0.631	0.239	0.966	0.889	3.688
Paper	0.580	1.865	1.993	4.142	0.270	-8.341
Wine	0.595	-0.571	1.483	0.320	0.056	7.243
Spirits	1.100	0.131	1.493	0.944	0.221	-0.031
Own-Price Elasticities						
	ϵ_{LL}		ϵ_{KK}		ϵ_{MM}	
Industry	Canada	U.S.	Canada	U.S.	Canada	U.S.
Steel	-0.092	-0.033	-0.342	-0.191	-0.694	-0.308
Cotton	-0.099	-0.077	-0.571	-0.307	-0.662	-0.559
Silk	-0.094	-0.071	-0.203	-0.227	-0.538	-1.016
Cement	-0.179	-0.011	-0.255	-0.054	-0.409	-0.295
Sugar	-0.273	-0.385	-0.334	-0.014	-0.623	-0.583
Oil	-0.177	-0.052	-0.590	-0.432	-0.280	-0.366
Paper	-0.209	-0.276	-0.422	-0.169	-1.317	-1.178
Wine	-0.168	-0.013	-0.371	-0.386	-0.922	-0.419
Spirits	-0.324	-0.508	-0.803	-0.087	-0.906	-0.653

Source: Keay (2000, pp. 232-233)

Table 8: Patents Issued in Canada by Country of Residence of Patentee, 1900-1914

	Total	Canada	United States	Great Britain	Other
1900	4552	707	3216	254	375
1905	6647	888	4451	309	999
1910	3233	1198	5021	342	1672
1914	9241	1334	5202	558	2147

Source: Naylor (1975, Vol. 2, p. 46)

Table 9: Description of Electricity-Related Patent Categories

Category	Title	Description
306/200	Electricity: Circuit Makers and Breakers	This is the generic class for devices, per se, of general application which are used for closing or opening electrical circuits and the combination of these devices with their operating means
310	Electrical Generator or Motor Structure	This is the residual class for all subject matter, not elsewhere classified, relating to electrical generator or motor structure
320	Electricity: Battery or Capacitor Charging or Discharging	This class provides for a method or apparatus for controlled or regulated charging, discharging, or combined charging and discharging of one or more voltaic cells, batteries or capacitors
322	Electricity: Single Generator Systems	This is the class for single electric energy generators for supplying single load circuits, there being means to regulate or control the generator output, where means may be electrical or non-electrical and may act in prime mover for the generator or the power transmission means between the generator prime mover and the generator
324	Electricity: Measuring and Testing	This is the residual class for all subject matter relating to the measuring, testing of electrical properties, or the measuring, testing or sensing of non-electric properties by electric means
337/174	Electricity: Conductors and Insulators	This class is for inventions relating to the structure of electrical conductors and insulators and the apparatus specialized to mounting, supporting, encasing in conduits, and/or housing the same
339/439	Electrical Connectors	This is the generic class for a pair of mated conductors comprising at least two electrically conducting elements which are interconnected to permit relative motion of such conducting elements during use without a break in electrical conductivity there between
340	Communications: Electrical	This is the residual class for subject matter relating to communication by means which are in part or in whole electrical

Note: If two categories are listed the first indicates the Canadian category number while the second indicates the United States category number.

Source: http://www.uspto.gov/go/classification/.

Table 10: Correlation Coefficients: Canada and U.S. Patent Series, 1880-1929

	Can	$U.S.$	$U.S._{-1}$	$U.S._{+1}$
Can	1.0000			
$U.S.$	-0.1157 (0.4286)	1.0000		
$U.S._{-1}$	0.2958 (0.0791)	0.0009 (0.9949)	1.0000	
$U.S._{+1}$	-0.1907 (0.1943)	0.0009 (0.9949)	-0.0291 (0.8463)	1.0000

(P-Values in Parentheses)

Note: The Canadian and United States patent series over the period 1880-1929 have been first differenced and the United States series has been lagged and leaded one period.

