Comparative Technological Creativity in Britain and America at the End of the Nineteenth Century: The Antipodean Experience

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Abstract:

This paper uses patent data from colonial Australia to provide an estimate of comparative Anglo-American inventive activity at the end of the nineteenth century. These data confirm the traditional belief of a widening inventive gap in this period. The paper argues that much of this gap can be accounted for by each nation's factor endowment and demand pattern. The results, however, also indicate that tariffs may have had a role to play as well. The paper concludes by highlighting the need for further understanding of the ways in which competition, tariffs, and perceptions of security can impact on technological creativity.

At the end of the nineteenth century America replaced Britain as the world's leading economic power, a transition most typically expressed in terms of income per capita. Between 1870 and 1913, American real income per capita grew at around twice the rate of British. As a result by 1903 the average American enjoyed a higher income than their British cousin.[1] The reason for this occurrence has long fascinated scholars and commentators alike. Central to most explanations proffered has been the technological efflorescence of the United States in the second half of the nineteenth century. While Britain pioneered the technology of the first industrial revolution, it was in the United States that the logic of mechanization and large-scale, standardised production under one roof was to take its next step. This ‘American system of manufacture’, which first drew international attention to itself at the Great Exhibition at the Crystal Palace in 1851, was built on the growing skills and ingenuity of the American mechanic and inventor. Right across the spectrum of manufacturing and services, from the capital-goods industry through to telephony, American average and best practice techniques appeared to surge ahead of, and set the standard for, the rest of the world. In short, by the end of the nineteenth century, America had become the technological dynamo of the world, the source of both more inventive input and output than anywhere else, even the once pre-eminent Britain.

While this depiction of the Anglo-American technology gap resonates strongly throughout the literature and can be supported by numerous detailed case studies of the period, the dimensions of the gap, particularly with regard to invention, have proved difficult to quantify. There is simply no unambiguous index of a nation's technological or inventive performance. To a large extent this is due to the intangible, almost invisible nature of much inventive and technological activity. Those responsible for the countless minor improvements introduced on the shop floor and made possible by the acquisition of experience often saw no value in, or were simply not predisposed to, recording their ideas in order to protect their intellectual property, let alone for posterity. As a consequence, students of technological change have had to turn to indirect measures to gauge changes in the supply and impact of inventive ideas through time.

Streit, for example, provides a list of 1,012 major inventions made between 1750 and 1950 that includes the name of the inventor and his country of origin.[2] To the extent that these inventions constitute a meaningful sample of inventive activity, the list, summarised in table 1, sheds some light on the changing location of technological leadership over this period. It shows that the relative contributions of Britain and America to the first Industrial Revolution (1776–1825) are almost exactly reversed in the second (1875–1925). Britain's inventive dominance is steadily lost over the course of the nineteenth century, so that by 1875 it is just one of the sources, albeit still an important one, of new technological ideas.

– Table 1 here –

There are, however, problems with Streit's database of invention. Firstly, what is considered as a major invention is subjectively determined. It is certainly conceivable that others may wish to alter that list with consequences for the percentages given in table 1. Secondly, it is not clear that 'major' inventions alone are the crucial factor in explaining comparative inventive performance. Indeed, it may well be that the myriad of small inventions which improve upon such major new ideas and make them viable is what really matters in practice.[3] To the extent that many of these micro-inventions may emerge in nations other than that responsible for the macro-invention, then table 1 may not reflect inventive activity either in its level or location.

Measures of partial and total factor productivity have also been commonly used. These too are certainly consistent with the rise of American technological prowess at the end of the nineteenth century. Between 1873 and 1913 American total factor productivity (TFP) grew at three times the rate of British, while output per employee in the United States rose from 85.9 per cent of the British level in 1870 to 115.5 per cent by the outbreak of the First World War. In manufacturing the productivity differentials were even wider with America labour productivity consistently operating at twice the level of British throughout this period.[4] The problem with using productivity figures to measure rates of technological progress, however, is that new technology is not the only source of productivity growth in the economy. Scale effects and organizational change, for example, also impinge on TFP, as does capital intensity on labour productivity. Given the indisputable presence of such productivity-enhancing forces in the United States and United Kingdom at the end of the nineteenth century, one cannot take productivity growth as anything more than a very rough proxy for technological advance.

An alternative approach is to seek measures of progress and inventiveness via some distinct feature or characteristic of the technology under examination. In the paper industry, for example, a major manifestation of technological progress in the latter half of the nineteenth century was in increases in the operating speed of the paper-machine. Information about maximum and average operating speeds in American and British paper mills thus provides useful comparable data on average and best practice techniques in both industries.[5] The mapping of such design and machine characteristics across time has also shed light in other industries. While such an approach gets closer to the micro-level process of introducing new technology, it is clear the measures it creates are unique to the technology in question and, hence, have relevance only at the firm or industry level of analysis. Unable to be aggregated, such measures do not permit quantitative conclusions to be drawn about national performance.

Another proxy often utilised is patent data. Although subject to well-known limitations, there is an extensive literature that shows that patents, if used with care, can be revealing indicators of the rate and direction of inventive effort.[6] This measure has the further advantage of incorporating all ideas patented and not just the major ones. However, as each patent system differs in procedures, protection, and costs, direct international comparisons of patenting across systems is not meaningful. By focusing attention on the patterns of international patenting within one single system, some of these problems can be effectively bypassed. As the largest market for technological ideas, the US patent system is typically taken as the best for such analysis.[7] A major drawback of focusing on the US patent system is that it perforce does not permit the United States' inventiveness to be directly contrasted with that of other nations. This, however, need not be an insurmountable problem. There is no reason to believe that the logic of revealing technological performance through patenting in a third market should not apply in patent systems other than the American. In principle, any patent system which granted equal access, costs and protection to potential patentees of all nation; whose workings were familiar to both Britons and Americans; and which was embedded in an economy that was rich, diverse and desirous to utilise the full range of technologies available on the international market, should provide a suitable viewing point of comparative Anglo-American inventiveness.

This paper contends that such a patent system existed in colonial Australia. It uses American and British patenting in Australia between 1882 and 1904 to gauge relative movements in each nation's inventive efforts in this crucial period at the turn of the century. Econometric analysis of this data in turn enables some observations about the determinants of the Anglo-American inventive gap to be made. While this analysis offers broad support for many existing accounts of the American and

British technological divergence at this time, it does also highlight the need for further research on the relationships between tariffs and technological development.

I

This paper makes extensive use of over 5,000 patent applications lodged by American and British residents or their assignees in the Colony of Victoria between 1882 and 1904. These data form the basis of the comparative indices of Anglo-American inventive effort presented in this section. The year 1882 is taken as the starting point of the series primarily because by that time the Victorian system appears to have achieved the maturity and reputation necessary to secure interest from international patentees. This is suggested by the fact that prior to 1882 British and American patenting in Victoria was highly variable and often very limited. Thus, it is important to note that, while between 1857 and 1881 about 400 British and American patents were lodged in Victoria, more than half of these appeared between 1877 and 1881. Only from 1882 do the numbers of foreign patents filed in Victoria grow in a reasonably steady manner.

