A Panel Data Approach to Growth Empirics for Canada

by

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Major paper presented to the Department of Economics

of the University of Ottawa

as a requirement for the completion of the Master's Degree

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Ottawa, Ontario

January 1997

I would like to thank Serge Coulombe and Kathleen Day for their valuable guidance as well as the research opportunities they have given me. I am without question indebted to them.

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Introduction

Growth theory is one of the most popular fields in economics today. It has attracted attention because it approaches economic growth in an interesting fashion. Proponents of the endogenous growth models of the late 1980s (Romer (1986), Lucas (1988)) envisage growth as a process that is determined endogenously, by factors such as technology. Such models assume that an economy is always in steady-state equilibrium and therefore does not converge to some idealised level of income. Consequently, endogenous growth models do not predict (or explain) out-of-steady state behaviour nor do they predict the elimination of regional disparities among a set of growing economies. These theoretical predictions contrast sharply with the findings of several empirical studies[1] that have found that income disparities between economies diminish over time; in other words, that income levels of nations converge.

The prediction of convergence across countries is a key result of neoclassical growth theory. Convergence in per capita income or in productivity levels (however one wishes to define it) may be broadly defined as the reduction of regional disparities within a group of countries or regions through time. This view of the growth process was initially proposed by Robert Solow in 1956. His interpretation of this process eventually became known as the neoclassical approach to growth. This view stipulates that an open economy (or economies) converges to a steady state that is determined by the investment rate, the growth rate of the work force (or labour force), depreciation and the rate of technical progress. These factors being considered exogenous, in theory, growth is then exogenously determined. An economy converges to its steady state automatically and naturally.

This research will focus on two types of convergence. Absolute convergence is a prediction of the neoclassical growth model. It implies that economies converge to a steady state common to all of the units in a sample of regions or nations. One might think that absolute convergence is not realistic in the sense that it may seem unreasonable to assume that a poor economy has a steady state that is identical to that of a richer economy. However, when examining growth within a country, it

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[1] See de la Fuente (1995) and Barro and Sala-i-Martin (1995) for a wide ranging review of studies which have established that there has been convergence among a wide cross-section of nations, as well as within many nations.

is realistic to assume that preferences, technology and the institutional framework are similar enough to support the absolute convergence hypothesis.

The idea of incorporating variables that can control for initial conditions is an effort to capture convergence toward a region's own steady state. The notion of convergence to a province (or region) specific steady state is called conditional convergence. This aspect of convergence is captured by the initial conditions and the varying levels of the investment rate and the growth rate of the work force in individual provinces. The notion of conditional convergence a priori seems more reasonable that the notion of absolute convergence as even in a homogeneous economy, such as Canada, there remain persistent differentials in such economic variables as capital formation, unemployment and the natural resource base.

This research will apply the neoclassical growth model to the Canadian economy by examining the evolution of real provincial output per worker. The main objective of this paper is to determine which type of convergence best characterizes the evolution of this output measure, absolute or conditional convergence. A secondary objective will be to contrast two alternative approaches to modelling the growth process; the traditional method as outlined in Barro and Sala-i-Martin (1991) and Mankiw, Romer and Weil (1992), among others, and the techniques put forth by Coulombe and Lee (1993,1995,1996) in a series of papers. The use of panel data estimation techniques allows us to consider varying intervals between observations and consequently to examine the stability of estimated speeds of convergence. We find that parameter instability permeates both approaches but that the use of panel data estimation techniques reveal that traditional cross sectional approaches may not produce realistic estimates of the speed of convergence.

This first section will present the textbook neoclassical growth model and the dynamic panel data approach. It is here that we present the models of Barro and Sala-i-Martin (1991), Mankiw, Romer and Weil (1992) and Coulombe and Lee (1995). Section 2 reviews the concepts of β and σ convergence and how they are related. A discussion of the data follows in Section 3. This section will focus on the dynamic evolution of the data series in an effort to identify trends that might point to convergence or steady-state differentials across provinces. Section 4 discusses the estimation techniques and the results. We initially focus on the least squares with dummy variables approach which allows us to test the hypothesis of initial condition differentials. We also focus on the conditional convergence control variables and examine their impact on the growth equations. In Section 5 we attempt to shed some light on the appropriate estimation methodology: that of Islam (1995) and the like, or that of Coulombe and Lee (1995). This section includes a discussion of our results and their implications for empirical applications of growth theory in the Canadian context. Conclusions are provided in the final section.

Section I: Textbook neoclassical growth model and the dynamic panel data model

The neoclassical approach to economic growth is the original analysis of Solow (1956). It assumes a Cobb-Douglas production function with labour augmenting technological progress[2]:

$$Y(t) = K(t)^{\alpha}(A(t)L(t))^{\tau} \qquad \alpha,\tau > 0 \quad \alpha + \tau < 1 \tag{1}$$

in which Y is output, K is the capital stock, L is labour, A is technology and α is the capital share of output. The technology factor is assumed to be labour augmenting and the production function is characterized by decreasing returns to scale. The labour force and technology, by assumption, evolve exogenously according to the following paths, exogenously determined by n (the growth rate of the work force) and g (the rate of technical progress):

$$\begin{aligned} L(t) &= L(0)e^{nt} \\ A(t) &= A(0)e^{gt} \end{aligned} \tag{2}$$

To solve the model, we must make the assumption that there exists an investment rate s, which represents a constant fraction of output. Further, we may define effective units of capital and output. These are simply capital or output expressed in terms of units of effective labour ($\hat{y} = \frac{Y}{AL}$ *and* $\hat{k} = \frac{K}{AL}$). On this basis, we can obtain the dynamic evolution of $\hat{k}$. Substituting (1) into (2), and expressing the relation in terms of effective units of labour, we take the derivative of $\hat{k}$ with respect to time to obtain:

[2] This section borrows heavily from Islam (1995) and Mankiw, Romer and Weil (1992). An equivalent, but alternative way of approaching the model is presented in Barro and Sala-i-Martin (1995, chapter 1).

$$\frac{d\hat{k}(t)}{dt} = s\hat{y}(t) - (n+g+\delta)\hat{k}(t)$$
$$= s\hat{k}(t)^{\alpha} - (n+g+\delta)\hat{k}(t) \tag{3}$$

δ is the rate of depreciation and is assumed to be constant. Solving for $\frac{d\hat{k}(t)}{dt} = 0$ in equation (3) we obtain the steady-state value, $\hat{k}^*$ to which $\hat{k}$ converges:

$$\hat{k}^* = \left[\frac{s}{n+g+\delta}\right]^{\frac{1}{1-\alpha}} \tag{4}$$

Substituting (4) into the now modified equation (1) and taking natural logarithms, we can obtain an expression for steady-state per capita income:

$$\ln\left[\frac{Y(t)}{L(t)}\right] = \ln A(0) + gt + \frac{\alpha}{1-\alpha}\ln(s) - \frac{\alpha}{1-\alpha}\ln(n+g+\delta) \tag{5}$$

This is the basic equation that Mankiw, Romer and Weil (1992) estimate for a broad spectrum of countries. Their estimation was made possible by two assumptions. The first is that the rate of technical progress is identical for all countries (individuals in the sample). This implies, for instance, an even and equal diffusion of technology across the sample. It is not such a strong assumption to make within the Canadian federal system[3]. A second and more restrictive assumption which reflects the preceding restriction concerns the constant term A(0). A cross-sectional analysis of this type

[3] This assumption will in fact be maintained throughout our paper as well. We will eventually show that there are in fact no province specific effects, which further supports this assumption.

imposes an identical production function on all the countries within the sample. This is quite a strong assumption. To overcome this problem, Mankiw, Romer and Weil (1992) assume that ln A(0) = a + ε, which still imposes an identical production function on all economies, but allows for a country specific shift or shock term. The modified equation then becomes:

$$\ln\left[\frac{Y(t)}{L(t)}\right] = a + \frac{\alpha}{1-\alpha}\ln(s) - \frac{\alpha}{1-\alpha}\ln(n+g+\delta) + \varepsilon \qquad \textbf{(6)}$$

This model is problematic, as Islam (1995) points out. Mankiw, Romer and Weil (1992) postulate that the country specific shift terms are independent of the investment rate, s, or the work force growth rate, n. Such an assumption permits the estimation of the model using cross-section data with a simple OLS procedure. However, given the dynamics of these types of growth models and the over-riding assumption of identical production functions across the sample, there is every reason to believe that ε is correlated with s and n. The problem associated with relaxing such an assumption is that OLS becomes invalid. One might suggest the use of instrumental variables, as Islam (1995, p.1134) points out, but this would require a set of instruments correlated with s and n, but uncorrelated with the initial conditions a (or A(0)). Such instruments are not readily known.

Islam (1995, p. 1134) suggests that the use of a dynamic panel data framework "provides a better and more natural setting to control for this technology shift term ε." Reformulation of the model for the panel data approach must begin with an examination of the transitional dynamics, that is out-of-steady-state behaviour. Approximation of equation (6) around the steady-state value of $\hat{y}(t)$, $\hat{y}^*$[4] yields the following convergence relation:

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[4] Again the steady-state value of $\hat{y}(t)$ is obtained by solving for $\frac{d\ln \hat{y}(t)}{dt} = 0$, in (9).

$$\frac{d\ln\hat{y}(t)}{dt} = \beta\left[\ln(\hat{y}^*) - \ln\hat{y}(t)\right] \tag{7}$$

where the speed of convergence β=(n+g+δ)(1-α). This convergence equation implies:

$$\ln\hat{y}(t) = (1 - e^{-\beta})\ln\hat{y}^* + e^{-\beta}\ln\hat{y}(t-1) \tag{8}$$

Subtracting $\ln\ \hat{y}(t-1)$ from both sides of equation (8) and rearranging, we obtain the following partial adjustment model:

$$\ln\hat{y}(t) - \ln\hat{y}(t-1) = (1 - e^{-\beta})(\ln\hat{y}^* - \ln\hat{y}(t-1)) \tag{9}$$

Substituting for $\hat{y}^*$ in equation (9) yields the conditional convergence equation (10):

$$\begin{aligned}\ln\hat{y}(t) - \ln\hat{y}(t-1) &= (1 - e^{-\beta})\frac{\alpha}{1-\alpha}\ln(s) \\ &\quad - (1 - e^{-\beta})\frac{\alpha}{1-\alpha}\ln(n+g+\delta) - (1 - e^{-\beta})\ln\hat{y}(t-1)\end{aligned} \tag{10}$$