Table 11: Vector Autroregression Model

	(1) $\ln Can$
$\ln Can_{-1}$	-0.5947 (0.000)
$\ln Can_{-2}$	-0.1660 (0.147)
$\ln U.S._{-1}$	**0.5767** **(0.025)**
$\ln U.S._{-2}$	0.1212 (0.638)
Const	0.0547 (0.196)

(P-Values in Parentheses)

Note: The Canadian and United States patent series over the period 1880-1929 have been first differenced and natural logarithms were taken of each.

Table 12: Detailed Patent Data from Category 320

Canada		United States				
Month	Year	Month	Year	Invention	Inventor	Inventor Country
1	1884	12	1883	Automatic Electric Regulator for Storage Batteries	Perkins, Charles G.	United States
7	1885	7	1882	System of Electric Lighting and Power Distribution	Starr, Eli T. & Peyton, William	United States
2	1890	1	1889	Apparatus and Connection for Charging and Discharging Storage Batteries	Kookogey, William P.	United States
4	1890	11	1889	Electrical Distribution	Currie, Stanley C.C.	Unknown
5	1890	10	1888	System and Means to be used in the Supply or Distribution of Electricity for Lighting or Other Purposes	Edmunds, Henry	United Kingdom
7	1896	1	1899	Automatic Switch for Storage Batteries, Etc.	Hopkinson, John	United Kingdom
6	1898	3	1898	Electrical Distribution System	Bliss, William Lord	United States
5	1903	8	1902	Electrical System of Lighting and Power	Moskowitz, Morris	United States
7	1903	1	1900	System of Electrical Distribution	Hubbard, Albert S.	United States
11	1903	2	1901	Storage Battery	Suren N., N. Harry	United States
12	1903	2	1901	Apparatus for Controlling the Connections of Storage Batteries with Charging Circuits	Suren N., N. Harry	United States
5	1904	3	1898	Electrical Distribution System	Bliss, William Lord	United States
6	1904	1	1904	Electrical Generation	Sperry, Elmer Ambrose	United States
11	1906	9	1903	Electric Lighting System	Leitner, Henry & Lucas, Richard Norman	United Kingdom
12	1908	5	1904	Electrical Distribution System	Turbayne, William A.	United States
8	1910	12	1910	Primary and Secondary Storage Battery System	Gugler, Julius H.	United States
12	1910	6	1912	Electric Distribution System	Etchells, James & Crouch, John Peachey	United Kingdom
8	1911	3	1915	Electric Train Lighting System	Darker, Alfred Henry	United Kingdom
10	1912	1	1911	Electrical System of Distribution	Jepson, John W.	United States
12	1913	7	1915	Regulator for Storage Batteries	Conrad, Frank	United States
5	1914	5	1917	Method of Charging Secondary Batteries	Jacobson, Edward B.	United States
5	1915	11	1918	Electricity Storage System	Kettering, Charles F.	United States
6	1915	8	1917	Dynamo Electric Generator	Darker, Alfred Henry	United Kingdom
10	1916	6	1911	Train Lighting System	Grob, Hugo	Germany
11	1916	1	1915	Method of Charging Storage Batteries	Wilson, David H.	United States