It goes without saying, of course, that Victorian patents, like all patents, are at best only imperfect measures of inventive activity. After all, not all inventions are patented or even patentable and not all patents are of the same commercial value. Yet, if one is aware of these and other problems and consciously attempts to minimise and contain their effects, there is an abundance of evidence in the literature to suggest that patents do constitute a representative sample of all inventive activity and, hence, can be a very revealing source of information.[8] For example, one way of neatly sidestepping the inherent 'value problem' of determining the economic impact of invention from the patent record is to take variations in patenting as reflections of changes in the intensity of resources devoted to inventive activities rather than as measures of the realised rate of invention. This assumption is based on the reasonable belief that there is a fairly stable relationship between the use of resources in invention and the desire to patent. After all, it is hard to believe that a firm or individual would commit resources to patenting in order not to invent. This is especially the case given that both contemporary and historical studies of patenting behaviour suggest that patentees respond rationally to cost-benefit calculus. Patent applications tend to be filed only when the expected value of receiving a patent is greater than the cost of lodging the claim.[9] This is because patentees are, and have always been, chiefly concerned with making profits. Expectations, of course, are not always realistic or realizable; yet the intent of most patentees is clearly to make money, as evidenced by the fact that a majority of patents do apparently manage to find commercial uses.[10] This is a finding that one would expect to hold *a fortiori* for those who chose to patent outside their own country. One was not likely to spend money taking out a patent out in far-flung Australia if one did not have confidence in its commercial worth there and elsewhere.

The problems of using Australian patent data are compounded by the peculiarities of the Australian patent system in the pre-Federation era. Prior to the establishment of the Commonwealth Patent Office in 1904, each colony operated its own independent patent system. Patents filed and granted in any other jurisdiction, even in the United Kingdom, had no legal status in any of the Australian colonies. As a result, an inventor wishing to protect his or her idea right across Australia was compelled to file an application in each of the six colonies. This was a time-consuming and costly process. Where such duplicate patenting was beyond the means of the inventor, he or she usually instead took out a patent in what was perceived as the biggest market for the invention, invariably New South Wales or Victoria, and simply left it unprotected elsewhere. Of the rival systems, the Victorian was the most modern, effective and largest in pre-Federation Australia. In particular, the comparatively low cost of patent protection in Victoria made it the most popular system with both foreign and local inventors. Moreover, given its grounding in British patent law, Victorian Patent Office practices and procedures were broadly familiar to international inventors and their agents.[11]

The Colony of Victoria is an appropriate system to concentrate our attention on for economic reasons as well. A pivotal feature of Australia's, and especially Victoria's, economic development in the second half of the nineteenth century was the broadening of its economic base away from primary production and the rudimentary industry that supported that primary base. This was the time of 'Marvellous Melbourne', when the beginnings of Australia's rich and highly urbanised consumer culture, as well as the manufacturing and service industries that helped to feed it, emerged.[12] Despite the popular image of nineteenth-century Australia as little more than a series of sheep runs and gold mines, the entire primary and mining sectors of Victoria accounted for only 18 per cent of Victorian GDP in 1889, whereas manufacturing and construction was responsible for just under a third of output.[13] Local manufacturers boasted that Melbourne was well on the way to becoming the ‘Manchester of the South Seas’.[14]

The Australian colonies were also relatively prosperous and urbanised places to live. In 1901, 51 per cent of all Victorians lived in cities and towns with more than 25,000 inhabitants.[15] Average income levels in Australia and Victoria throughout the latter quarter of the nineteenth century were among the highest in the world. According to Maddison, Australia’s three million inhabitants (more than a third of whom lived in Victoria) in 1889 enjoyed a real per capita income that was approximately 50 per cent greater than the average American and 25 per cent larger than the average Briton.[16] Moreover, between 1866 and 1938 the growth of per capita income was faster in Victoria than anywhere else in Australia.[17] At the heart of this vibrant Victorian society was its capital, Melbourne. With around half a million inhabitants in 1891, Melbourne was Australia’s largest city, comparable in size to Birmingham, Madras and Madrid. The vitality of the city was well known to contemporaries. Twopenny, a traveller to Melbourne in the early 1880s, for example, saw it as a rich and cosmopolitan city that represented the 'fullest development of Australasian civilization, whether in commerce or education, in wealth or intellect, in manners and customs – in short, in every department of life'.[18] This expansion, sophistication and diversification of the Australian economy in the latter half of the nineteenth century was a clear signal to Europe and North America that these British colonies were no longer merely producers of raw materials; a development that induced foreign inventors to consider patenting more than just their agricultural, pastoral, and mining inventions in the Australian colonies.

By this time, of course, there had already been a long tradition of granting patents in most countries, and Australians and other nationals were well accustomed to their use. Successful inventors, such as Thomas Edison, took the patenting of their inventions in non-American patents system, including the Australian ones, very much as a matter of course.[19] Indicative of this willingness to patent across national boundaries was the fact that Patent Offices and patent agents in every system established contacts and exchanged information and publications. From as early as 1864, Britain, for example, sought to exchange publications with all foreign patent offices with the result that the Patent Offices of Britain as well as of colonies like Victoria had valuable libraries containing reports and specifications of patents issued in various parts of the world. Moreover, from 1864 the British *Commissioner of Patents' Journal* also published and circulated booklets, which furnished information on how prospective patentees could protect their inventions in each of the Australian colonies. These and other measures had the desired effect. A manual compiled by two leading international patent agents in 1905 listed the Australian system amongst the twenty or so, in which it was worthwhile for inventors to seek patent protection.[20] Australia in the latter half of the nineteenth century was, therefore, clearly part of the international patenting network.[21]

– Table 2 here –

Proof of this can be found in the diversity of British and American patenting in Victoria. Table 2 records the revealed technological advantages (RTA) of British and American patentees in the Colony of Victoria between 1857 and 1903. First employed by Soete, the RTA of a country in a given technological field is determined by dividing the proportion of that country's patents in an industry by its share of all patents over the same period. By normalising the patent data, this procedure enables attention to be focused specifically on those areas where a nation exhibits relative technological strengths, as evidenced by those industries' RTA readings of greater than one.[22]

Table 2 indicates two things. First, Americans and Britons took out patents relating to all areas of the economy, not just the primary and mining sector. Indeed, the strengths of their patenting overwhelmingly lay in the manufacturing and service sectors, especially, with regard to the manufacture of books, paper, alcoholic beverages, industrial metals, textiles and clothing; the generation of heat, light and power; engineering and metalworking; and railways and communication technologies. Second, the proprietors of American and British inventions clearly saw Australia, and especially Victoria, as more than a pastoral and mining economy and were thus prepared to engage with it across the full spectrum of technologies. Econometric analysis conducted elsewhere has demonstrated that this engagement both widened and deepened across time.[23]

Given this involvement, it is contended here that changes in American and British patenting in Australia reflect underlying movements in the degree of overall inventive activity occurring in each country. This is not to say that American or British patent counts in Victoria give an accurate representation of the absolute level of inventive activity in these countries: they clearly do not. Imperial connections undoubtedly made the typical British inventor more aware of Australia than their American counterpart; and, indeed, this is why in most years British patent applications did outnumber American. But surely the critical variable when analysing the Anglo-American inventive gap is not so much the absolute level of patenting, but the relative changes in that level? In other words, what needs to be accounted for is the divergent rates of change in inventiveness in each nation. It is on this dimension of the phenomenon that the Australian patent data can shed light.