As there are no measures of output per effective units of labour, estimation of this equation is problematic. For this reason, this equation cannot be estimated in this form. One can transform equation (10), as Mankiw, Romer and Weil (1992) and Islam (1995) did, in terms of output per worker (Y/L). We have previously defined:

$$\hat{y}(t) = \frac{Y(t)}{L(t)A(0)e^{gt}} \tag{11}$$

so that we may express:

$$\ln\hat{y}(t) = \ln\left(\frac{Y(t)}{L(t)}\right) - \ln A(0) - gt$$
$$= \ln y(t) - \ln A(0) - gt \tag{12}$$

where y(t) is productivity. We can incorporate (12) into (10) to find, after rearranging:

$$\ln y(t) = e^{-\beta}\ln y(t-1) + (1 - e^{-\beta})\frac{\alpha}{1-\alpha}\ln(s)$$
$$- (1 - e^{-\beta})\frac{\alpha}{1-\alpha}\ln(n+g+\delta) + (1 - e^{-\beta})\ln A(0) + g(t - e^{-\beta}(t-1)) \tag{13}$$

Expressing equation (13) in panel data form, as does Islam (1995) we have the following notation:

$$y_{it} = \gamma y_{i,t-1} + \omega_1 x_{it}^1 + \omega_2 x_{it}^2 + \eta_t + \mu_i + v_{it} \tag{14}$$

where:

$$y_{it} = \ln \textit{ of real output per worker}$$
$$\gamma = e^{-\beta}$$
$$\omega_1 = (1 - e^{-\beta})\frac{\alpha}{1 - \alpha}$$
$$\omega_1 = -\omega_2$$
$$x_{it}^1 = \ln(s)$$
$$x_{it}^2 = \ln(n + g + \delta)$$
$$\mu_i = (1-e^{-\beta})\ln A_i(0)$$
$$\eta_t = g(t - e^{-\beta}(t-1))$$

Note that i refers to the cross-sectional unit (provinces in our case) and t to the time period.

Coulombe and Lee (1995), Lee and Coulombe (1995) and Coulombe and Day (1996) transform equation (14) further. They prove that by subtracting the mean of $y_{it}, \overline{y_{it}}$ from both sides of equation (14), we eliminate the province specific term u_i from the equation. The transformed equation, for our purposes, becomes:

$$\tilde{y}_{it} = \tau\tilde{y}_{i,t-1} + \pi_1\tilde{x}^1_{it} + \pi_2\tilde{x}^2_{it} + e_{it} \tag{15}$$

where:

$$\begin{aligned}
\tilde{y}_{it} &= \ln(y_{it}) - \overline{\ln(y_i)} \\
\tau &= e^{-\beta} \\
\pi_1 &= (1 - e^{-\beta})\frac{\alpha}{1 - \alpha} \\
\pi_1 &= -\pi_2 \\
\tilde{x}^1_{it} &= \ln(s) - \overline{\ln(s)} \\
\tilde{x}^2_{it} &= \ln(n + g + \delta) - \overline{\ln(n + g + \delta)}
\end{aligned}$$

Such formulations are quite different from traditional convergence analysis in that we can allow for the interval between observations to be very short--one year in fact. These analyses have generally covered long periods by considering the average values or evolution of explanatory variables between the base period and the end period. As a result, the estimated model would be different in that the β coefficient estimated is actually β(Tend-Tbase). In this analysis, we assume the length of time between observations is from one to twenty-four years. The use of short intervals in growth empirics is contentious. Mankiw (1995) argues that the cost of using panel data as opposed to purely cross-sectional data may not be justified. His argument is based on the belief that the use of yearly data contains too much noise, such as business cycles, and that "short-run fluctuations and long-run growth are fundamentally different phenomena" (Mankiw, 1995, p. 307). Dorwick and Nguyen (1989) argue that cyclical distortions tend to strengthen estimates of convergence[5]. Islam (1995) agrees and consequently uses time spans of five years in an effort to filter the effects of business cycles. However, division by the mean, as proposed by Coulombe and Day (1996), eliminates the national business cycle leaving only province specific cyclical variations. This investigation will shed some light on these issues.

As previously mentioned, a simplifying assumption posited by Mankiw, Romer and Weil (1992) and Islam (1995) regards the impact of g. We maintain the assumption that g affects all cross-sectional units in the same manner. While this is a strong assumption in the multi-country scenario, it is less so in intra-country analysis. In the Canadian context, given the relative homogeneity of the population, free flow of goods, services and ideas, and the role of the central government, this assumption is less onerous. As a result, we assume η_t affects all provinces in an identical fashion, and the province specific term u_i will capture this for all provinces in equation (14).

[5] The flip side of the coin is that business cycle issues become irrelevant if the cycles are of identical magnitude and duration. Unfortunately, this is not the case for across Canadian provinces.

Section II: Two concepts of convergence: β and σ convergence

Empirical studies of growth within and across nations have traditionally hinged on the speed at which economies converge and the evolution of the dispersion of income or productivity across nations. The speed at which economies converge is called β convergence. It refers to the annual rate at which the income or output per capita of a poorer nation (or region) converges to that of a richer nation (or region). Economies are said to converge if the growth rate of poor economies is larger than that of richer economies, so that these economies converge over time to a steady-state level of income. If this convergence leads to a steady state that is identical across economies than we say than the convergence is absolute. If, on the other hand, economies converge to steady states which are proper to themselves (based on the investment rate, the rate of technical progress, resource base, preferences, etc.) we say these economies converge conditionally. Therefore, for conditional convergence, economies attain steady-state levels of income or output per capita that may differ and are based on structural factors.

σ convergence deals with the evolution of the dispersion of per capita output or income. Economies are said to converge in the sense of σ if the dispersion of their per capita income measure decreases over time.

There is an intuitive link between these two measures of convergence. Barro and Sala-i-Martin (1995) demonstrate that β convergence is a necessary but insufficient condition for σ convergence, that is that economies must converge in levels before a reduction in dispersion is to be observed. The relationship between these two concepts can be formalized in the following equation[6]:

$$\sigma_t^2 = e^{-2\beta}\sigma_{t-1}^2 + \sigma_a^2 + \sigma_u^2 \tag{16}$$

where σ_t^2 is the variance of Gross Provincial Product (GPP) per worker, σ_a^2 the variance across provinces of the steady-state level of GPP per worker and σ_u^2 the variance of the disturbance term of the convergence equation. Given the differential nature of equation (1), solving it for the steady-state level of dispersion is possible (by solving for the steady-state level of variance, σ_t^2). The steady-state is found by solving equation (1) for $\sigma_t^2 \dot{=} \sigma_{t-1}^2$, which produces:

$$\sigma_*^2 = \frac{\sigma_u^2 - \sigma_a^2}{1 - e^{-2\beta}} \tag{17}$$

If it is assumed, or found, that there are no differences in the steady-state levels of GPP per worker, then σ_a^2 is null, leaving a direct relationship between the steady-state level of dispersion and β in equation (2), but also a direct relationship between σ_t^2 and β in equation (1).

Figure 1 displays the theoretical behaviour of dispersion, according to equation (1). The dispersion falls, rises or remains constant depending on whether it begins above, below or at the steady-state level of dispersion, σ_*^2. For this example, we assume a β of 0.02 and $\sigma_a^2 = 0$.

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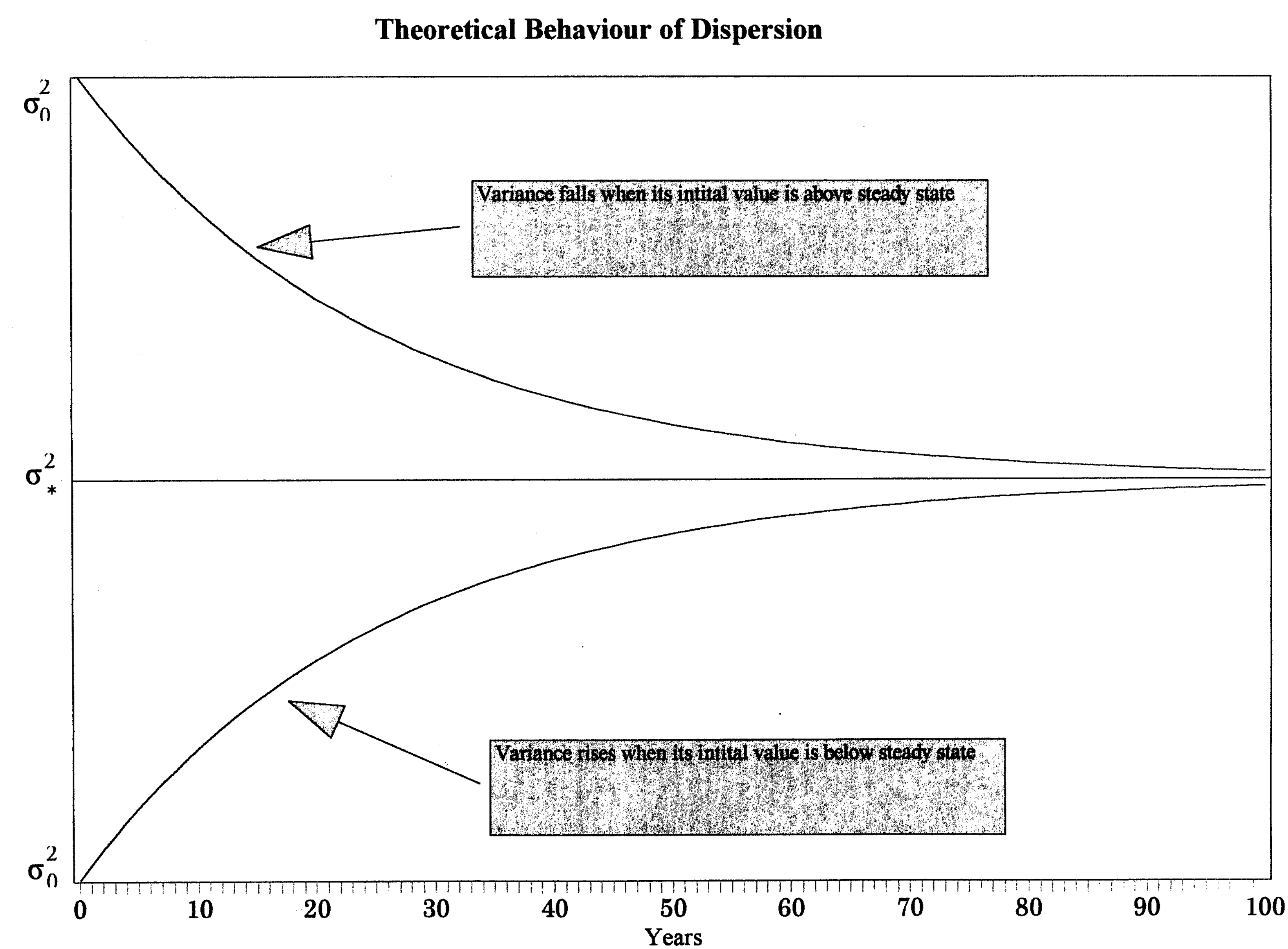
[6]We show in the following sections that we cannot accept the hypothesis of conditional convergence for our sample. As a result, equations (16) and (17) express the relationship between the speed of convergence and dispersion in an absolute convergence framework. In the case of conditional convergence, these equations would be altered to account for steady-state covariances among the cross-sectional units.