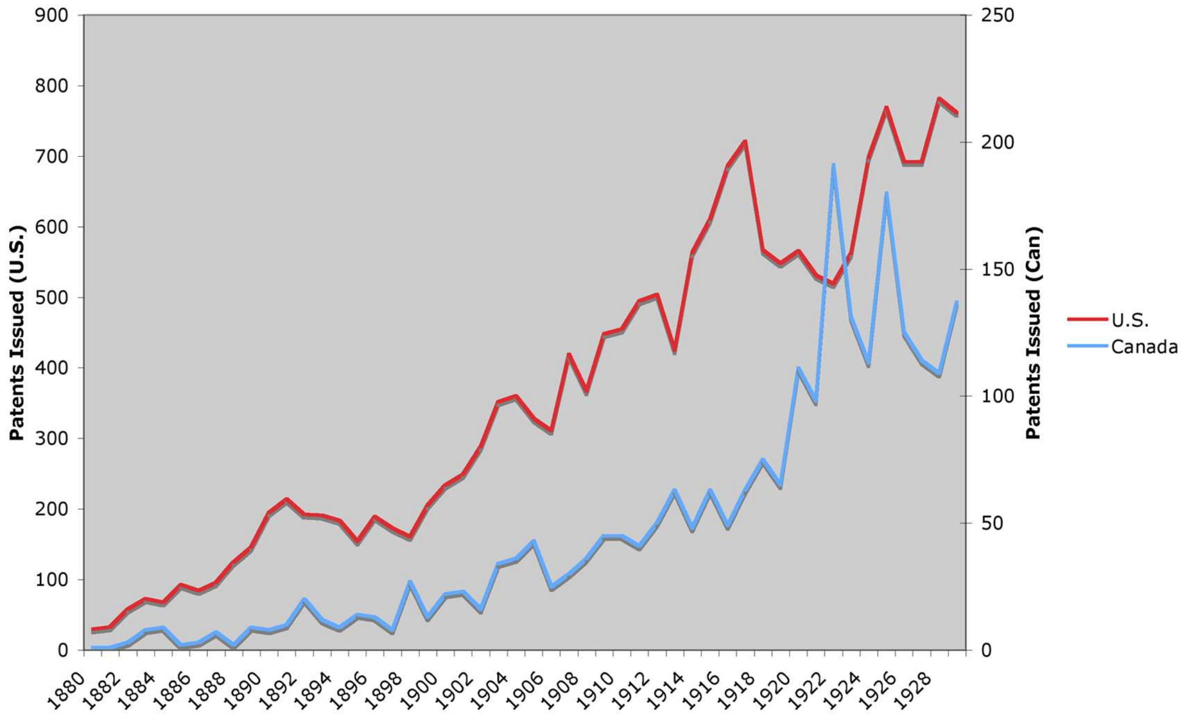
Appendix

Figures 12 (A) to (H) display the electricity-related patents by category in the United States and Canada. All of the categories were characterized by a strong upward trend in electricity patenting. In categories 306 (Circuit Makers & Breakers), 337 (Conductors & Insulators), 339 (Electrical Connectors), and 340 (Electrical Communications) the trend in patenting accelerated after 1900. Before 1900 the upward trend in patenting was only slightly positive, implying a gradual rise. After 1900, the trend line became steeper for both countries. In contrast, categories 320 (Battery/Capacitor Charging & Discharging), 322 (Single Generator Systems), and 324 (Measuring & Testing) display a significant upward trend in the level of patenting after WWI. Category 310 (Electrical Generators), reveals an upward trend over the entire 1880-1929 period, for both Canada and the United States.