– Figure 1 here –

It ought to be said that such a contention is not such a methodological leap as it may appear. The practice of using patenting in a third market to reveal patterns and changes in the strengths of different countries' inventive activity is well established in the literature. Cantwell, for example, has used foreign patenting in the United States to uncover valuable information about inter alia the nature of German, French and British technological strengths since the end of the nineteenth century.[24] All that is novel here is that the third market that has been chosen is Australian rather than American, a choice that permits a rare quantitative insight into comparative British and American inventive activity to be made.[25] Such a comparison is depicted in figure 1. It illustrates that there was, as predicted by the literature, a divergence in the rate of both the breadth and intensity of inventive activity taking place in Britain and America at the end of the nineteenth century. Though subject to fluctuations, the ratio between American and British patenting activity consistently widened in favour of the Americans at an average rate of 4.75 per cent per annum between 1882 and 1904. Comparative per capita patenting also saw the American lead grow on average at 3.81 per cent each year. These findings, of course, should not be interpreted as suggesting that the scale and depth of American inventive effort first overtook the British in the 1880s – the data do not address this question – but it does indicate that the indigenous supply of new technological ideas was expanding more rapidly in America at this time than in Britain. Standard belief in the relative technological rise of America and decline of Britain at the end of the nineteenth century, therefore, does not appear to have been greatly misplaced.

II

Since the seminal work of Habakkuk technological divergence between America and Britain in the nineteenth century has been a topic that has held the fascination of scholars on both sides of the Atlantic. Habakkuk's explanation for the phenomenon was grounded in the Hicksian belief that technologies tend to be primarily chosen and developed so as to economise on the utilisation of scarce, relatively expensive factors of production. He thus argued that the relatively high costs of labour in nineteenth-century America, a result of the abundance of cheap land available on the frontier to the American worker, provided the necessary rationale for the American manufacturer and inventor's greater proclivity in this period to develop and invest in labour-saving machinery than their counterparts in Britain. The source of America's greater technological creativity lay in its distinctive factor endowment.[26]

The debate that this thesis engendered has shed much light on the process of technological development in both Britain and America. While this is not the place to recount at length every ebb and flow of this lively debate, not the least because this has been done elsewhere,[27] its chief findings do bear repeating. Most students of the debate would probably concur with the following six propositions, which either refine or correct in some way Habakkuk's original thesis. First, while labour was certainly relatively expensive in the United States, America also suffered from a relative scarcity of capital, which *ceteris paribus* ought to have activated against the development of capital-intensive technologies.[28] Second, the shortage of labour in America was acutest for skilled industrial workers. It was they who tended to be replaced by machinery.[29] Third, there was a distinct resource-using bias in American technology, a product of American's relative abundant natural endowment. One consequence of this was that by British standards American machinery appeared remarkably wasteful of resources such as wood. However, given the fact that there existed a complementarity between material inputs and capital equipment in manufacturing in this period, this 'wastefulness' reflected a rational substitution of resource-intensive machinery for expensive labour, rather than any American profligacy.[30] Fourth, the process of technological development has clear path-dependent elements and that in the late nineteenth century it was the more capital- and scale-intensive paths that offered the greater potential for technological advance.[31] Fifth, the emergence of a vibrant and independent capital-goods sector in America enabled the development, on-going improvement and rapid diffusion of special-purpose machinery necessary for standardised mass production.[32] Sixth, the inherent scale and homogeneity of the American markets, once integrated by the canals and railroads, provided significant economic rewards and opportunities to all those who could offer ways to innovate production technologies and organisations.[33]

Together these factors can be pieced together to form a consistent explanation for the emergence and persistence of the Anglo-American technology gap in latter half of the nineteenth century. Such a framework is explicitly expounded at some length by David and Broadberry.[34] At its heart lies factor prices. Relatively expensive wages in America, especially in the skilled manufacturing sector, combined with an abundance of raw materials provided strong incentive to American manufacturers to adopt more capital-intensive production technologies than was the case in Britain. This shift towards mechanization in turn created a greater demand for mechanical equipment and expertise. To cater for this demand an independent capital-goods industry arose to provide an increasing array of special-purpose machinery constructed from interchangeable parts. Over time, the added experience, experimentation and familiarity with machinery that this development granted afforded America with an ever greater technological capability that was to manifest itself in a continuous stream of faster and more efficient capital equipment. The roots of American inventive success, therefore, are to be found in its factor endowment and more rapid move towards capital-intensive manufacture. Complementing these supply-side processes was the expansion and integration of America's markets, markets that offered both the level of demand necessary for the mass production of standardized products as well as a financial lure sufficient to stimulate and focus the creativity of the nation's inventors.

While each components of this multifaceted approach have been subjected to detailed research and analysis independently, it is noteworthy that the framework in its entirety has rarely been explicitly tested. The index of comparative Anglo-American inventive activity put forward in the last section, however, offers the possibility of doing so by enabling the determinants of USA/UK patenting (*RELPAT*) and USA/UK patenting per capita (*RELPPT*) to be directly evaluated. Owning to the paucity of comparable industry data prior to the first decade of the twentieth century, such an analysis must be conducted at the national level. The regressions estimated here take the form

RELPAT (or RELPPT) = f (RELFACTOR, RELCAPITAL, RELMANU, RELSCALE, RELGDPPC, RELOPEN, RELTARIFF, RELAUST, D1884, D1904)

where *RELFACTOR* is relative USA/UK factor prices, *RELCAPITAL* is relative capital intensity, *RELMANU* the relative importance of manufacturing in each economy, *RELSCALE* are relative scale effects, *RELGDPPC* relative GDP per capita, *RELOPEN* the relative openness of the economies, *RELTARIFF* the relative degree of protection, *RELAUST* the relative engagement of each nation with Australia, and *D1884* and *D1904* dummies representing major changes to the Victorian patent system.

Data for our estimates are necessarily drawn from a variety of sources and in places rely on indirect proxies. Comparative factor prices in the US and UK (*RELFACTOR*) are calculated as the ratio of average real wages to average real machine prices expressed in pounds sterling.[35] *RELFACTOR* thus picks up all of the direct and indirect effects of factor prices on inventive activity. One would expect this variable to be positively signed, as the relatively high factor price ratio in the United States ought to encourage the development of labour-saving technology and move toward a more capital-intensive form of production with greater potential for further technological advance. To the extent that average real wages are influenced by the accumulation of human capital and machine prices by the existence of a dynamic capital-goods industry and the availability of cheap supplies of key material inputs such as wood and metals, one would expect these forces to reinforce the positive sign of *RELFACTOR.* In other words, relatively faster rates of human capital formation, specialized capital-goods manufacturers and abundance of key industrial resources in the United States act to amplify the disparity in the ratio of factor prices in each country. Another variable, *RELCAPITAL*, attempts to gauge comparative capital intensity more directly. *RELCAPITAL* is the ratio of US real capital per worker to British measured in pounds sterling. The expectation is that this variable will also be positively signed. Given the significance of the manufacturing sector in the technological success of the United States, the relative growth of the sector in each country may matter. *RELMANU* contrasts the share of the labour force employed in the manufacturing sector in each of the two countries. It is to be anticipated that this variable should carry a positive sign as well. A large proportion of the workforce engaged in manufacturing implies more learning by doing and more familiarity with skills and expertise necessary to function at the cutting-edge of technology at the end of the nineteenth century. It means inter alia more mechanics, engineers, chemists as well as specialized machine-makers; people endowed with the know-how and know-why required to advance technology in an increasingly mechanized and scientifically orientated world of production. Scale, especially in the manufacturing sector, may also have played a part. This paper uses the comparative size of the labour force employed in manufacturing (*RELSCALE*) as a proxy for scale effects. *RELSCALE* ought to be positively signed. Finally, demand-side considerations are captured by *RELGDPPC*, which gives the ratio of US to UK real per capita GDP evaluated in 1990 Geary-Khamis dollars. As with the other explanatory variables, the expected sign of *RELGDPPC* is positive.

