Testing the Convergence Hypothesis using Time Series Data: Some Results for Australia, Canada, UK and USA

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Abstract: Tests of the Convergence Hypothesis or the tendency for per capita income levels to narrow over time, have generally utilised cross-sectional data and have usually found conflicting evidence see for example, Levine and Renelt (1992). In this study we utilise time series data on Australia, Canada, UK and USA for the period 1870-1993, and time series tests, based upon the Augmented Dickey-Fuller approach, to consider both "catching-up" and "long run convergence" with particular attention focused upon Australia and Canada. These two concepts of convergence are defined and their time series connotations developed. The differing implications of Solow-type exogenous and Rebelo-type endogenous growth models on convergence are developed and the results of the paper used to consider support for each approach. The paper finds evidence in favour of long run convergence in per capita income levels for the UK and Australia for the period 1870-1992 and catching-up in all other bi-variate comparisons giving some support for the exogenous approaches to economic growth. However, the pace of catching-up to the USA's GDP per capita has not been uniform, and Canada's superior performance appears to stem from stronger links with the USA.

1. Introduction.

Australia and Canada have distinct and divergent macroeconomic histories. Australia's GDP per capita was well above the UK's and USA's level in 1870, and more than twice the Canadian level. By the 1980s Canadian GDP per capita almost matched the USA's, and was substantially above Australia's and the UK's levels. This variety of historical experience rests uneasily with the convergence hypothesis, which postulates the tendency for per capita income levels to narrow. Why Canada and Australia, both regions of recent European settlement with British colonial origins, should have widely different macroeconomic histories raises a number of puzzles. Export staples figure prominently in the early development of both economies, and the shift towards industrial and service employment in the twentieth century appears equally strong in both countries. More distinctively the education system in Canada tends to follow the USA model, and that in Australia the UK system. Imports of goods and capital from the USA are also more prominent for Canada. Our particular concern lies in establishing whether the relative economic performance of Australia and Canada derives from the strength of their economic links respectively with the UK and the USA.

Most tests of the convergence hypothesis utilise cross-sectional data and report convergence for industrial economies (normally defined to include Australia, Canada, the UK and the USA), see Baumol (1986) and Dowrick and Nguyen (1989). Outside the industrial world convergence club, there appears less tendency for per capita income differences to narrow, see DeLong (1988) and Levine and Renelt (1992). Although diminishing returns provide a simple economic underpinning for the convergence hypothesis, Barro and Sala i Martin (1992) and Mankiw, Romer and Weil (1992) argue investment in human capital might reduce the tendency for returns to diminish. Their perspective suggests convergence may be protracted, which might help explain the diversity of Canadian and Australian macroeconomic experience. Alternatively doubts have grown around the ability of cross-sectional tests to distinguish convergence. In particular, Bernard and Durlauf (1994), identify inconsistencies between cross-sectional and time series tests, favouring time series methods for pure tests of the convergence hypothesis. Using such tests, Bernard (1992) and Bernard and Durlauf (1993) reject convergence, even among industrial economies. It may be that Australia and Canada do not belong to the same convergence club.

This paper deploys time series unit root-based tests to consider the convergence in GDP per capita between Australia, Canada, the UK, and the USA during the period 1870-1992, and pays particular attention to the experience of the two British dominions. While both Canada and Australia had close and complimentary links with the UK, shaped by trade, investment and migration during the century after 1870, Canada's economic links to the USA were also strong. Rather differently, the USA became the UK's major

industrial competitor during the 1890s, and maintained global ascendancy for much of the twentieth century, see Nelson and Wright (1992). The convergence hypothesis suggests Australia, Canada and the UK should have experienced per capita GDP convergence with the USA during the twentieth century. Investigating pairwise GDP per capita convergence between Australia, Canada, the UK, and the USA sheds light on particular British-Australia, and Canada-USA economic relations, and on the convergence hypothesis more generally, in relation to the USA's global leadership.