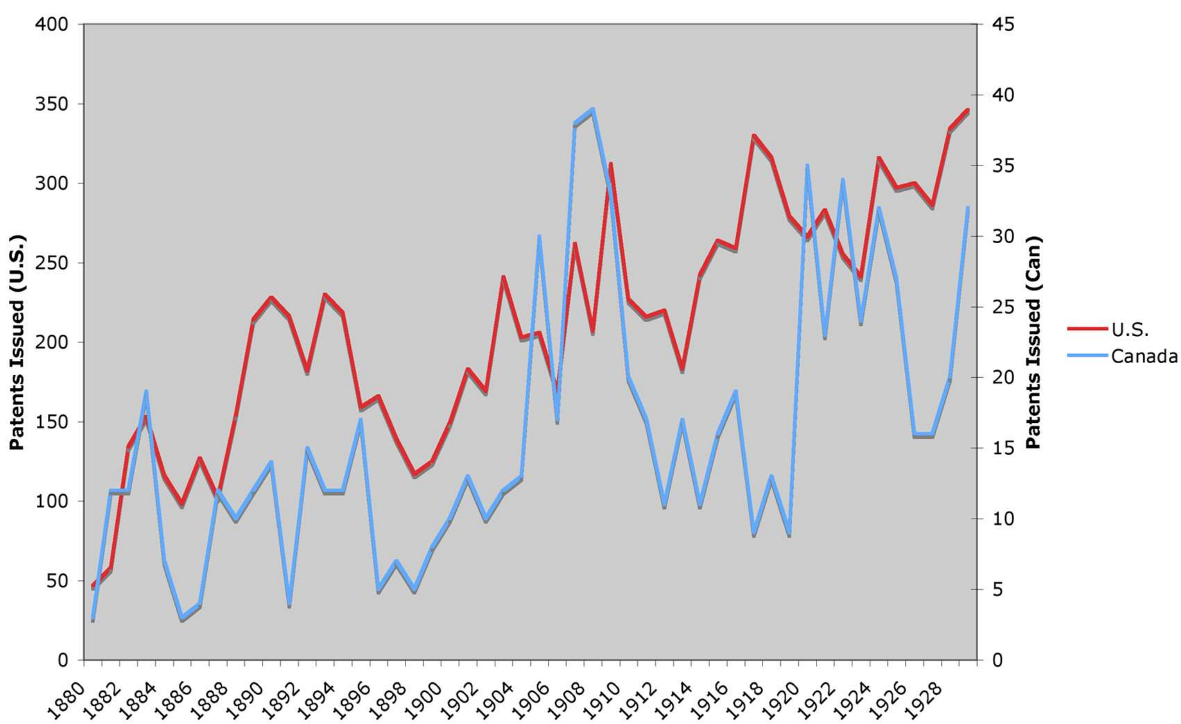
The general pattern of patenting in electricity was similar between Canada and the United States. The most significant divergence in patenting in most categories followed WWI, where the United States suffered a large decline in patenting relative to Canada. Overall, the United States issued substantially more patents in every category. For example in category 310, in 1929 three hundred and sixty-four patents were issued in the United States and thirty-two were issued in Canada.

Figure 12: Patents by Electricity Category: Canada and the U.S., 1880-1929

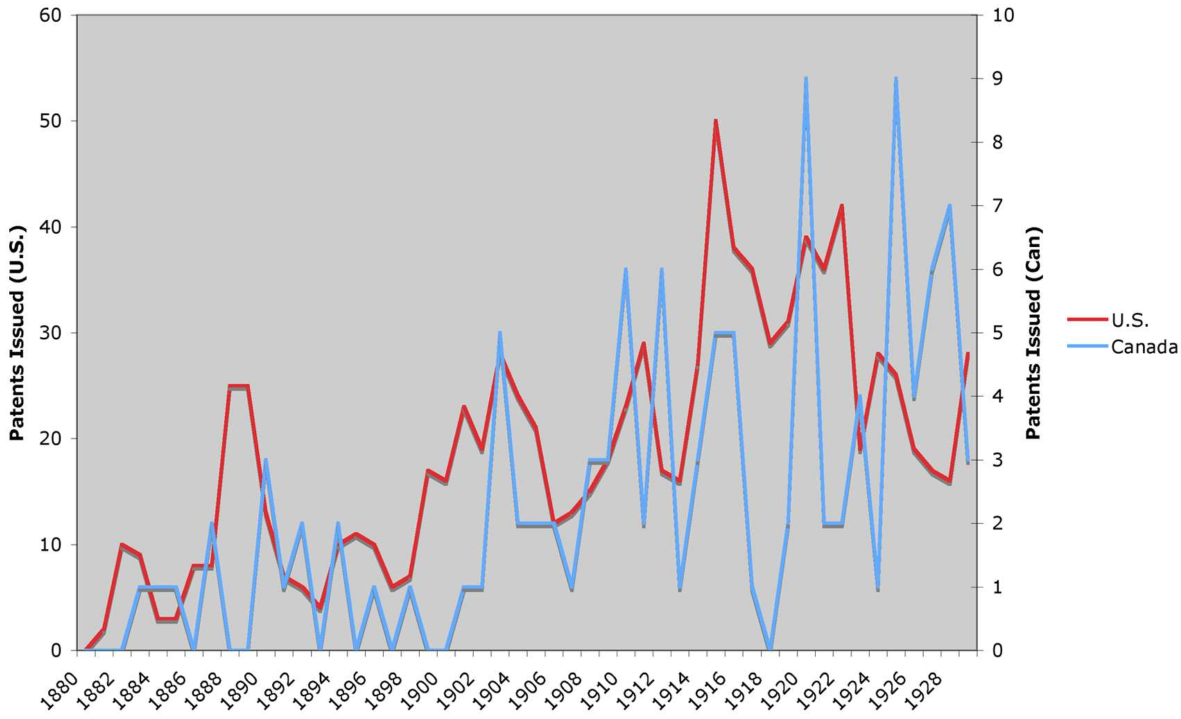
A) Circuit Makers & Breakers (306/200)