Figure 1

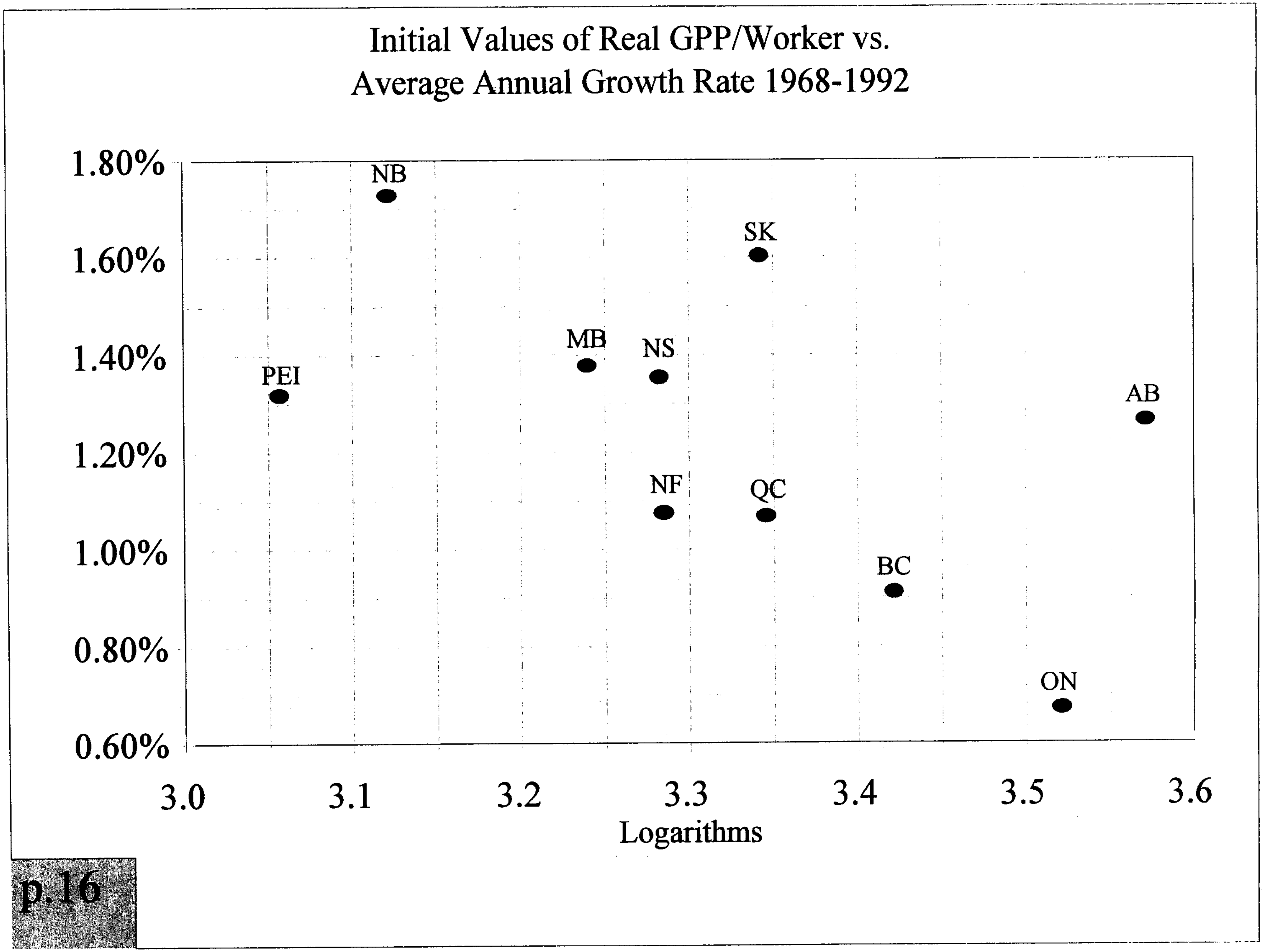

Theoretical Behaviour of Dispersion
Variance falls when its intital value is above steady state
Variance rises when its intital value is below steady state
σ_0^2
σ_*^2
σ_0^2
0
10
20
30
40
50
60
70
80
90
100
Years

Coulombe and Day (1996), use these results to produce dynamic forecasts of σ_t^2 within a panel data approach. We too use these relationships as a testing mechanism for the internal consistency of the panel regression results. Specifically, we will estimate equations (16) and (17) on the basis of the estimated σ_u^2 and β for the varying cross-sectional intervals (and methods). This will produce forecasts for σ_t^2 and σ_*^2 which we can analyse to gauge the appropriateness of the techniques employed.

Figure 2 plots the initial values of real GPP per worker for Canadian provinces against their average growth rates over the 1968-1992 period. There clearly exists an inverse relationship; the lower the initial level of GPP per worker, the higher the growth rate. This seems to support the β convergence hypothesis: poorer[7] provinces have seen productivity increase at a quicker pace over the sample than did richer provinces. Figure 3 plots the terminal values of real GPP per worker for all ten provinces against their average growth rates over the 1968-1992 period. Terminal GPP per worker levels are much more centred, indicating that there has been a "catch up" in GPP per worker levels. This is further confirmed by Figure 4, which charts the evolution of the standard deviation (one of many possible measures of dispersion) of the natural logarithm of GPP per worker over the sample. Figure 5 plots the evolution of the logarithm of real GPP per worker for all Canadian provinces, excluding Alberta. The evolution of these series is quite markedly negative suggesting that there effectively seems to be σ convergence. Given the appearance of σ convergence, one would expect to find that there has been convergence in levels (β convergence) over the sample.

[7] Note that throughout the text, we refer to poorer or richer provinces as provinces with high or low incomes or productivity levels.

Figure 2



Initial Values of Real GPP/Worker vs.
Average Annual Growth Rate 1968-1992
1.80%
1.60%
1.40%
1.20%
1.00%
0.80%
0.60%
NB
SK
MB
NS
PEI
AB
NF
QC
BC
ON
3.0
3.1
3.2
3.3
3.4
3.5
3.6
Logarithms