Moving beyond the standard explanation of the Anglo-American divergence, it is worth considering the roles of openness and protection. Recent research has stressed the importance of openness to technological development not only because of the competition it engenders, but also because it acts as an excellent source of technological information and inspiration.[36] A common measure of openness used in the literature is the ratio of its imports to total output. The rationale behind this measure is that the more a nation imports, the more that it is exposed and, *ipso facto*, stimulated by international engagement. *RELOPEN* adopts this approach by calculating the comparative ratio of imports to total output in each country. A positive sign is to be expected on this variable.

The effects of commercial policy also need to be considered. After all, protectionism was a feature – some would contend a crucial feature – of nineteenth-century American economic development. It may have had a role in its technological development as well, for, as Schumpeter argued, 'Restraining competition, while reducing the stick incentive, may improve the quality or the certainty of the carrot incentive to innovate'.[37] In other words, by 'liberating' firms from the pre-occupation of short-term survival engendered by unhindered competition, it is possible that protectionism may provide firms with the breathing space and capital needed to loosen the technological shackles that bind them. The best known application of such an idea is the infant industry argument, the belief that protection can offer time to a new domestic industry to get on its feet and reduce its costs to internationally competitive levels. Although in practice infant industry protection rarely disappears when it should with the onset of maturity, it is nevertheless contended by some that such tariffs did in fact aid to some degree the success of a number of American industries in the nineteenth century, including the pig iron, steel, tinplate and cotton industries.[38] The gains, what is more, may not have been simply static or short-term in nature, as the breathing space the tariff created also presumably afforded infant industries the opportunity to not just familiarize themselves with best-practice technology, but to experiment and develop it further. Reinforced by scale-dependent learning effects, these processes could act as a significant fillip to further technological advance.[39]

In theory, tariffs may also influence the development of new technology indirectly by contributing to an environment conducive to inventive activity. Difficulties in appropriating sufficient returns on one's ideas and efforts are widely recognized as common barriers to creativity. Where the fruits of a firm's or individual's research and development or learning cannot be protected and, hence, can be acquired relatively freely by competitors and even firms in other industries, then there is a real possibility of a sub-optimal level of investment being made in the generation of new technological ideas.[40] To the extent that a tariff permits larger profits to be earned, a case for protection could be made on the grounds that it may encourage a more socially desirable level of inventive effort to take place. As David correctly points out, however, in such circumstances a more tightly targeted measure may achieve the same result without the concomitant pitfalls. If the problem that needs to be addressed really stems from the fact that the learning that a firm acquires from production can spillover to others who have not invested in that learning, then, he contends that it is more efficient for society to subsidize the creation of new knowledge through 'pilot plants' rather than induce the concurrent replication of the same – and hence redundant – learning in a number of different places with a tariff.[41]

Such an argument, however, assumes that firms are aware that the knowledge they are generating can and will be costlessly acquired by competitors. In reality, such awareness is far less certain. More often than not the firm does not know what future learning will give rise to and, more importantly, which parts of it, if any, will succeed and be appropriable. Moreover, learning is an on-going process, not a discrete event, so that one cannot expect the same 'pilot plant' to be able to be the source of all new ideas. One cannot pick with certainty where and when the crucial insights may be made. In part this is because creativity is influenced by psychological and sociological parameters that do not easily yield to the tools of rational economic analysis.[42] It is in this context that tariffs may have a bigger input into the inventive processes than traditional analysis suggests. Given that the security of one's investment in invention matters, then the psychological reassurance offered by a tariff may be just enough to galvanize an otherwise cautious inventor working in an uncertain environment to take the plunge. Similarly, the perception of protection may instill firms and the wider community as whole with the confidence needed for them to invest more freely in the development of new technologies. Financial institutions, for example, may see an industry whose protection has been just increased as somewhat less of a risk.

Evidence of this factor at work can allegedly be seen in the German steel industry at the end of the nineteenth century. According to Webb, the larger, securer and less variable demand of the tariff-cartel system in Germany reduced the perceived risk of investing in mass production and vertical integration there. This form of organization in turn promoted the introduction and further development of capital-intensive technologies in German steel-making.[43] Here it would seem to be the perception, almost as much as the reality, of security and stability that was crucial.

Testing the nature of the relationship between tariffs and technological development is complicated by the absence of a clear index of protectionism. Arguably the most reasonable – if imperfect – measure is the proportion of the value of all imports collected as custom duties.[44] The measure is not without problems. It does not account for the effects of prohibitively high tariffs that discourage all importation, and hence, deflate (rather than increase) the measure. Nor do duties collected take into consideration the impact of non-tariff barriers or the effectiveness of the protection provided by the array of varying tariff rates across different industries, or even the fact some custom duties are levied purely as revenue-raising devices on items that cannot be produced locally. Yet, bearing these qualifications in mind, it remains the case that, as Capie puts it, the ratio of duties collected to total imports is still the 'best indicator available of the overall state of protection'.[45] In this paper, the comparative ratio of duties collected to total import value (*RELTARIFF*) is taken to reflect changes in the relative degrees of protection experienced in each country. Those who attribute a constructive role to tariffs would expect *RELTARIFF* to be positively signed, whereas those who regard protectionism as counterproductive would predict a negative relationship.[46]

One possible problem with the index of comparative inventive activity offered in this paper is that changes in the scale of American and British patenting in Australia may be influenced by factors unrelated to the process of technological change. The largest potential problem in this regard is that the relative propensities to patent in Australia may be significantly shaped by each nation's differing knowledge of Australian society. As it has already been seen, this probably did have an effect on the absolute level of patenting carried by America and Britain in Victoria. What is of more concern to this exercise is if over time the flow of new knowledge about Australian conditions differed between countries. If it did, then, this would alter the relative marginal propensity of inventors in the two countries to patent there. In other words, it is possible that some of the divergence in patenting between Britain and America may be due to the fact that American knowledge of, and familiarity with, Australian conditions improved dramatically more than British over the 1880s and 1890s and this encouraged them to patent more. To allow for this possibility, the variable *RELAUST* is introduced into the analysis. *RELAUST* is a measure of the relative importance of the Australian economy to America and Britain. It does this by contrasting the share of Australian trade out of all trade in both countries. The rationale of *RELAUST* is that one would expect most relevant economic knowledge about Australia to have been primarily derived thorough commercial interaction. The more that a nation traded with Australia, the more it is likely that that nation's inventors would have seen the potential for their intellectual property there and, hence, have been encouraged to seek the relevant patent protection. If such knowledge considerations are indeed of importance to US and UK patenting in Australia, one should expect the coefficient on *RELAUST* to be both positive and significant.