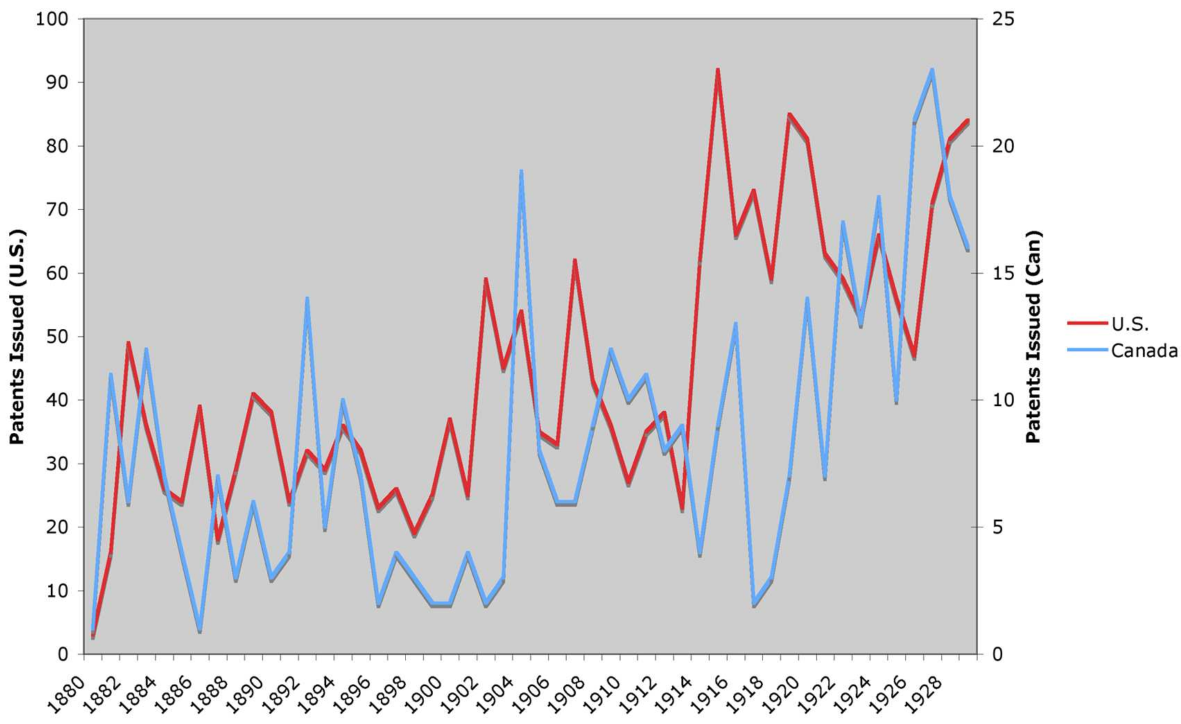
B) Electrical Generators (310)