The time series approach developed by Bernard and Durlauf (1994) gives rise to two definitions of the convergence hypothesis, one associated with long run convergence and the other with catching up. Here we extend their work by giving attention to the possibility of structural discontinuities in the convergence process. Thereafter we define the two convergence hypotheses, report the pairwise time series test results, and consider their implications for Australian and Canadian macroeconomic history.

2. The macroeconomic history of Australia and Canada.

Two features of the comparative macroeconomic history of Canada and Australia stand out. In 1870 Australia's GDP per capita was the highest in the world and more than twice the Canadian level, whereas since 1870 Canada's GDP per capita growth has been among the fastest in the world and Australia's the slowest.Ostensibly these GDP per capita data lend support to the convergence hypothesis, at least on the basis of typical cross-sectional tests which simply investigate correlations between starting levels and growth rates. Yet that faster Canadian growth was sustained once Australian GDP per capita were surpassed, which does cast some doubt on the simple version of the convergence hypothesis.

The diverse performance of the two British dominions ocurred despite some clear similarities in the two economies. Both countries have small populations compared to large land resources. Canada does have a larger population, but this was as much the case in 1913 as today. In 1913 Australia's population was around 4.8 million, or 63% of Canada's, by 1989 it had reached 16.8 million, 64% of the Canadian figure. Further, export staples, wool in the case of Australia and wheat for Canada, loom large in the early economic development of both countries. Yet by 1987 only 6% of the Australian and 5% of the Canadian workforce were employed in agriculture. Industry and services accounted respectively for 26% and 68% of Australian, and 25% and 70% of Canadian employment in 1987.

Clearer signs of diversity in the economic development of the two dominions can be observed in the orientation and expansion of their external trade. Export-GDP ratios were little different in 1913, Australia's at 18.3% was modestly above the 15.1% Canadian level, and around 50% of Australia's and Canada's exports went to the UK in 1913. However there was also a substantial market for Canadian exports in the USA. In 1913 around one third of Canadian exports went to the USA and subsequently the dominance of the USA in Canada's trading links have grown. Canada's exports to the USA were over four times those to the UK in 1950 and over 12 times by 1975. In contrast Australia's exports to the UK were four times greater than to the USA in 1950. It was not until 1969 that the USA replaced the UK as Australia's largest export market. Canada's closer links with the faster growing USA market was accompanied by a rising export-GDP ratio which reached 23.9% by 1987, whereas Australia's ratio fell to 13.5%.

Perhaps more important, given their role in technology transfer, were imports of goods and capital respectively from the USA and the UK. Canada's merchandise imports from the USA were three times the level from Britain by 1913, and the relativities were five and twenty times in 1950 and 1975. In contrast Australia's imports from the UK were five times the USA's level in 1950, and remained greater until 1967. British investment did preodominate in both Australia and Canada before 1914, but was primarily portfolio, and in effect financed Canada's import of merchandise from the USA. The USA's overseas investment in Canada exceeded the UKs by the 1920s, and was eight times as great by 1970. Much of the USA's investment in Canada was direct; Wilkins (1974), estimates half was in manufacturing by 1929. Alternatively the USA's manuafcturing investment in Australia was under 10% of the level in Canada in 1929. For 1984 Dyster and Meredith (1990) note the UK's share of foreign owned corporate equity in Australia was around twice the USAs.

Elements of overall investment also exhibit distinctive features in Canada and Australia, partcularly in relation to human capital. Since 1945 the physical investment ratio has been around 24% of GDP in both economies. In earlier years the Canadian ratio was higher, averaging 25% during the 1900-13 boom, but more generally was around 16% before 1900 and in the 1920s. The Australian ratio averaged 13% before 1914, but rose 18% during the 1920s, principally due to

the boom in the early part of the decade. More distinctive are the respective levels of investment in human capital. MacKinnon (1989) argues Australian education followed the British model, to the neglect of secondary and tertiary education. In 1920-1, respectively 14% and 28% of sixteen years olds were students in Australia and Canada. The comparable figures for 1970-1 are 55% and 86%. Low levels of secondary education in Australia are reflected in the figures for higher education. For 1975 Maddock and McLean (1987) note 6.7% of the 20-4 years age group were students in Australia, compared to 9.3% in the UK, 18.3% in Canada, and 24.4% in the USA.