Figure 3

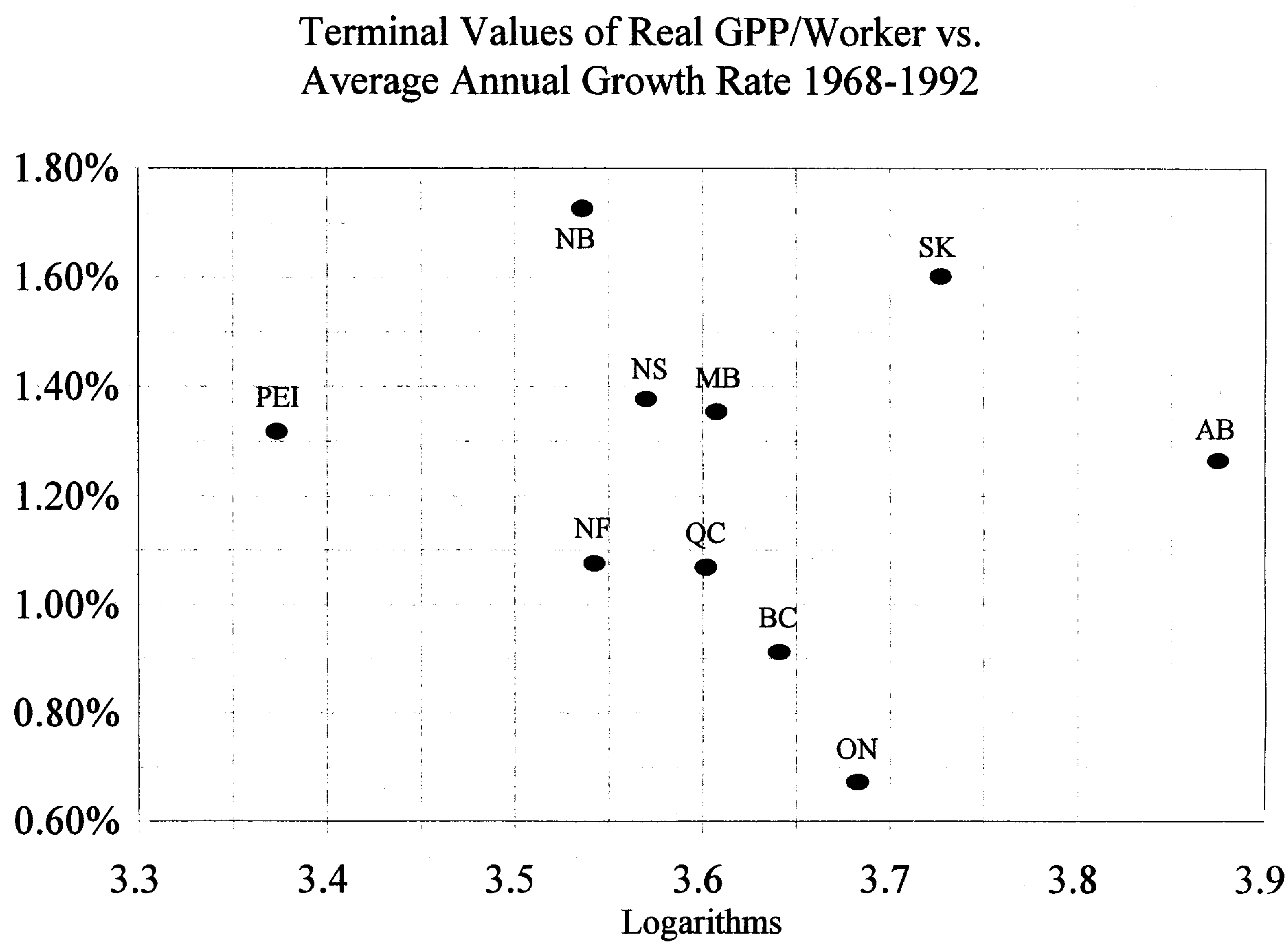
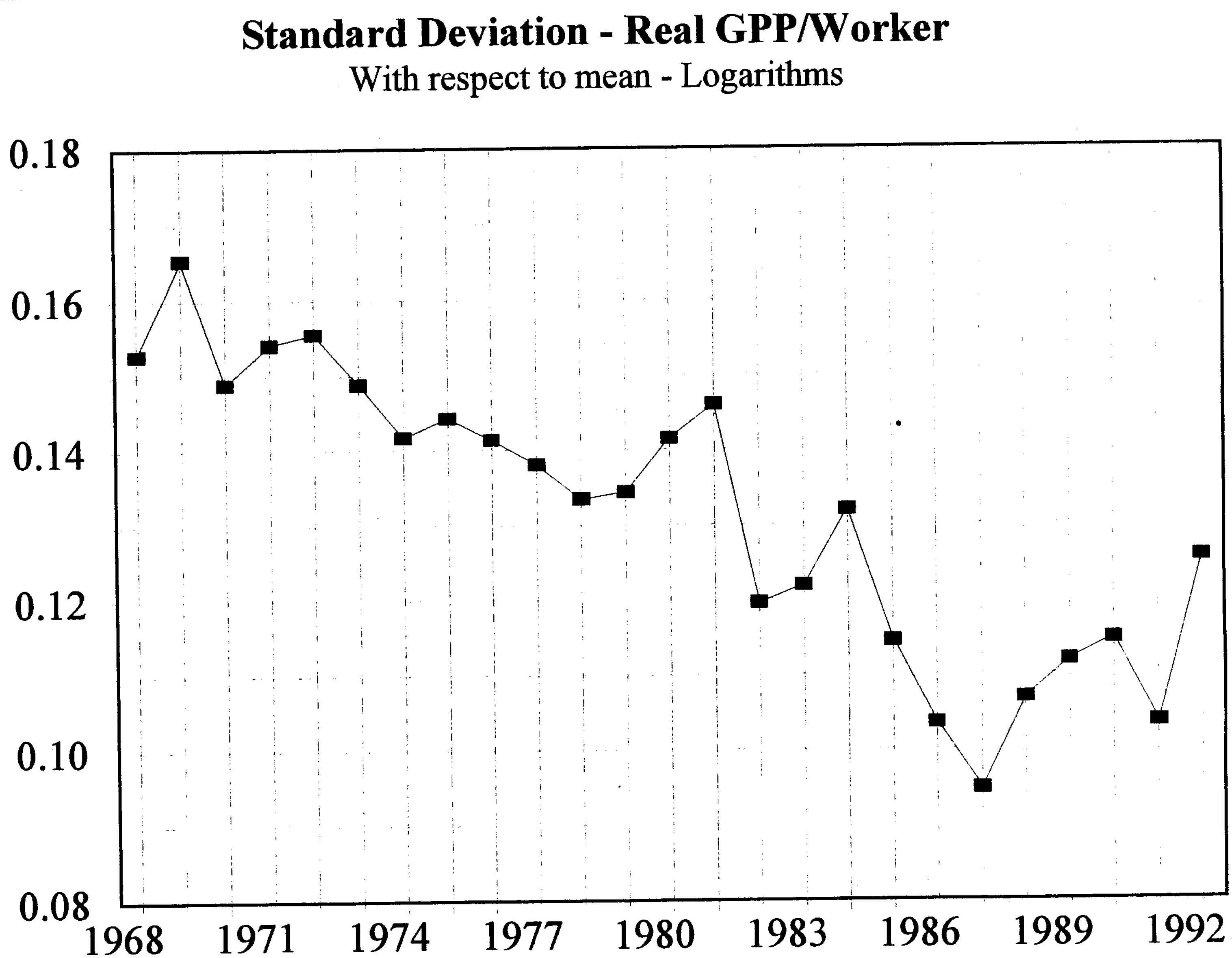

Terminal Values of Real GPP/Worker vs.
Average Annual Growth Rate 1968-1992
1.80%
1.60%
1.40%
1.20%
1.00%
0.80%
0.60%
NB
SK
PEI
NS
MB
AB
NF
QC
BC
ON
3.3
3.4
3.5
3.6
3.7
3.8
3.9
Logarithms

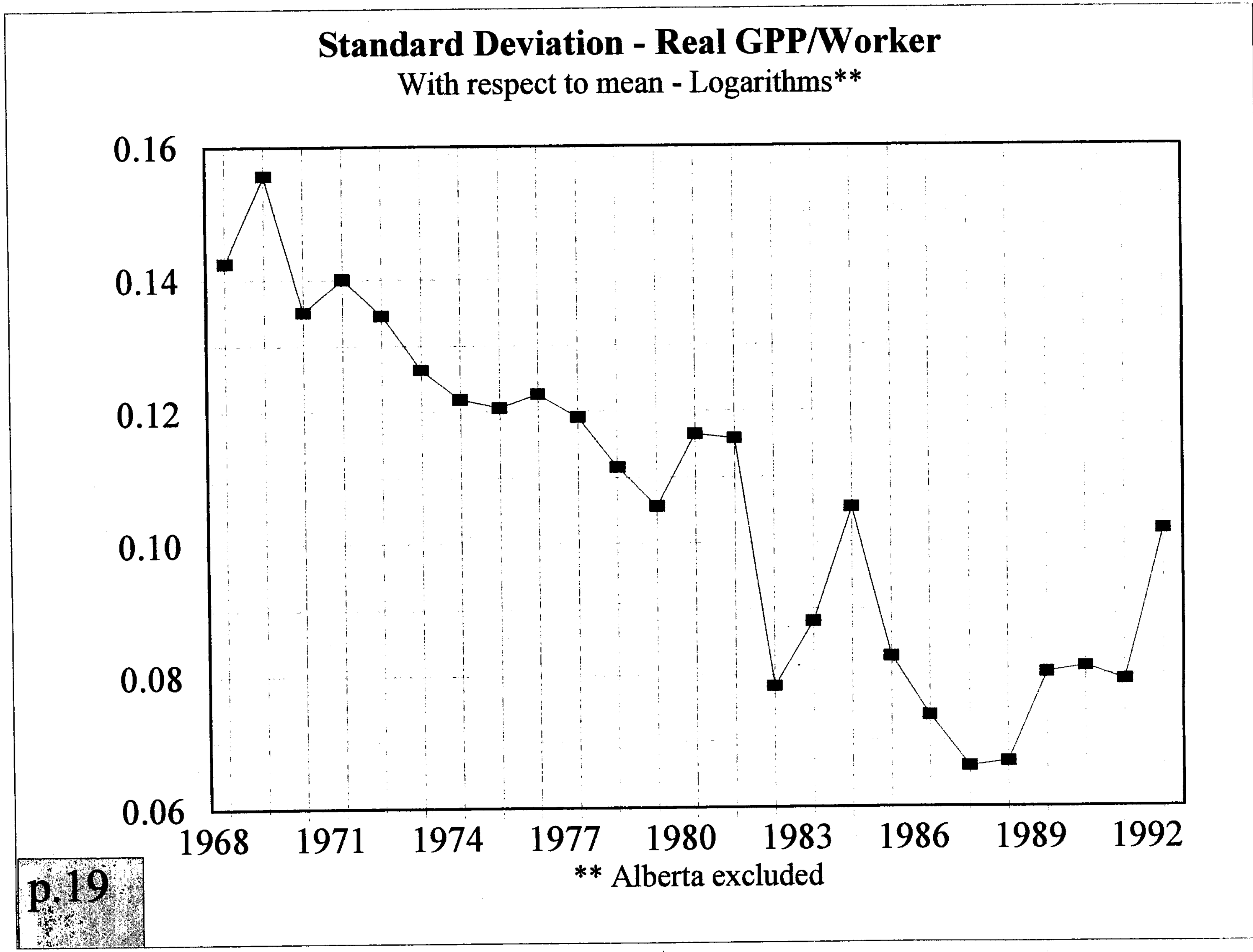
Figure 4



Standard Deviation - Real GPP/Worker
With respect to mean - Logarithms
0.18
0.16
0.14
0.12
0.10
0.08
1968
1971
1974
1977
1980
1983
1986
1989
1992

p.18

Figure 5



Standard Deviation - Real GPP/Worker
With respect to mean - Logarithms**
0.16
0.14
0.12
0.10
0.08
0.06
1968
1971
1974
1977
1980
1983
1986
1989
1992
** Alberta excluded

p.19

Section III: Data

The neoclassical growth model as presented by Mankiw, Romer and Weil (1992), and others, predicts similar speeds of convergence for various income measures (output per capita or output per worker, in which output may be expressed in a variety of fashions). The analysis of Coulombe and Lee (1995) does not support this prediction in the Canadian context. Their work revealed that speeds of convergence were conditional on the output measure examined. These authors argue that the Canadian federal system skews rates of convergence based on alternative output measures because of the presence of interregional transfer payments, which are at the root of our federal system. Further, the objective of fiscal federalism is to reduce regional economic and social disparities. Output or income measures that include fiscal transfers will necessarily lead to findings of convergence that are different from output measures which net out these transfers. To focus on the underlying "true" economic dynamics of the provincial economies, the output measure examined must not reflect fiscal transfers. Gross provincial product at factor cost is an ideal candidate. This measure of output excludes interregional fiscal transfers and is more reflective of the economic activity of a region (Statistics Canada, 1990). Therefore, this measure of output has been used in a number of studies focussing on Canadian regional disparities[8].