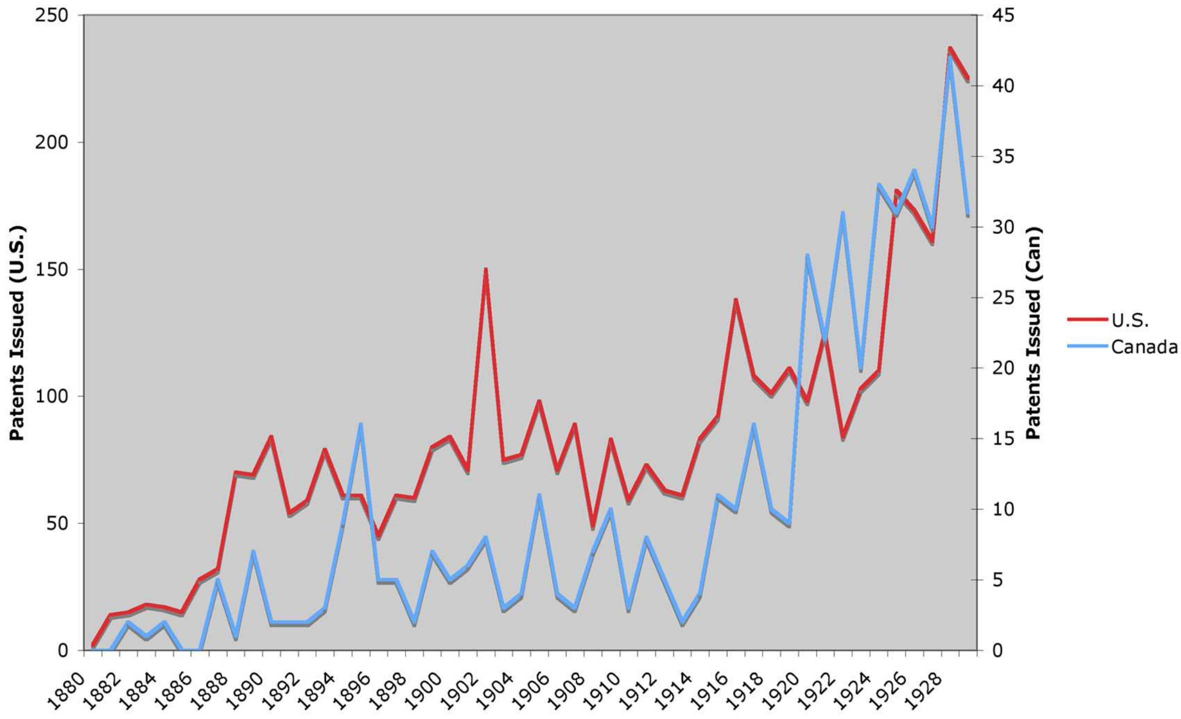
C) Battery/Capacitor Charging & Discharging (320)



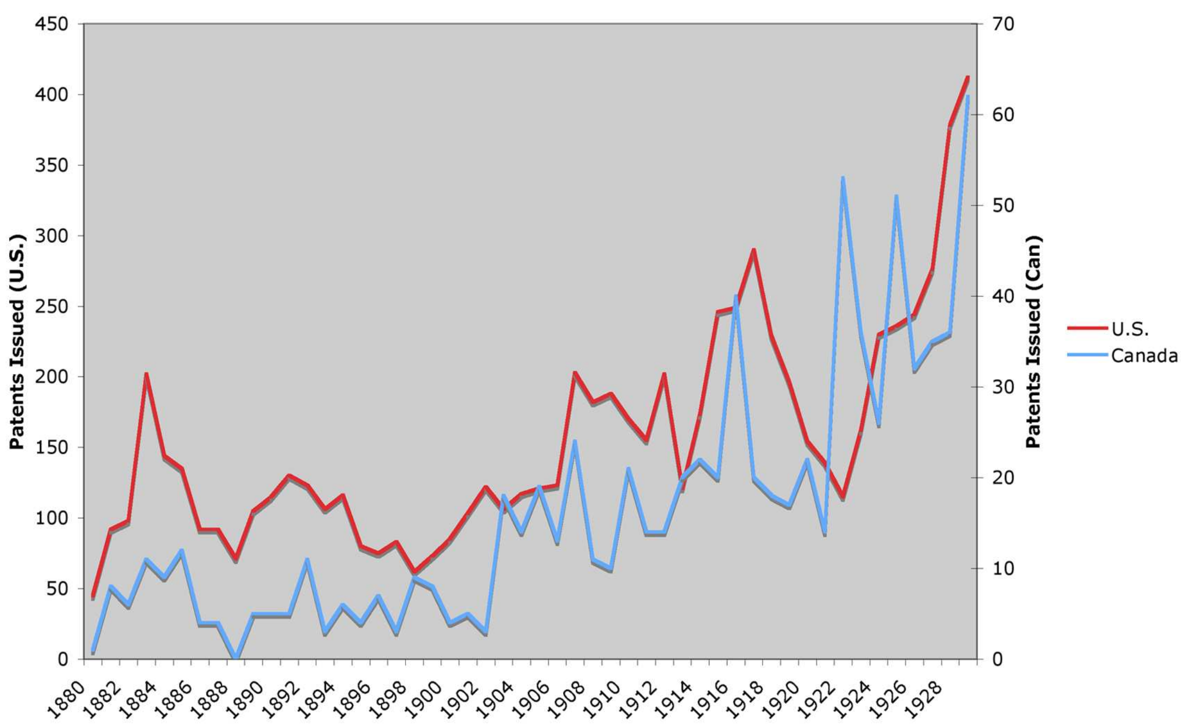
D) Single Generator Systems (322)