Surveying the macroeconomic records of Australia and Canada highlights their close economic links respectively with the UK and the USA. These links are most simply illustrated in the flows of merchandise and capital. Further the tendency for the education sytem in Canada to follow the USA, and in Australia the UK model also distinguishes the two dominions. *A priori* the force of technology transfer from the USA, and the capability for assimilation, should be stronger for Canada. Whether or not the comparative fortunes of the Australian and Canadian economies may be explained by their respective relations with the UK and the USA will be investiagted statistically by a pairwise time series investigation of convergence between the four economies. Since these tests raise the issue of discontinuities in the convergence process, we first consider the experience of the individual economies.

3. Time series analysis and convergence

The economic underpinnings of the convergence hypothesis arise naturally within the standard or augmented Solow neoclassical growth model. Here differences in initial endowments are seen to have no long term effects on growth with deficient countries able to catch-up to the leaders who suffer from diminishing returns. In contrast, Rebelo (1991),-type models imply leadership can be maintained with non-convergence the likely outcome. As such, not only are tests of convergence interesting in their own right, but they emerge as one natural testable implication of alternative models of growth. However, convergence is but one implication of such models and does not in itself represent a full test of the competing approaches. In order to test for convergence some form of clear definition and some appropriate form of time series data are required where, as we will see, the crucial feature to be exploited are the time series properties of the data.

Durlauf (1989), and Bernard and Durlauf (1994), utilise the Dickey-Fuller unit root testing procedure as a time series based test of convergence. Here convergence implies output innovations in one economy should be transmitted internationally. The absence of transmission implies that per capita output differences between countries contains a unit root, since output shocks generating relative GDP movement infinitely persist causing economic divergence - an implication of the endogenous growth models of Rebelo. Utilising slightly different definitions to Bernard and Durlauf (1994), this can be illustrated via the concepts of *catching-up* and *long-run convergence.*

Definition:

Catching-up: consider two countries i and j, and denote their log per capita real output as y_i and y_j. Catching-up implies the absence of a unit root in their difference $y_i - y_j$.

This concept of convergence relates to economies *out of long run equilibrium* over a *fixed interval of time*, but assumes that they are sufficiently similar to make tests (and rejections), of the hypothesis non-trivial. In this case catching-up relates to the tendency for the difference in per capita output to narrow over time. Hence non-stationarity in $y_i - y_j$ must violate the proposition although the occurrence of a non-zero time trend in the deterministic process in itself, would not.

Long-run convergence: consider two countries i and j, and denote their log per capita real output as y_i and y_j. Long-run convergence implies the absence of a unit root in their difference $y_i - y_j$ and the absence of a time trend in the deterministic process.

Catching-up differs from long-run convergence in that the latter relates to some particular period T equated with long-run equilibrium. In the former case the existence of a time trend in the stationary $y_i - y_j$ series would imply a narrowing of the (log per capita output) gap or simply that the countries though catching-up had *not yet* converged. This catching-up could be oscillatory, but must imply non divergence of output differences. Conversely, the absence of a time trend in the stationary series implies that catching-up has been completed.

Clearly long-run convergence and catching-up are related in that both imply stationary $y_i - y_j$. In either case, output shocks in one country have only transitory effects and are transmitted to the other such that output dissparities do not persist - are stationary. However, long-run convergence relates only to similar economies in long-run equilibrium

and therefore represents a much stronger version of the convergence hypothesis.