Finally, allowances need to be taken for changes in Victorian patent law in this period, changes which conceivably could have affected each country's propensity to patent to different extents. Two changes stand out in particular. In 1884, the Victorian Legislative Assembly passed the Patent Law Amendment Act, an Act that inter alia dramatically reduced the costs of taking out a patent in Victoria. This led to a surge of patenting amongst local Australian inventors.[47] The dummy variable *D1884* tests whether this Act altered the relative patenting propensity of America and Britain as well. The other change in legal setting that requires consideration occurs in 1904, when the colonial and Commonwealth systems overlapped. This paper takes the Commonwealth statistic for that year as the more reliable. It is possible, however, that potential patentees in different countries at the time may have understood the situation differently with the result that relative patenting propensities in 1904 may have changed as a consequence. This possibility is tested for with the dummy variable *D1904*.

III

The results of ordinary-least-squares estimations of *RELPAT* and *RELPPT* are given in table 3. All variables in the regressions are in logarithmic form. The first thing to note is that neither of the two dummies reflecting institutional changes to Australian patent systems in 1882 and 1904 were significant. This is consistent with the findings of earlier research that found the Patent Law Amendment Act of 1882 to have little effect on the rate of international patenting in Victoria.[48] *RELAUST* is also insignificant and of the wrong sign, suggesting that the relative economic interaction of America and Britain with Australia was unrelated to their propensity to patent there. In fact, read literally, table 3 indicates that, if anything, the more either country traded with Australia, the less likely that its inventors were to patent in the Colony of Victoria.

– Table 3 here –

The results do, however, give strong support for the conventional model of comparative Anglo-American technological development at the end of the nineteenth-century. For example, the best regressions, (4) and (8), indicate that approximately 74 per cent of variation in comparative USA/UK patenting and 68 per cent in comparative per capita patenting can be explained by variables inherent to the British and American economies. These regressions are also fairly robust, exhibiting no significant signs of autocorrelation, hetereoscedasticity, multicollinearity or specification bias. Table 4 uses the coefficients estimated by these regressions to gauge the relative contribution of each the main explanatory variables to the growth of Anglo-American patenting in Victoria.

– Table 4 –

Together tables 3 and 4 confirm the overwhelming primacy of factor prices. For every percent change in the ratio of American factor prices relative to British, the patenting gap between them broadened by around two-and-a-half percent and the per capita gap by two per cent. These findings are consistent with the view that America's factor endowment played the dominant role in the creation of its technological leadership. American machinery made relatively cheap by abundant resources not only directly induced the development of labour-saving technologies, but provided the rationale for its deeper and more rapid mechanization and the richer learning trajectory that this generated. The relative capital intensity of production in both countries was, therefore, central to the emergence of the Anglo-American inventive gap.

Given the integral role of manufacturing in this technological development, it is not surprising to find that *RELMANU*, the comparative share of the labour force engaged in that sector in each country, was also a significant influence on the relative degrees of inventive activity taking place. Indeed the comparatively fast growth of American manufacturing in the last quarter of the nineteenth century was one of the most important factors explaining the surge of American technological creativity of the period. According to table 3, a one per cent change in *RELMANU* tended to lead to more than a 4 per cent change in the index of relative patenting and 3.6 per cent change in the index of relative per capita patenting. Combining these results with the prodigious expansion of the manufacturing sector in American at the time – between 1882 and 1904 the share of American labour force in manufacturing grew at average rate of 0.84 per cent per annum compared to virtually no increase at all in Britain – and the quantitative importance of this variable becomes apparent. The theoretical significance of *RELMANU* stems from the fact that, *ceteris* *paribus*, growth in the size of the manufacturing workforce brings about increases in both a nation's learning opportunities and the skilled labour capable of exploiting them. By the beginning of the twentieth century, it is noteworthy that there were already more people engaged in manufacturing in America than in Britain.

Relative GDP per capita, it seems, was also a significant determinant of the inventive gap. A single percentage point change in American average real GDP relative to Britain in this period resulted in around a three per cent change in comparative patenting intensities. These findings suggest that demand-side considerations also had a part to play in the story, both directly by enticing greater inventive effort from the population and indirectly by encouraging the development of new corporate business structures in America which were particularly well equipped to garner the innovative potential of scale- and capital-intensive production.[49]

Two variables, *RELSCALE* and *RELCAPITAL*, have been excluded from the best regressions. As regressions (3) and (7) demonstrate, when *RELSCALE* is included it is not only insignificant, but also affects the significance of other variables, most notably *RELMANU*, whose coefficient is nearly halved and t-ratio becomes insignificant. Given that the coefficient of determination remains high and correlation between *RELSCALE* and *RELMANU* is 0.93, it seems safe to suppose that in regressions (3) and (7) the two variables are strongly collinear. As Intriligator has noted one way of dealing with such multicollinearity is 'to include only explanatory variables that, on theoretical grounds, directly influence the dependent variable and that are not accounted for by the other included variables'.[50] As *RELMANU* appears to incorporate the effects of scale on inventive activity, dropping *RELSCALE* from the regressions does not create specification bias in the estimation.

Similar problems are confronted with *RELCAPITAL*. Table 3 indicates that this variable is both weak in strength and insignificant. There are two reasons why this would appear to be the case. First, as Field has pointed out machinery used in production is only one component of the capital stock, and that as a result some of the changes in comparative capital-labour ratios in this period may reflect greater investment in structures and inventories in one country rather than the deepening and widening of mechanization.[51] Second, the impact of American's growing capital intensity seems to be picked up by *RELFACTOR* and *RELMANU*, both of whose significance is reduced when *RELCAPITAL* is introduced. As the correlation coefficient between *RELFACTOR* and *RELCAPITAL* is 0.80, it is reasonable to conclude that multicollinearity is also a problem in regressions (2) and (6). Removing *RELCAPITAL* from the analysis clearly enhances the estimations without reducing their explanatory power.

Table 3 also highlights the importance of non-domestic factors. *RELOPEN*, thus, was found to be a significant influence on comparative patenting performance.[52] Given the greater depth of its involvement in international trade, Britain benefited more from this factor than America.