As in Coulombe and Day (1996), this analysis focusses on GPP per worker because GPP per worker is the national accounting measure that is the most closely associated to the theoretical measure that should converge in the neoclassical framework. Additionally we restrict our analysis to the use of provincial output deflators as published by the Conference Board of Canada. Given the

[8] See for instance Coulombe and Day (1996) and Coulombe and Lee (1995).

high reliance on natural resources of many Canadian provinces, the use of provincial data on output deflators is a natural hedge against assigning too much importance to relative price movements relating to variations in natural resource prices. The use of provincial deflators does not entirely remove these effects as some provinces, Alberta in particular[9], have experienced rapid acceleration in real GPP per worker during the 1970s which was only marginally offset by the choice of deflator.

The investment rate is defined as the ratio of investment to GPP.

Figure 6 graphs the average investment rate by region for the period 1968-1992. The investment rates seem very much to converge in the first half of the sample period, as the gap between the average investment rate of the Central Canadian provinces and the Atlantic and Western provinces closes noticeably in the early 1980s. The standard deviation is plotted as well and also reflects the narrowing gap between the regional investment rates. This would lead us to believe that there may not be a significant relationship over the sample between the investment rate and output per worker as the convergence in investment rate ends in the early 1980s, mid-way through the sample period. Secondly, the investment ratios stabilize at the same level for each region by the mid 1980s. There must exist differences in long-run investment rates for there to be conditional convergence. Consequently, there can be no province specific steady-state (with respect to the investment rate) if each province has a investment rate that is almost the same as that of the rest of the provinces. The investment rate then seems, a priori, not to influence the growth process in Canada during this sample. This will in fact be confirmed by the empirical analysis.

Figure 7 plots the annual employment growth rate for each Canadian region. Of noticeable

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[9] Figures 4 and 5 display the evolution of the dispersion of real GPP per worker with and without Alberta. Clearly, the inclusion of Alberta demonstrates the impact that natural resource price movements may have on the evolution of output and its dispersion in a provincial context.

difference is the fact that there seems to be no gap or systematic level differences between the employment growth rates of the provincial regions. As a result, there is no convergence in this series. This is supported by the standard deviation which does not tend to decrease at any point in the sample. Further, the growth rate of employment seems to move in phase across regions, suggesting that these growth rates evolve with the national business cycle rather than more regional cyclical fluctuations. As a result, we are unlikely to capture convergence effects related to out-of-phase business cycles.

Figure 6

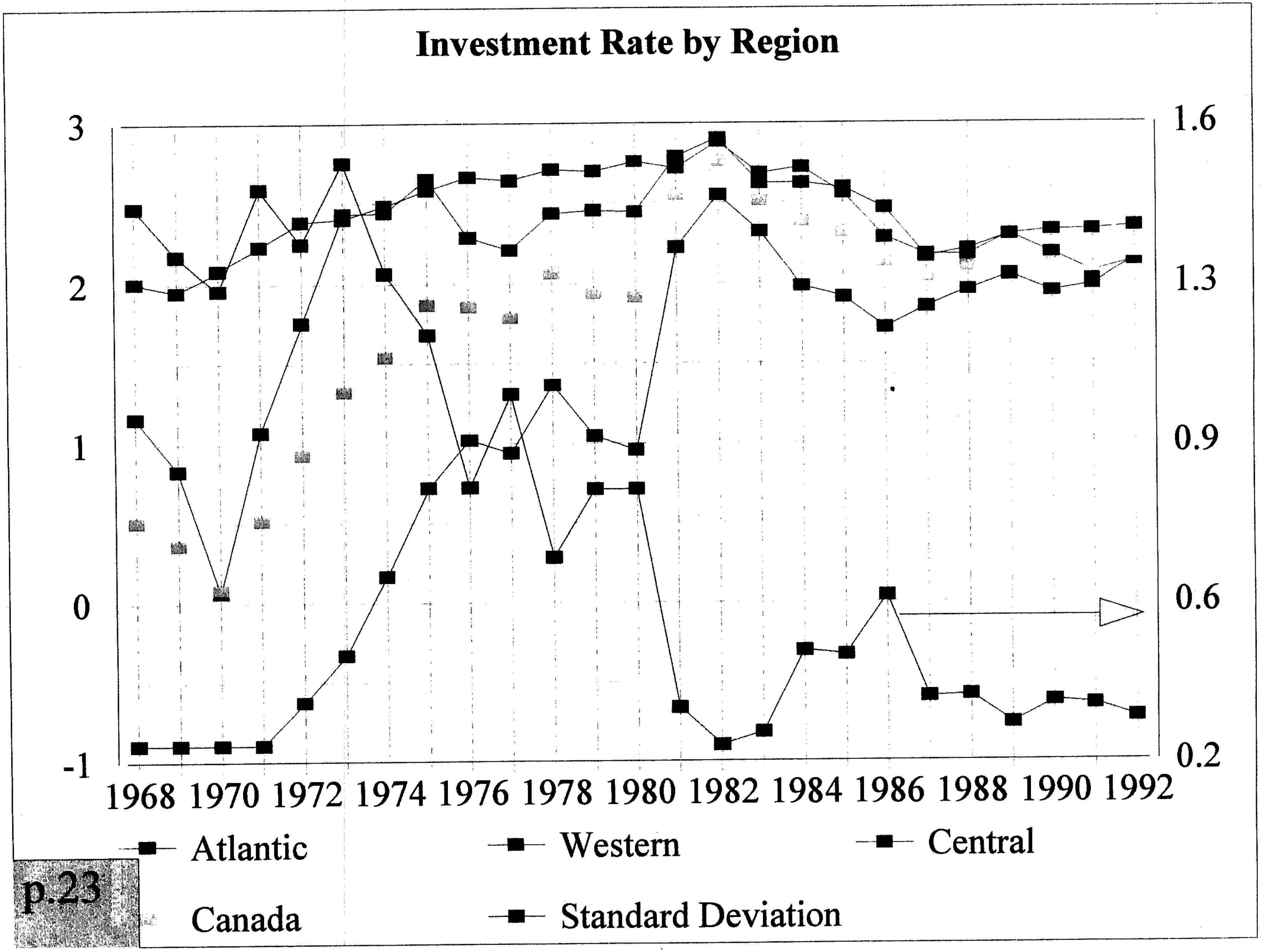
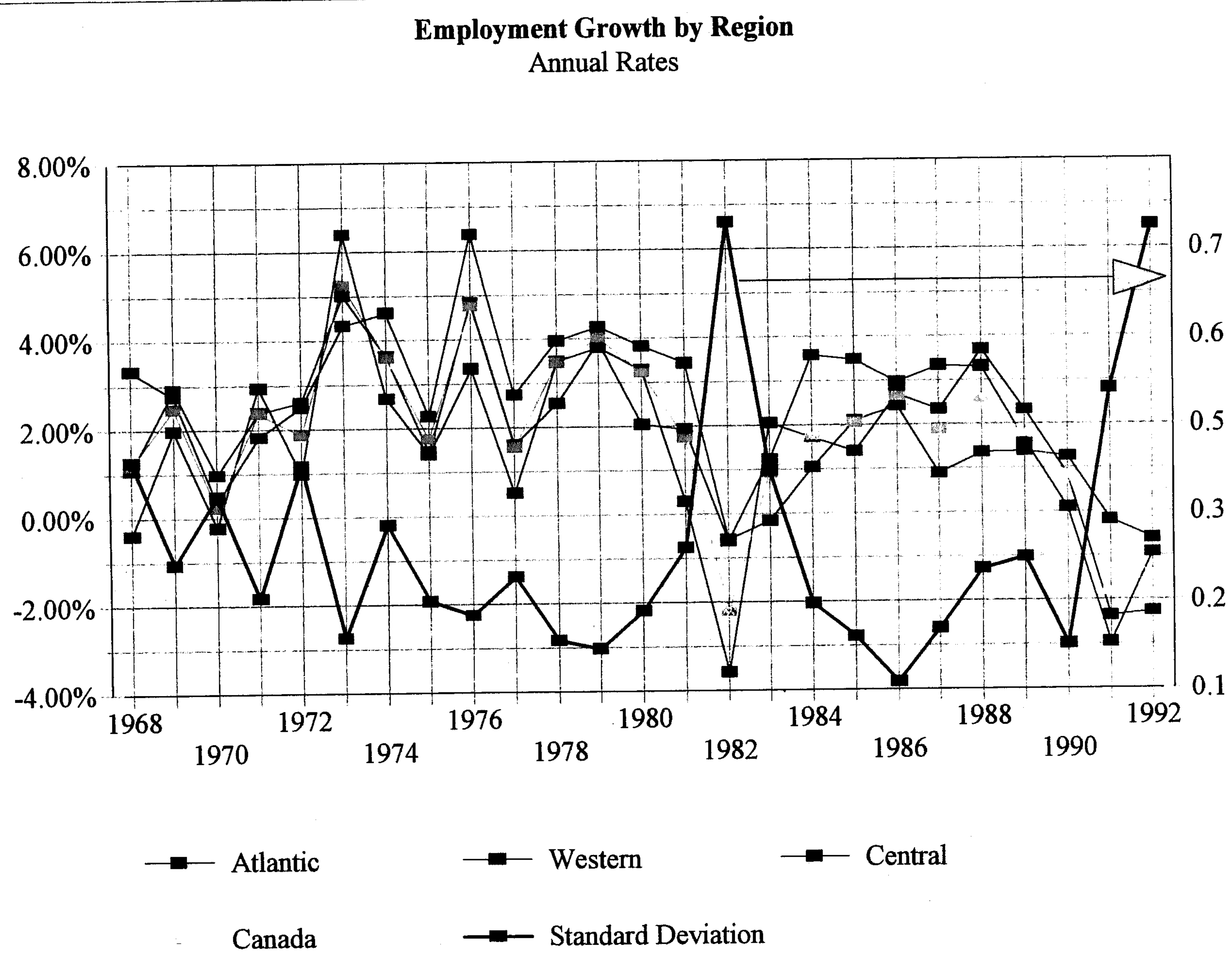

Investment Rate by Region
3
2
1
0
-1
1.6
1.3
0.9
0.6
0.2
1968 1970 1972 1974 1976 1978 1980 1982 1984 1986 1988 1990 1992
Atlantic
Western
Central
Canada
Standard Deviation
p.23

Figure 7



Employment Growth by Region
Annual Rates
8.00%
6.00%
4.00%
2.00%
0.00%
-2.00%
-4.00%
0.7
0.6
0.5
0.3
0.2
0.1
1968
1970
1972
1974
1976
1978
1980
1982
1984
1986
1988
1990
1992
Atlantic
Western
Central
Canada
Standard Deviation

This analysis will focus on Canadian provincial data for the years 1968-1992. Data on employment, gross provincial product and investment rates are obtained from CANSIM:

Employment, 15 and over:	Series: D768890, D769857, D768616, D769890, D769839, D769902, D769946, D769967, D769988, D769920.
Gross Provincial Product at Market Prices:	Series: D31544, D31558, D31572, D31586, D31600, D311614, D31628, D31642, D31656, D44000.
Indirect Taxes, Net of Subsidies:	Series: D12547, D12549, D12551, D12553, D12555, D12557, D112559, D12561, D12563, D12565.
Investment:	Series: D31732, D31754, D31776, D31798, D31820, D31842, D31864, D31886, D31908, D44024.