As defined above, tests of catching-up and long-run convergence hinge, therefore, on the time-series properties of $y_i - y_j$. The natural route for such tests involves Dickey-Fuller type tests based on the bi-variate difference in log per capita output between pairs of countries, i and j, i.e.,

$$y_{it} - y_{jt} = \mu + \alpha(y_{it-1} - y_{jt-1}) + \beta t + \sum_{k=1}^{n} \delta_k \Delta(y_{it-k} - y_{jt-k}) + \varepsilon_t \quad (1)$$

where y indicates the logarithm of per capita output. If the difference between the output series contain a unit root, $\alpha=1$, output per capita in the two economies will diverge. The absence of a unit root, $\alpha<1$, indicates either catching-up, if $\beta\neq0$, or long-run convergence if $\beta=0$.

The main reservation surrounding the robustness of unit root tests in general, and therefore their application to tests of convergence in particular, concerns the possibility that structural discontinuities in the series may lead to erroneous acceptance of the unit root hypothesis. Perron (1989), and Rappoport and Reichlin (1989), consider the importance of incorporating the effects of discontinuities when investigating the statistical properties of long-run historical series. Alternatively, Zivot and Andrews (1992), contend that discontinuities have been too readily accepted and that macroeconomic time series usually contain a unit root.

Applying Perron's unit root testing strategy requires the prior specification of breakpoint years. Christiano (1992), and Zivot and Andrews (1992), favour an alternative approach based upon recursive searching for endogenous discontinuities at every year within the sample. They deploy dummies similar to Perron's to incorporate crash and trend breaks, but dispense with the single year dummy, D(TB). Critical values reported by Zivot and Andrews (1992), for testing the significance of α with breaks at any year are much greater in absolute value than Perron (1989), raising a stringent barrier to the rejection of a unit root.

4. Time series test results for convergence

This section reports pairwise tests for long run convergence, and catching-up. On the basis of the results in table 1 based on equation 1, for the 1870-1992 period, neither version of the convergence hypothesis receives support, since a unit root cannot be rejected in the cross- country differences in GDP per capita. However the likelihood of structural discontinuities in the Canadian and Australian growth records, for example associated respectively with the crashes of 1917 and 1891, suggests their impact on the convergence process warrants investigation.

Interestingly the British and Australian economies appear to have been convergent during the century following the discontinuity associated with the 1891 Australian crash. The absence of both a unit root and a deterministic trend in the UK-Australia data for the period 1892-1992, favours the strong version of the convergence hypothesis.

Whether or not the failure of the time series approach to typically identify convergence stems more widely from discontinuities in the process can be assessed by applying Zivot and Andrews' search procedure to the comparative series. The results in table 2 report the maximum absolute ADF statistics obtained by endogenous searching over the period 1870-1992 for crash, trend, and joint crash and trend changes in a naturally extended version of equation 1.

All the pairwise results reject the existence of a unit root in some variant of the model and are supportive of some form of the convergence hypothesis. Consider first the Canada-USA and UK-Australia results, which appear similar in that the inclusion of single crash, respectively in 1917 and 1891, overturns the unit root. These results do contain a significant joint crash and trend change discontinuities in 1891 and 1917, but the absence of a significant individual trend break and the closeness of the crash, and joint crash and trend break ADF statistics point to the dominance in both cases of the crash. Further in the Australia-UK case, $\beta=0$, (the 't' ratio for β in equation 1 is 0.014), suggesting long run convergence between the two economies, with a discontinuity in 1891. The Canada-USA results are different in that they contain a significant deterministic trend, (in this case the 't' value for β is -5.61), which points to catching up rather than long run convergence.

All of the other pairwise results contain significant trend discontinuities, and hence favour the weaker catching-up version of the convergence hypothesis. In the case of Canada and the UK, the significant deterministic trend contains a discontinuity at the time of the 1928 crash implying a slower catch-up rate. For Canada and Australia a trend break at any point between 1891-1919 overturns the unit root. Australia's and the UK's pairwise results with the USA contain significant trend discontinuities which pinpoint faster catching up towards the USA GDP per capita from the years of World War Two and 1950 respectively for Australia and the UK.