The results indicate that *RELTARIFF* was also strongly significant, its positive coefficient suggesting that increases in protection, in at least this instance, tended to promote, rather than dampen, inventive activity.[53] How can we account for this finding? The first thing to note is that in protectionist nineteenth-century America, internal competition for domestic markets was probably sufficiently intense in itself to discourage any tariff-induced tendency for complacency. Even with tariffs, business survival in America still demanded the continual striving for best practice. As Head, for example, noted with respect to the steel rail industry in late nineteenth-century America, despite protection, 'the size of the US market allowed for plant level scale economies to be realized while many domestic firms could coexist providing both competition and a continuous flow of technological innovations for each other'.[54]

But tariffs may also have had a role to play beyond the facilitation of scale-dependent learning.[55] With its large, protected home market, growth-validating values and institutions, and abundance of key raw materials, American industrial leadership at the end of the nineteenth century seems in retrospect to be a 'success' just waiting to happen. In this story, while tariffs may not have been the catalyst for that success, they were by the same token not complete hindrances either. Indeed, our results suggest that in some ways tariffs could have complemented the market-driven processes that were behind America's rise. By creating a perception of relative certainty and opportunity, protectionism may have reinforced the belief, initiated by market conditions, that investing in new technologies, machinery and business forms would bring its just rewards. That such reassurances were to prove ultimately unnecessary does not mean that they were insignificant to those who did not have the benefits of hindsight. Nor, in accepting this view, would one be required to believe that protectionism was the engine of American technological development: it patently was not. Instead its effects were felt at best at the margin where it encouraged relatively timid investors and inventors to act more frequently and expeditiously than they otherwise would have. It is worth noting that, to the extent that this is true, such an outcome was only possible because of the underlying potential of the late-nineteenth-century American economy. Without that latent potential, all of the protectionist's reassurances would have had little positive effect on American's willingness to engage in inventive activity.

IV

This paper has attempted to shed some new light on aspects of a very old question: the technological divergence of America and Britain at the end of the nineteenth century. In particular, it has addressed the issues of why America at this time was relatively more inventive than Britain. While many enlightening comparative studies of specific industries or technologies have been conducted before, what is novel about this paper is its quantitative focus on the 'big' picture. Rather than emphasizing the uniqueness of each industry’s, or even firm’s, experience with technological change – an inevitable consequence of the microanalysis of the process – it has instead sought to identify systemic factors that can account for differences in the path of national technological systems. This is not to say that detailed study of technological change is not immensely valuable – the wonderful fruits such research has already borne is ample testimony of this – only that it is equally important to continue to think about the big themes that bind these details together.

In this regard, the main findings have provided quantitative support for much of the conventional thinking about Anglo-American technological creativity in this period. Patent data from colonial Australia, therefore, do appear to indicate that differing factor endowments and demand conditions as well as the expansion of American manufacturing did in fact lie at the heart of the diverging degree of inventive activity carried out in each country throughout the late-Victorian and Edwardian era. Moreover, to the extent that such features of the American environment were unobtainable in Britain, these findings lessen the culpability of British workers, inventors and entrepreneurs for their nation’s relative technological decline after 1870.

The results have also raised questions about the role of protection in technological creativity. One is accustomed to thinking of protection as an obstacle to creativity. Our analysis, however, casts doubt on this assumption by suggesting that increases in the average nominal rate of tariffs in Britain and America between 1882 and 1904 on the whole stimulated, rather than discouraged, inventive effort. Of course, these findings in themselves in no way prove the efficacy of protectionism. Rather, what they do highlight is the need for further research, especially at the micro-level, on the ways in which competition, tariffs and perceptions of security can impact on individual and organizational creativity. Should the positive relationship between protection and inventive activity uncovered in the Australian data be replicated elsewhere, its explanation will almost certainly lie in such considerations. Indeed, it is possible that, if real, the beneficial role of tariffs found in this paper may be unique to the American experience of the late nineteenth century and, *ipso facto*, have no general applicability. After all, this period witnessed the unprecedented confluence of a number of factors in the United States – the emergence of new scale- and high-technology-intensive industries, ideal demand patterns, sufficient internal competition and an abundance of key resources – which would have acted to have amplified the quality and certainty of any tariff-induced incentive to invent. To the extent, then, that there are any technological benefits from protectionism, these many be realizable only in industries where, paradoxically, the potential for success already inheres.

APPENDIX

Data used in estimation: sources and methods

Victorian patent data: Information about each individual application filed in the colony during this period was collected from the Victorian Patent Office's journal *Patents and Patentee* as well as the original applications and specifications submitted and still held by the State Library of Victoria. These data are found in Magee, 'Patents' and *Knowledge generation*. It should be noted that the Commonwealth of Australia Patent Office began accepting applications on 13 February 1904. In 1904, therefore, overseas applications were received both by the Victorian and Commonwealth Patent Offices. Because the imminent demise of the Victorian Office was known by many potential patentees, this paper has chosen to use the statistics provided by the Commonwealth Office for this year. These are found in the *Australian Official Journal of Patents* Vol. 1 1904.

Wages and capital good prices: Wage and capital good price data for the UK come from Feinstein, *National income*, T140 and T133 and for the US from Department of Commerce, *Historical statistics*, series D-589, D-590, D-574 and E-7 and E-20. Cost of living indexes come from Feinstein, 'New look', pp. 170–1 and Department of Commerce, *Historical statistics*, series E-158. Note that American wage data used relate to all industries, and the capital price data to metals and metal products.

Capital-labour ratios: Data on UK capital-labour ratios come from Feinstein, *National income*, T51. US data were calculated from Kendrick, *Productivity trends*, pp. 305 and 308, 320 and 331. US data for the period 1880–1888 were interpolated on the basis of the average compound growth rate in this period.

Manufacturing, total labour force and population data: UK data for manufacturing and total labour force size come from Feinstein, *National income*, T125 and Broadberry, *Productivity race*, p. 43, while US data are found in Kendrick, *Productivity trends*, pp. 305, 308 and 456. US data for the period 1880–1888 were interpolated on the basis of the average compound growth rate. Population data came from Mitchell, *Statistics*, pp. 11–13 and Department of Commerce, *Historical statistics*, A-2.

Real GDP per capita: Comparative real GDP per capita data supplied in Maddison, *Monitoring*, Table D-1a p. 196.

Import shares: Comparative import data come from Department of Commerce, *Historical statistics*, series U-10 and Mitchell, *Statistics*, p. 453. US national output estimates calculated from Kendrick, *Productivity trends*, pp. 296–7 for the years 1889 to 1913, and from Balke and Gordon, 'Estimation', pp. 84–5 for the period 1882–1888. Balke and Gordon's series is spliced onto Kendrick's at this point. UK national output data are from Feinstein, *National income*, T10.

Tariff duties: US duties data come from Department of Commerce, *Historical statistics*, series U-19; UK data from Mitchell, *Statistics*, pp. 453 and 583.

Trade with Australia: US data regarding trade with Australia were taken from Department of Commerce, *Historical statistics*, U-13, U-132, and U-150. Note that the US trade figures for Australia include trade with other parts of Oceania and, hence, very slightly overstate the importance of Australian trade with America. The comparative data for the UK come from Mitchell *Statistics*, pp. 453 and 505–7.

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Tables and Figures

Table 1. *Major inventions by country of origin, 1776–1925 (as a percentage of total)*

	Total	Britain	USA	Germany	France
1776–1825	163	43.6	11.7	9.8	26.4
1826–1875	292	22.6	24.0	21.2	21.6
1876–1926	343	14.0	43.7	17.5	14.0

Source: Streit, *Union now*.