Gross Provincial Product at Factor Cost = GPP at Market Prices - Indirect Taxes, Net of Subsidies.

The gross provincial product (GPP) figures are deflated using a series of provincial GDP deflators published by the Conference Board of Canada as part of their *Provincial Outlook: Economic Forecast* publications.

The growth rate of employment per province is n. Given the difficulties associated with measuring technical progress and depreciation, we must fix an arbitrary value. Many growth empiricists[10] fix the sum of these values at 0.05. This is the procedure adopted here as well. Depreciation and technical progress are assumed constant for all provinces through time.

[10] Barro and Sala-i-Martin (1995), p.37 for instance.

Section IV: Estimation and results

A variety of techniques are available for estimation of panel data with cross-sectional specific effects. The choice of techniques relies on the nature of these individual (in our case provincial) effects. There are two alternatives: fixed effects or random effects. Given the orientation of the model, that is that we assume some correlation between the explanatory variables and the individual effect, we must abstain from those techniques based on random effects. These types of effects are by definition random in nature and do not account for correlation with the explanatory variables. Hausman (1978) argues that if the conditional mean of the province specific terms are not independent of the explanatory variables ($E(u_i|x_{it}\neq 0)$) then the random effects estimator is biased and inconsistent while the fixed effects estimator is unaffected. Fixed effects, then, can accommodate such correlation. In cases such as ours, where the sample of provinces represents the full set of cross-sectional units, Greene (1993, p. 469) believes that "it is reasonable to assume that the model is constant," implying that the fixed effects approach is better. We will then, initially, focus on the Least Squares With Dummy Variables approach.

Given the relative linearity of the equations to be estimated, ordinary least squares may be used as opposed to non linear least squares. The use of either technique produces similar results. We can easily extract the estimate of β from the coefficient of ln y(t-1). Islam (1995) chooses Least Squares with Dummy Variables as well, although his model was estimated with several different approaches. A Monte Carlo study of the results concluded that among the estimators used in his study, the Least Squares with Dummy Variables and the Minimum Distance estimator performed the best (over maximum likelihood estimation for instance).

Growth theorists assume, with very few exceptions[11] that variances are the same across cross-sections, that is $var(u_{it}) = var(u_{jt})\ \forall\ i,j$. This is a heroic assumption given the typically large number of countries included in cross country growth regressions. One would imagine that regressions performed on such data sets are groupwise heteroscedastic. At the same time, the assumption of zero covariances across units seems equally restrictive. This may be a reasonable assumption if countries were completely independent from each other. The reality is, however, that most countries are very open and there exists a certain degree of interdependence among them. We can imagine this to be even more pronounced within a country, such as between the Canadian provinces, or the American states. In short, the classical assumptions of homoscedastic variances and zero covariances are violated. Accommodating these violations is possible[12]. However, it is not the objective of this paper to do so. We focus on the sensitivity of interval lengths on the finding of conditional (or absolute) convergence. As a result, it becomes impossible to estimate 10 variances (as well as the province specific term) in large intervals. There develops a lack of degrees of freedom problem as we increase the interval length from 1 year (240 observations) to 24 years (10 observations). In order to generate estimates that for as many intervals as possible, we abstain from correcting for heteroscedasticity and ignore the presence of covariances among cross-sectional units.

The estimation procedure followed is presented in tables 1 and 2. These tables present the estimation results, based on a series of tests, for equation (14) with an interval length of one year. For brevity, only these results are presented, as the procedure used is identical for all interval lengths

[11] See for example de la Fuente (1995) and Barro and Sala-i-Martin (1995). These authors assume homoscedasticity and no covariances between cross-sections, as does Islam (1995).

[12] In fact, by subtracting the mean as in equation (15), we are creating non-zero covariances as Coulombe and Day (1996) point out.

(and for equation (15)). Furthermore, the results are identical for each combination of intervals and equations examined.

The initial stages of the estimation process consisted in testing a series of hypotheses for all regressions. Three issues are of concern. The first is to examine the nature of the province specific terms in equation (14). Given the relative homogeneity of the Canadian economy we could expect to find that there be no discernible province specific effects, that is that initial conditions are identical across provinces. This can be argued on the grounds that capital and technology are perfectly mobile within Canada and that economic agents take advantage of any type of structural inefficiencies, thereby eliminating, on the aggregate, any province specific effects. We therefore test the hypothesis that the province specific effects are identical.

A second series of tests will be performed on the coefficients of the investment and population growth series. The neoclassical model, as developed in equations (14) and (15), predicts that the coefficients on these variables should be of opposite signs. This implies two sets of tests. The first series of tests focusses on the relationship between these coefficients. We test whether they are of identical and opposite magnitude. The second test focusses on the issue of conditional versus absolute convergence by testing the statistical significance of the investment and employment growth coefficients. Should we find that the coefficients of the investment and employment series are not statistically different from zero, we are compelled to support the notion of absolute convergence. If, on the other hand we find these coefficients to be statistically different from zero, we conclude that each province converges in levels to its own level of productivity (which depends on the investment rate and employment growth rate). .

In all instances, we cannot reject the hypotheses that there are no province specific effects in equation (14). Table 1 presents the estimation results of equation (14) for a one-year interval with the imposition of the constraint that province specific effects are equal and that $\omega_1 = -\omega_2$. These tests are carried out sequentially; in the first instance we test the restriction on the provincial effects. Based on these test results, we perform the regressions again incorporating the restrictions on the province specific effects and imposing the restriction $\omega_1 = -\omega_2$. The test statistic W1 in Table 1 represents the Wald test statistic for the restrictions on the province specific effects. It is distributed as χ^2 with 9 degrees of freedom with a critical value of 16.9 at the 95 per cent confidence level. The test value of 13.6 is less than the critical value and precludes us from rejecting the null hypothesis of identical provincial effects. This is in line with what we would expect given the remarkable similarity in the provincial coefficient estimates. The second test statistic, W2, refers to the joint restrictions[13] placed on the provincial effects and $\omega_1 = -\omega_2$. The 14.5 value obtained is less than the associated critical value of 18.3 (χ^2 with 10 degrees of freedom). We cannot reject this restriction as well. Further, the coefficients on the S and P variables are not statistically significant.

Table 1: Estimation Results for Equation 14 with one-year intervals

$\ln(y_{t-1})$	S	P	NF	PEI	NS	NB
0.8567 (0.0352)	0.01236 (0.00745)**	-0.00633 (-0.0186)**	0.508 (0.1296)	0.491 (0.1256)	0.512 (0.1309)	0.504 (0.1279)
QC	**ON**	**MB**	**SK**	**AB**	**BC**	
0.521 (0.1339)	0.531 (0.1372)	0.515 (0.1324)	0.524 (0.1333)	0.555 (0.1409)	0.521 (0.1332)	
$\overline{R^2} = 0.9576$		W1 = 13.6	W2 = 14.5	Sample period: 1968-1992, 240 obs.		

Standard errors in parentheses; Standard errors are significant at the 95% confidence level unless otherwise indicated;** indicates these coefficients are not significant at the 95% confidence level.

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[13] In all cases the tests were performed jointly and individually only to have the results of the individual restrictions coincide with those of the joint restrictions. For brevity, only the joint restrictions are discussed.

Table 2 presents the results of the ultimate model for this equation based on the preceding test results. It assumes a constant encompassing A(0) but it excludes the investment and employment growth series as they are not jointly (or individually) significant[14]. This represents an absolute convergence process as there are no variables to control for province specific steady-states.

Table 2: Final Estimation Results for Equation 14 with one-year intervals

ln(yt-1)	constant
0.9600 (0.0134)	0.154 (0.0453)
$\overline{R}^2$ = 0.957	
Implied β = 0.0408	

Standard errors in parentheses; unless otherwise indicated, estimates are significant at the 95% confidence level

The preceding tables serve as examples of the procedure followed to detect, for each interval and for each equation, which model best suited the data. The general procedure was to start with the full model for the given interval and each equation (14 or 15) and sequentially test these hypotheses. In all instances, we could not reject the hypotheses that the absolute convergence model best describes the data. The results of these regressions are presented in Tables 3 and 4.

[14] Additional tests revealed that we could not reject the hypothesis that $\omega_1 = \omega_2 = 0$, which is in line with the finding that $\omega_1 = -\omega_2$.