The results therefore show how the omission of significant discontinuities can lead to incorrect inferences being drawn regarding convergence and importantly the possible causes of economic growth. In contrast with previous time series studies all the results favor at least the weaker catching up version of the convergence hypothesis, and more distinctively Australia and the UK appear to have attained long run convergence. The results lend support to exogenous, Solow-type growth modelling strategies, while no case supports one important implication of the Rebelo model, i.e., long term non-convergence. However, as stated earlier such implications do not constitute full tests of the growth models.

5. Concluding remarks

Doubts have grown in recent years about the value of the convergence hypothesis. Partly the skepticism concerns the inability of cross-sectional studies to discern convergence other than between a narrow range of industrial countries, but more fundamentally the basic utility of the cross-sectional approach has been questioned see for example, Bernard (1992), Bernard and Durlauf (1994) and Quah (1992, 1993). Moreover, the recent development of time series convergence tests has led to results which hereto have been wholly unfavourable to the convergence hypothesis, even for industrial economies. The novelty of this paper's statistical findings lies in the support found for the convergence hypothesis via a time series perspective. Incorporating discontinuities led to the rejection of a unit root for all the comparative Canadian, Australian, UK, and USA GDP per capita series.

In themselves these results offer support for the catching-up version of the convergence hypothesis. Further the absence of a deterministic trend in the UK-Australia series points to the attainment of long run convergence between these two economies. Such results have broader utility when related to current debates on exogenous versus endogenous growth. Solow and augmented Solow-type models of exogenous economic growth imply convergence or catching-up. However, Rebelo-type models allow the possibility for perpetual leadership. The results here give some support for the exogenous over endogenous models although care should be taken not to take such implications too far without full tests of the appropriate economic models.

The results also shed light on the particular macroeconomic history of the four economies. Most interestingly the UK's economic links with its northern and southern dominions appear strikingly different.

6. References

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Appendix

Table 1
Unit root tests .
Differences in GDP per capita (without discontinuities)

Countries	Sample	ADF	LM(SC)	Q6
UK-Australia+	1870-1992	*-3.250*	0.792	4.029
UK-Australia+	1892-1992	*-5.531**	0.309	7.969
USA-Australia	1870-1992	*-2.301*	0.047	1.823
USA-Canada	1870-1993	*-3.156*	0.574	2.441
Canada-UK	1870-1993	*-3.026*	0.663	1.724
Canada-Aus	1870-1992	*-2.894*	0.273	4.751
UK-USA	1870-1993	*-3.160*	0.994	5.818

* denotes significant at the 5% level based upon MacKinnon (1991),
ADF denotes ADF(2) except those marked + which relate to ADF(4).

Table 2
Unit root tests - Differences in GDP per capita
Zivot and Andrews (1992), Approach

Country	*Year*	*Crash*	*Trend*	*Crash & Trend*
UK-Australia +	*1870-1992*	*-5.418**	*-4.192*	*-5.440**
		[1891]	*[1935]*	*[1891]*
USA-Australia	*1870-1992*	*-4.085*	*-4.483**	*-4.585*
		[1891]	*[1943-44]*	*[1941]*
USA-Canada	*1870-1993*	*-5.364**	*-3.699*	*-5.431**
		[1917]	*[1951]*	*[1917]*
Canada-Australia	*1870-1992*	*-5.506** ♣	*-5.365** ♦	*-5.431** ♠
		[1891]	*[1902 & 1905]*	*[1896]*
Canada-UK +	*1870-1993*	*-4.481*	*-4.211*	*-5.130**
		[1896]	*[1909]*	*[1928]*
UK-USA +	*1870-1993*	*-4.303*	*-4.828**	*-5.342**
		[1966]	*[1950]*	*[1941]*

Results based upon ADF(2) except those denoted + which relate to ADF(4),
** denotes significant at the 5% level based upon Zivot and Andrews (1992),*
[ ] denotes the year of the maximum absolute value of the ADF.
♣ denotes that any period between 1886 and 1897 leads to a rejection of DS null;
♦ denotes that any period between 1891 and 1919 leads to a rejection of DS null;
♠ denotes that any period between 1891 and 1921 leads to a rejection of DS null.