Table 2. *USA and UK revealed technological advantages in Victoria, 1857–1903*

SECTOR	UK	USA	SECTOR	UK	USA
Agriculture	0.27	0.56	carriage and coach-making	0.76	0.47
books, paper, and printing	1.37	1.68	engineering	1.29	1.44
bricks, pottery, and glass	1.38	0.57	industrial metals	1.02	2.31
furniture and bedding	0.56	0.61	metalworking	1.20	1.19
woodworking	0.92	1.01	general mining	0.34	0.73
chemicals, dyes, and oils	1.88	0.96	treatment of non-metal mine products	1.09	0.68
medicines and remedies	-	0.36	other manufacturing	1.95	1.07
explosives	1.64	0.86	pastoral	0.82	0.48
construction	0.59	0.49	railway	1.43	1.45
dairy, fishing, and forest products	0.60	-	shipping	0.77	0.71
alcoholic beverages	1.42	1.31	communication	1.58	2.58
food processing	1.23	0.49	services and distribution	1.16	0.77
food preservation	1.15	0.53	textiles, clothing, and footwear	1.18	1.99
refrigeration and ice-making	1.23	1.83			
tobacco products	0.51	3.57			
heat, light, and power	1.97	3.46			
household consumer	0.53	0.41	PRIMARY	0.42	0.51
household producer	0.43	0.23	MANUFACTURING	1.18	1.16
leather	0.79	0.29	TERTIARY	1.24	1.12
chemical/mechanical extraction of metals from ores	0.94	1.17	MINING	0.78	1.05

Source: Magee, *Knowledge generation*, pp. 240–1.

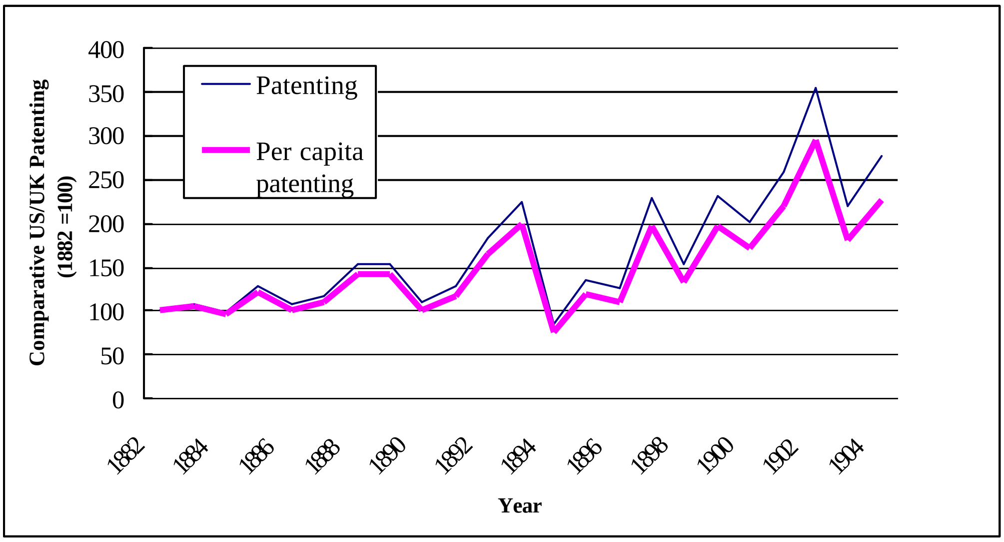

Figure 1. *Comparative USA/UK Patenting in Victoria, 1882–1904*

Sources: See appendix.

Data for Figure 1.

	US/UK patenting	US/UK Patenting per capita
1882	100.0	100.0
1883	107.3	105.9
1884	98.5	96.0
1885	127.2	122.6
1886	107.3	102.3
1887	116.8	110.1
1888	152.5	142.3
1889	153.7	142.0
1890	110.3	100.9
1891	128.2	116.2
1892	183.3	164.8
1893	224.8	200.3
1894	86.0	76.1
1895	135.9	119.3
1896	126.4	110.2
1897	228.3	197.6
1898	153.6	132.1
1899	231.8	198.2
1900	201.7	171.5
1901	259.9	219.1
1902	354.9	296.3
1903	219.6	181.8
1904	277.3	227.7

Table 3. *Determinants of USA/UK patenting and patenting per capita in Victoria, 1882–1904*

Dependent variable:	RELPAT	RELPAT	RELPAT	RELPAT	RELPPC	RELPPC	RELPPC	RELPPC
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
CONSTANT	-61.800	-62.218	-51.972	-59.264	-56.192	-56.906	-48.489	-53.721
	(-3.82)**	(-3.79)***	(-2.38)**	(-4.27)***	(-3.51)***	(-3.51)***	(-2.23)**	(-3.94)***
RELFACTOR	2.594	2.523	2.244	2.463	2.318	2.325	2.044	2.186
	(3.30)***	(2.27)**	(2.37)**	(3.88)***	(2.98)***	(2.11)*	(2.17)**	(3.51)***
RELMANU	4.905	4.801	2.599	4.429	4.078	4.115	2.266	3.617
	(2.64)**	(2.05)*	(0.67)	(3.14)***	(2.22)**	(1.77)*	(0.59)	(2.61)**
RELGDPPC	2.727	2.811	2.603	3.076	2.886	2.891	2.786	3.209
	(1.99)*	(1.78)*	(1.93)*	(2.58)**	(2.13)**	(1.85)*	(2.08)*	(2.74)**
RELOPEN	1.801	1.822	1.522	1.637	1.665	1.703	1.447	1.511
	(2.19)**	(2.16)**	(1.65)	(2.30)**	(2.04)*	(2.04)*	(1.58)	(2.16)**
RELTARIFF	2.533	2.474	2.392	2.249	2.392	2.382	2.281	2.127
	(3.02)***	(2.55)**	(2.80)**	(3.35)***	(2.88)**	(2.48)**	(2.68)**	(3.22)***
RELAUST	-0.164	-0.150	-0.155		-0.157	-0.149	-0.150	
	(-0.48)	(-0.43)	(-0.46)		(-0.46)	(-0.43)	(-0.45)	
D1884	0.062				0.052			
	(0.32)				(0.26)			
D1904	0.195	0.200	0.140		0.166	0.168	0.126	
	(0.80)	(0.81)	(0.55)		(0.68)	(0.67)	(0.49)	
RELSCALE			1.05				0.830	
			(0.72)				(0.57)	
RELCAPITAL		0.217				0.076		
		(0.17)				(0.06)		
R2(adj)	0.707	0.706	0.716	0.741	0.637	0.635	0.644	0.683
SEE	0.210	0.210	0.207	0.197	0.208	0.208	0.206	0.194
DW	2.60	2.60	2.54	2.74	2.60	2.60	2.55	2.73
Runs test	(17,12,11)	(15,13,10)	(15,11,12)	(15,14,9)	(14,14,9)	(14,14,9)	(15,12,11)	(15,14,9)
Reset	2.31	2.96	1.57	2.89	3.31	3.85	2.64	3.62
Arch	0.038	0.043	0.062	0.210	0.003	0.007	0.005	0.252

Notes: All variables, other than the dummies, are in log. The method of estimation is ordinary least squares. t-ratios are given in parenthesis. *, **, and *** denote significance respectively at the 10, 5, and 1 per cent level. SEE is the standard error of the estimate and DW the Durbin-Watson statistic. The runs test is a nonparametric test for detecting autocorrelation, where the first number given is the number of runs in the residuals, the second the number of (+) symbols, and the third the number of (-) symbols. The Reset and Arch tests are distributed as chi-squared.
Sources: See appendix.