Table 3: Estimation Results for Equation 14

Equation (14) 1968-1992										
Interval	1 year	2 years	3 years	4 years	6 years	8 years	12 years	24 years	Average	Standard Deviation of β
β	0.0408	0.0349	0.0315	0.0342	0.0309	0.0280	0.0140	0.0240	0.0298	0.0081
Standard Error	0.0134	0.0218	0.0322	0.0435	0.0638	0.0608	0.0967	0.2274		
$\overline{R^2}$	0.957	0.942	0.918	0.891	0.852	0.895	0.837	0.648		
σ_u^2	0.00096									
σ_*^2	0.01229									
Forecast R^2	0.957									
Theil's U	1.0									

Table 4: Estimation Results for Equation 15

Equation (15) 1968-1992										
Interval	1 year	2 years	3 years	4 years	6 years	8 years	12 years	24 years	Average	Standard deviation of β
β	0.0324	0.0270	0.01796	0.02098	0.01730	0.01509	0.00552	0.0133	0.0187	0.0083
Standard Error	0.0137	0.0243	0.0259	0.0411	0.0504	0.0608	0.0513	0.1645		
$\overline{R^2}$	0.954	0.930	0.947	0.904	0.905	0.897	0.949	0.78		
σ_u^2	0.0008									
σ_*^2	0.0127									
Forecast R^2	0.829									
Theil's U	1.27									

A number of interesting observations can be made from these results. In the first instance, and of particular interest, is that in all intervals for equation (14), we cannot reject the hypothesis that the provincial dummies are identical. This would imply that there are no differences in initial conditions for the sample period, that is that the A(0) term is statistically invariant with respect to the choice of province. A(0) loosely represents technology, or as Mankiw, Romer and Weil (1992, p.6) point out "the A(0) term reflects not just technology but resource endowments, climates, institutions...." The implications of the A(0) term are that it serves as a multiplier in the production function. Note that we assumed in the model that A(0) was labour augmenting. As a result, in our framework, we find that initial conditions augments labour's share of output by a factor of approximately 1.2[15]. The conclusion is then that the Canadian provinces as a whole seem to have identical production functions with no discernible province specific level of initial conditions[16]. One could possibly link this to the federal transfer payments system (FTP). The aim of the FTP is to reduce regional disparities across the provinces. As such, monies are redirected from wealthier provinces to those that are less fortunate. These payments are supposed to be directed in education, health and infrastructure spending, ensuring that citizens of poorer provinces have a similar quality of life by improving health, education and infrastructure levels in those provinces that are deficient. While the use of GPP at factor cost aimed to filter these effects and to measure economic output, removing the by-products of such policies is not possible. As a result, the automatic transfer of

[15] This value is obtained from Table 2, in which we take the average value of the constant terms (across intervals) and take the natural exponent of this value: in our case $e^{0.15} = 1.2$. This value is fairly constant across all interval estimations for equation (14).

[16] Interestingly, Coulombe and Day (1996) find that the hypothesis of province specific effects cannot be rejected when correcting for heteroscedasticity. However, as the authors note, the results obtained from these types of regressions are not supported by the Canadian experience.

resources from the richer provinces to the poorer provinces could attenuate any differences that may be encountered in the initial conditions as the effects of these policies are felt on education levels or infrastructure.

A second interesting result is the fact that, across the spectrum for both equations (14) and (15), we cannot reject the hypothesis that the coefficients of the investment and labour force growth rate are zero. This is surprising. It indicates that not only do provinces have similar production functions, but they would also seem to have the same steady-state. In fact, we unambiguously reject the model of conditional convergence for the model of absolute convergence. These findings are partially supported by those of Coulombe and Day (1996), but contradict those of Lee (1994) who finds evidence of conditional convergence with the inclusion of human capital variables, in an application of the extended model proposed by Mankiw, Romer and Weil (1992). This may be due to the particularities of the more homogeneous Canadian economy. It may be reasonable to postulate that differences in investment rates influence cross-country convergence through the effect of investment on the returns to capital. Within a country however, the returns to capital may not (indeed they do not here) bear on investment decisions. Differences in investment returns may be better captured by human capital, as greater levels of human capital increase the possible return on an investment (or of productivity in our case), as Lee (1994) finds. An educated workforce is likely to be more productive than a less educated workforce.

A third and more problematic result lies in the variability of the β estimates. They range from 0.0408 to 0.014 for equation (14) and from 0.0324 to 0.0055 for equation (15). While both approaches lead to the rejection of the conditional convergence model, we are left to wonder which value of β is appropriate.

Section VI: Interpretation of the results

How then do we decide which technique produces the most reliable estimate of the speed of convergence? In the first instance we propose to use equation (2) which describes the relation between σ_t^2 and the two forecasted variables, β and σ_u^2. Specifically we follow the procedure put forth by Coulombe and Day (1996) in that we produce dynamic forecasts of σ_t^2 for each equation (at the one year interval). From these results, we can differentiate between those results that are contrary to the facts and those that support the data.

A useful test statistic for comparison of alternative forecast methodologies is Theil's inequality coefficient[17]. This coefficient measures the systematic accuracy of forecasts obtained from an econometric model and is defined as:

$$U^2 = \frac{\sum (P_i - A_i)^2/n}{\sum A_i^2/n}$$

in which P_i is the forecasted change in the dependent variable ($\sigma_{t+1}^2 - \sigma_t^2$ in our case) and A_i the realised change in the dependent variable. The inequality coefficient is then the ratio of the mean squared prediction error to average squared variation in the dependent variable. The strength of Theil's U coefficient is that it is not influenced by the units in which the variables are expressed. As a result, the coefficient may be used to compare results of models expressed in various units of measurements without loss of generality.

From the definition of Theil's U coefficient, one can see that a perfect forecast leads to a U^2

[17] See Koutsoyiannis (1985, p.492-495) for an in depth discussion of Theil's inequality coefficient.

of 0. If $P_i=0$ then $U^2=1$ and the model forecasts no better than a forecast of no change in the dependent variable. If U^2 is greater than 1, then the model's forecasting capacities are worse than those of a zero change forecast. It is possible, then, to order a series of forecasting techniques on the basis of the strength of the U^2 statistic.

Unfortunately, while the use of the U^2 statistic allows us to evaluate the results of equations (14) and (15) without ambiguity[18], we are not able to produce satisfactory forecasts from the information generated by these equations. Equation (14) estimated at the one year interval yields the best results, with a U^2 of 1.01 while equation (15) estimated at a one year interval yields a U^2 of 1.27. These results do not produce acceptable forecasts as we could have obtained at least as equally satisfactory results disregarding the information obtained from these equations and assumed a forecast of zero change in σ_t^2 . On the basis of this analysis we would favour the use of equation (14) over that of equation (15), as the use of equation (15) produces forecasts which are worse than that which would be obtained were we to forecast on the basis of zero change in the dependent variable.

The variability of the β estimates poses another problem. An alternative technique that may be used to evaluate the results of β estimation is the use of the relation between β and the capital share of output. There exists a direct relationship between the speed of convergence and capital's share of output in our simple small open ecnomy neoclassical growth model. Specifically, as derived in Section II, we obtain the following relationship between beta and the capital share, α:

[18] Figures 8 and 9 in the Appendix graph the observed and predicted levels of dispersion for equation (14) and (15).

$$\alpha = 1 - \frac{\beta}{(g + n + \delta)}$$

The relationship shows that β, the speed of convergence, is determined by the capital share of output (α), the growth rate of the work force (n), the depreciation rate of capital (δ) and the rate of technical progress (g).

Many authors (Mankiw, Romer and Weil (1992), Barro and Sala-i-Martin (1995) and Islam (1995)) use benchmark values of δ, n, and g. These values are δ=0.05, n=0.01, g=0.02. Rough estimation of these numbers in the Canadian context yield results which are practically identical[19] (although a bit lower). In order to be consistent with estimates put forth by other economists, we shall use the benchmark values keeping in mind that in Canada, the values might be marginally lower. On the basis of beta estimates presented in Tables 3 and 4, we present the estimated capital shares in Table 5.

Table 5: Estimates of α, the capital share

	Interval Length								
	1	2	3	4	6	8	12	24	Average
Equation (14)	0.49	0.56	0.61	0.57	0.61	0.65	0.83	0.7	0.63
Equation (15)	0.60	0.66	0.77	0.74	0.78	0.81	0.93	0.83	0.77

These estimates do not compare favourably with Simon Kuznet's assertion that a stable capital share of 1/3 is a stylized fact that has typified the process of economic growth throughout the developed countries during the twentieth century (Barro and Sala-i-Martin, 1995, p.5). Indeed, the

[19]The average rate of capital depreciation over the 1968-1992 period is 0.05085, the average rate of growth in n is 0.0178 and the average rate of progress of g (defined as the growth rate of y/n) is 0.004.

share of the capital stock to total output in Canada has averaged exactly 1/3 over the 1968-1992 period. The estimates of the capital share presented in Table 5 do not support such a fact. For equation (14), the implied capital share ranges from 49 per cent, with the yearly estimate, to 83 per cent for the twelve-year interval, with an average value of 63 per cent. Similar results are obtained using the results from equation (15). Estimates of the capital share range from 60 per cent in the yearly intervals to 93 per cent for the twelve-year interval, with an average of 77 per cent. Note however that estimates based on short intervals are generally less than those based on longer intervals, for both equations. This fact alone, lends support to the panel data approach over the cross-sectional approach.

These results raise two issues. Equation (14) produces estimates of β which produce lower implied capital shares than does equation (15). We could then say that equation (14) seems to produce estimates of β that are more in line with observed capital shares and that the yearly estimate of equation (14) yields the best results in terms of implied capital shares. However, even this "optimal" estimate of α is substantially different from the observed values. This raises questions about the nature of the implied capital share. Mankiw, Romer and Weil (1992), Islam (1995) and Lee (1994) argue that this estimate of α not only captures the impact of the narrowly defined physical capital stock on output, but might capture a broader definition of the capital stock, one that would include the notion of human capital. Human capital is not a value that is easily measured and it is not included in calculations of labour's share of output. Yet, human capital affects productivity through the acquisition of skills, learning by doing, spillover and ingenuity (among others). We may even argue that human capital engenders external effects in that a higher degree of human capital raises the marginal productivity of physical capital and consequently encourages expansion of the capital stock, thereby further reducing the differential between the observed capital stock and its steady-state level.

Since the model as developed in this paper does not differentiate between alternative forms of capital, it is in one sense normal to obtain capital share estimates that are much higher than the stylized 1/3. Of course, such a conclusion in no way helps determine which estimate of β is more reflective of the underlying Canadian growth process. To be able to proceed further with this analysis, one would need precise estimates of the impact of human capital on growth. These estimates are difficult to produce as one needs to quantify a variety of variables, including how one should go about defining human capital (which has already been the subject of a considerable amount of literature) and equally important, how we measure its impact on production (including the effects of such vague issues as learning by doing, spillover effects and externalities).

The interesting point that these implied estimates of α puts forth is the notion of increasing returns to scale. The hypothesis that the sum of α and τ be less than 1 is imposed in the model assuring that we obtain decreasing returns to scale. Yet, knowing that labour's share of output is roughly 66 2/3 per cent, the estimated alpha would lead us to believe that such an assumption is unrealistic. It would indicate that in fact, the production function may indeed be characterized by increasing returns to scale.