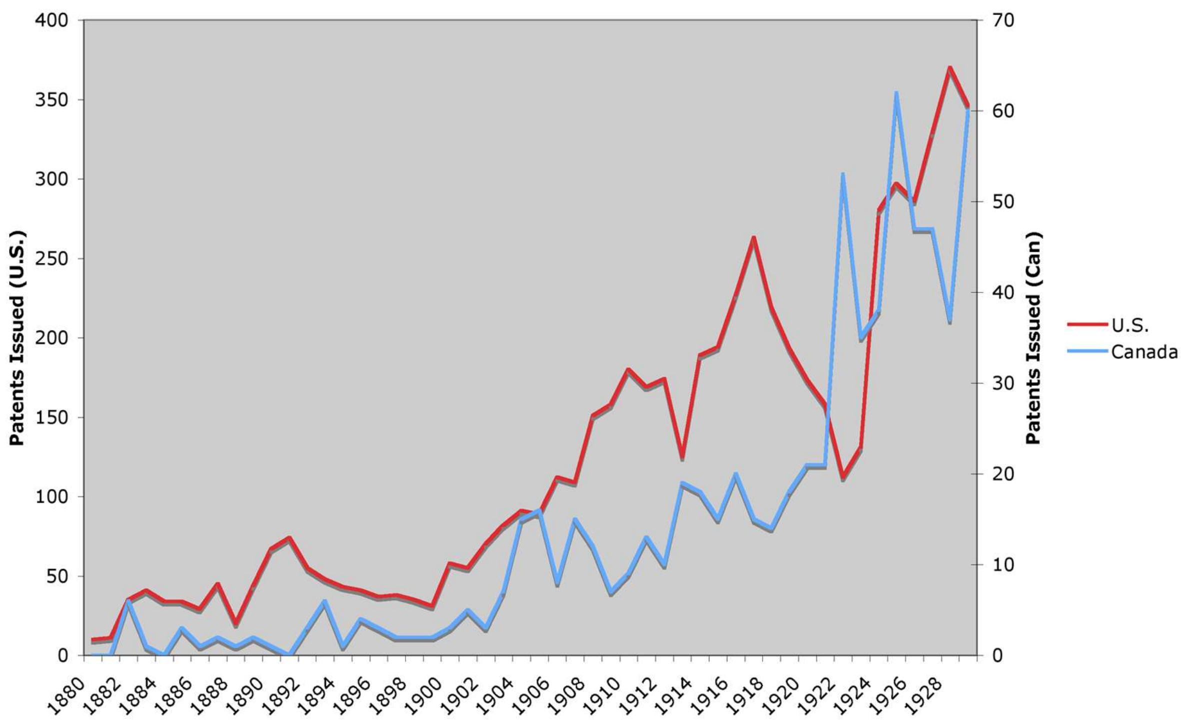
E) Measuring & Testing (324)



F) Conductors & Insulators (337/174)



G) Electrical Connectors (339/439)



H) Electrical Communications (340)