Table 4. *Contributions of different variables to the growth to US/UK patenting in Victoria, 1882–1904*

Annual average rate of growth of *RELPAT*	4.75	
Annual average rate of growth of *RELPPC*		3.81
Contribution of *RELFACTOR*	6.55	5.81
Contribution of *RELMANU*	2.83	2.31
Contribution of *RELGDPPC*	1.17	1.22
Contribution *RELOPEN*	-1.90	-1.75
Contribution of *RELTARIFF*	-4.23	-4.00

Source: Calculated from equations (4) and (8) in table 3.

Endnotes

[1] Maddison, *Monitoring*, p.196.

[2] Streit, *Union now*.

[3] Mokyr, *Lever*.

[4] Floud, 'Britain', p. 22; Broadberry, *Productivity race*, pp. 1 and 89.

[5] Magee, *Productivity and performance*, pp. 157-60.

[6] Griliches, 'Patent statistics'; Sokoloff, 'Inventive activity'; Sullivan, 'Revolution'; Magee, 'Technological development' and *Knowledge generation*, ch. 2.

[7] Pavitt, 'Indicators'; Cantwell, 'Historical trends'.

[8] See, for example, Griliches, 'Patent statistics'; Pavitt , 'Indicators'; and Israel and Rosenberg, 'Patent Office'.

[9] Griliches, 'Patent statistics', p. 1690; Sullivan, 'Estimates', pp. 37–58; Schankerman and Pakes, 'Patent rights', pp. 1052–1076; and Dutton, *Patent system*, pp. 108 and 112.

[10] Schmookler, *Invention*, pp. 47–55.

[11] Hack, *Patent profession*, pp. 11–15; Magee, *Knowledge generation*, pp. 16–19.

[12] Butlin, *Investment*; Davison, *Marvellous Melbourne*; Sinclair, 'Victoria's economy'.

[13] Sinclair, 'Victoria's economy'.

[14] Parsons, 'Some aspects'.

[15] Laughton, *Year-book*, p. 183.

[16] Maddison, *Monitoring*, p. 194.

[17] Sinclair, 'Victoria's economy', p. 6.

[18] Twopenny, *Town life*, p.3.

[19] Israel and Rosenberg, 'Patent office'; Magee, *Knowledge generation*, p. 83.

[20] Edwards and Edwards, *How to take out patents.*

[21] For further evidence, see Magee, *Knowledge generation*, pp. 208–14.

[22] Soete, 'Impact'.

[23] Magee, *Knowledge generation*, p. 123.

[24] Cantwell, 'Historical trends'.

[25] It could be argued by critics of this approach that because New Zealand patents grew more rapidly than American in this period, this indicates that New Zealand had become even more inventive than Americans at the beginning of the twentieth century. Such a conclusion, however, would be incorrect because it ignores the fact that for New Zealanders the Victorian patent system was effectively a 'home' patent system, rather than an independent 'third market'. As a result, one should expect a New Zealander's propensity to patent in Victoria to be significantly greater than an American's. This same phenomenon explains why Canadian patenting is so much greater in the United States than in many other major systems. As New Zealand's technological capability gradually increased from fairly basic levels in the latter half of the nineteenth century, it was only natural that its inventors would involve themselves ever more deeply with the Australian patent system.

[26] Habakkuk, *American and British technology*; Hicks, *Theory of wages*.

[27] See, for example, Broadberry, *Productivity race,* pp. 77–89.

[28] Temin, 'Labor scarcity'.

[29] James and Skinner, 'Resolution'.

[30] Ames and Rosenberg, 'Enfield Arsenal'.

[31] David, *Technical choice*.

[32] Ames and Rosenberg, 'Enfield Arsenal'.

[33] Chandler, *Scale and scope*; Broadberry, *Productivity race*.

[34] David, *Technical choice*; Broadberry, *Productivity race*.

[35] Given that the scarcity problem in America related to skilled labour, average wages rather than unskilled wages have been used.

[36] Mokyr, *Lever*, pp. 186–190; Lall, 'Technological change', p. 24; Taylor, 'Growth and convergence'.

[37] Schumpeter, *Capitalism*, p. 104.

[38] For discussions of this issue, see Lindert, *International economics*, p. 220; Sundararajan, 'Impact of the tariff', p. 604; Wright, 'American technology', p. 300; Irwin, 'US Tariffs'; and Irwin, United States iron industry'.

[39] Head, 'Infant industry'.

[40] Arrow, 'Economic welfare'.

[41] David, *Technical choice*, pp. 111–2.

[42] Mokyr, *Lever*, p. 175.

[43] Webb, 'Tariffs'.

[44] Lindert, *International economics*, pp. 302–305; Capie, *Tariffs and growth*, p. 25; Nye, 'Myth'.

[45] Capie, *Tariffs and growth*, p. 25.

[46] Some might argue that *RELTARIFF* is necessarily the mirror image of *RELOPEN*. This is, however, not the case. In fact, with a correlation coefficient of 0.095, there would appear to be virtually no statistical relationship between the two variables in this instance. There are a number of possible reasons for this, such as the effects of alterations in the rates of tariffs across products or in the structure of the economy over time, but perhaps the most important is that *RELTARIFF* and *RELOPEN* are in fact proxies for two different things: *RELTARIFF* gauges the impact of overall protection levels on technological creativity; *RELOPEN* the effect of foreign interaction on inventive activity. Both factors can conceivably coexist. One should not, therefore, expect variations in one variable to be perforce reflected in commensurate inverse changes in the other. What matters more when evaluating protection is the net effect of these two potentially opposing forces.

[47] Magee, *Knowledge generation*, p. 116.

[48] Magee, *Knowledge generation*, pp. 120–3.

[49] Chandler, *Scale and scope*.

[50] Intriligator, *Econometric models*, p. 189.

[51] Field, 'Unimportance'.

[52] Other measures of openness, such the ratios of export or total trade to output produced similar results. The import-output ratio is the preferred measure simply because it was the most statistically significant.

[53] The contribution of *RELTARIFF* reported in table 4 is negative because the ratio of duties collected to total imports actually fell in the US relative to the UK in this period. The level of the US ratio, however, was significantly higher throughout. For example, in 1890 the ratio stood at 29.6 per cent in the US and 4.8 per cent in the UK; in 1900 the figures were 27.6 per cent and 4.6 per cent respectively.

[54] Head, 'Infant industry', p. 163.

[55] A positive relationship between tariffs and economic growth in the late nineteenth century has recently been claimed in O'Rourke, 'Tariffs and growth'. According to O'Rourke, there are three likely explanations for this finding, all of which are largely peculiar to the period in question: that tariffs reduced the relative price of capital goods; that tariffs expedited the shift of labour out of agriculture into industry; and that tariffs permitted the tapping of a rich vein of learning. To the extent that the first two explanations bear on technological creativity, they are captured by *RELFACTOR* and *RELMANU*. *RELTARIFF*, thus, chiefly relates to the process of learning.