Nevertheless, equation (14) does seem to produce capital share estimates which are more in line with the traditional definition of the capital stock. Combining these results with the finding that the results of equation (14) seem to produce better dynamic forecasts of the dispersion series then does equation (15), we tenuously support the hypothesis that the model of equation (14) better captures the application of the neoclassical growth model in the Canadian context. There remains much work to be done in this field, particularly with respect to correction for heteroscedasticity and the inclusion of human capital control variables. Coulombe and Day (1996) estimate equation (15) with corrections for heteroscedasticity, but no comparison between alternative models has been attempted. Such investigations may produce interesting results and shed further light on the Canadian growth experience.

Conclusion

At the outset, we had planned to use estimation techniques employed by Mankiw, Romer and Weil (1992), Islam (1995) and Coulombe and Day (1996) to analyse the empirics of growth in Canada. Using panel data estimation techniques, we found that the evolution of regional productivity differentials seems to be best characterized by an absolute convergence type model. The implications of our findings are twofold: there do not seem to be any differences in the level of initial conditions or in the steady-state of the Canadian provinces. Canada seems to be a fairly homogenous economy with respect to output per worker.

One drawback from our results is the lack of robustness of the estimated speeds of convergence. Estimating the model for 8 different interval structures and two different models we obtain convergence speed estimates that fluctuate importantly. We cannot therefore pinpoint a specific convergence speed for the sample. We do, however, tentatively establish that the model presented in Mankiw, Romer and Weil (1992) and Islam (1995) better represent the Canadian growth experience on the basis of implied capital shares and dynamic forecasts of the dispersion series. Much work remains to be done before we can positively state that this result holds.

We can however put forth the hypothesis that the relatively high speeds of convergence obtained in the short interval estimation actually support the neoclassical growth paradigm to a greater degree than traditional cross-sectional analysis. We have shown that the use of estimates based on short interval forecasts produce estimates of capital's share of output which are closer to actual values. This would indicate that the panel data approach produces estimates which are more in line with growth theory in the Canadian context.

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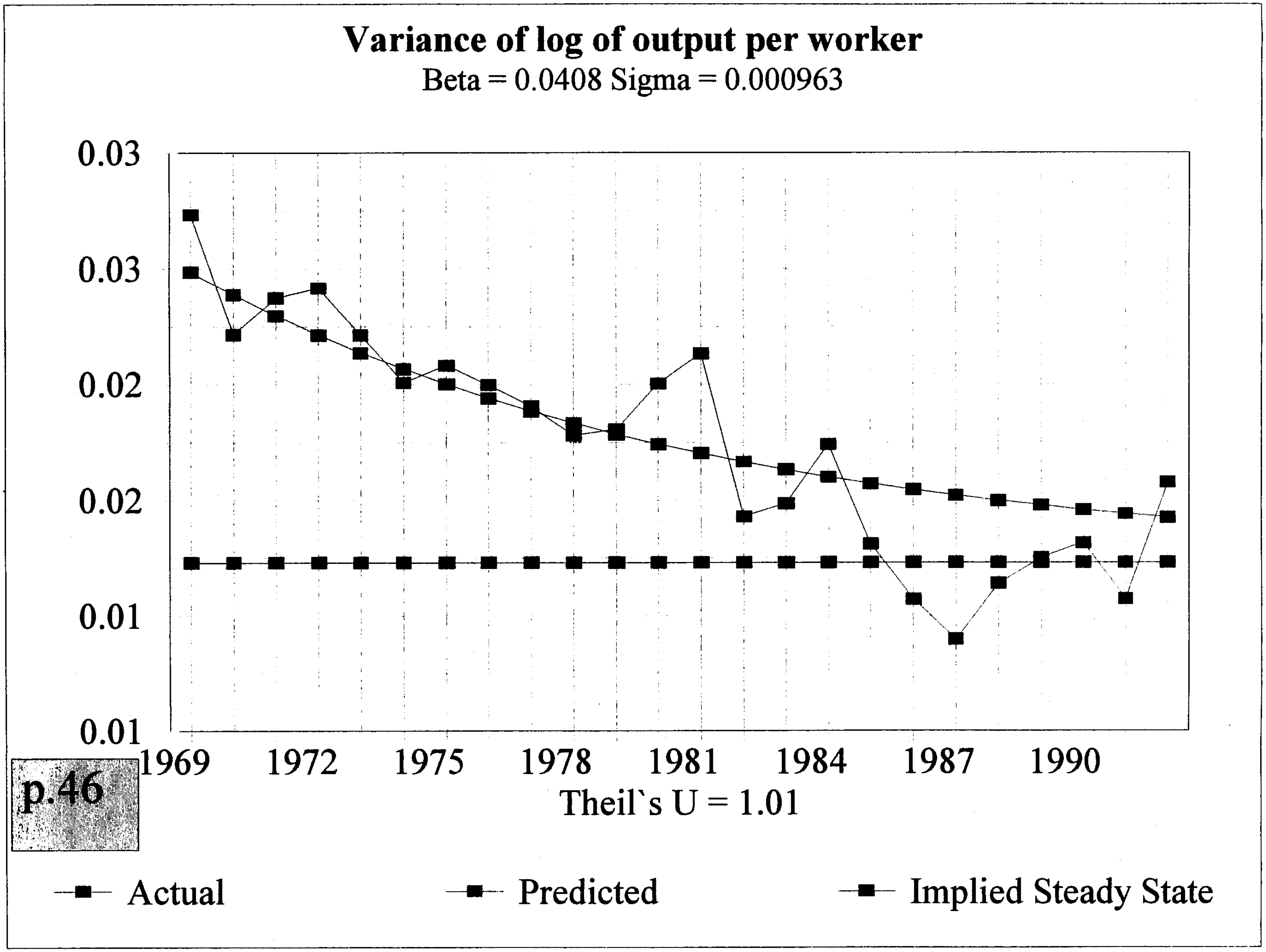
APPENDIX

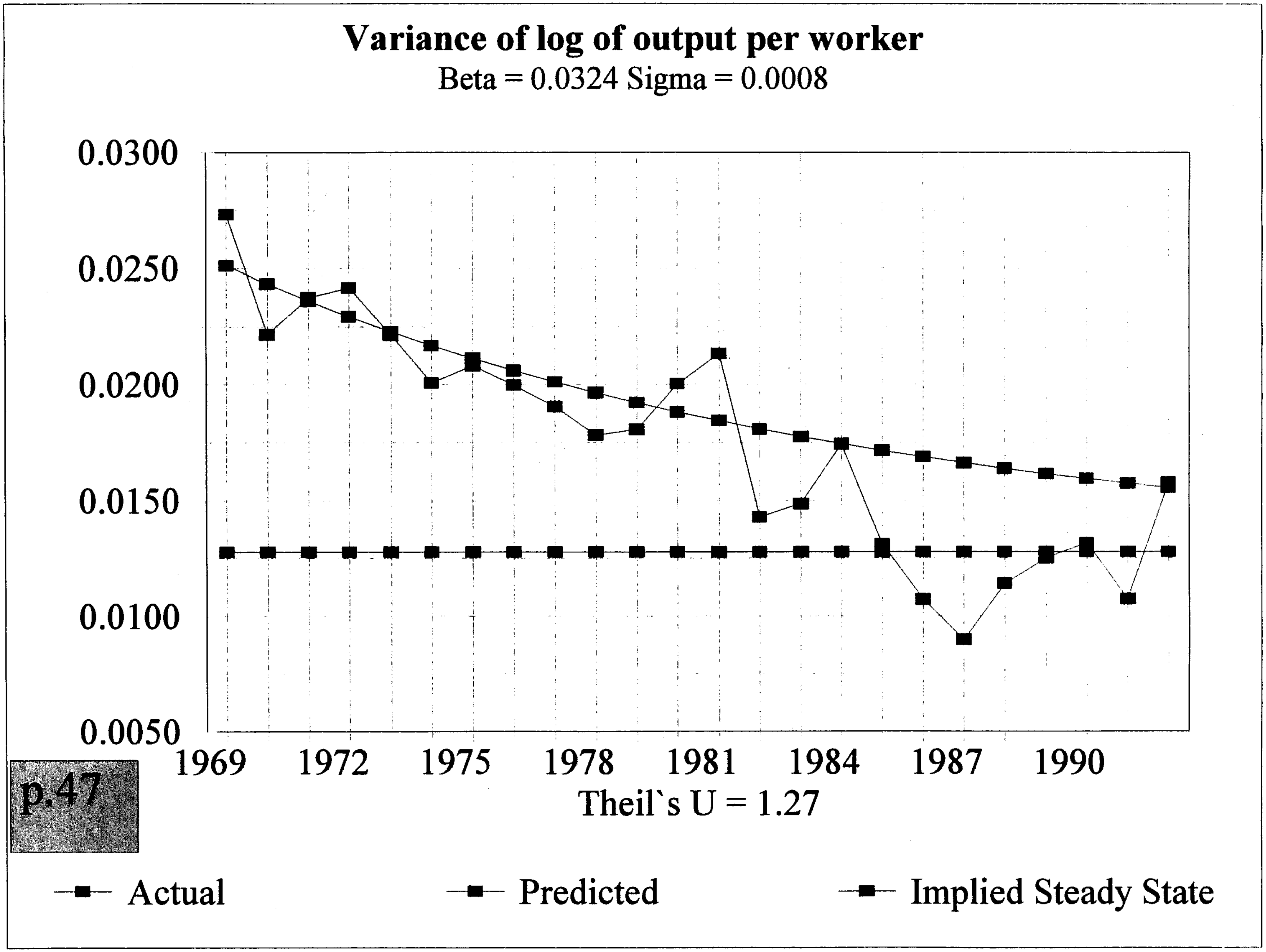
Figure 8



Variance of log of output per worker
Beta = 0.0408 Sigma = 0.000963
0.03
0.03
0.02
0.02
0.01
0.01
1969
1972
1975
1978
1981
1984
1987
1990
Theil`s U = 1.01
Actual
Predicted
Implied Steady State

p.46

Figure 9



Variance of log of output per worker
Beta = 0.0324 Sigma = 0.0008
0.0300
0.0250
0.0200
0.0150
0.0100
0.0050
1969
1972
1975
1978
1981
1984
1987
1990
Theil`s U = 1.27
Actual
Predicted
Implied Steady State

p.47