The Convergence across G7 Countries (1950-1992)

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1. Introduction

1.1 The background of this paper

In the winter semester of 2002, I took the course on Economic Growth taught by Professor Coulombe at the University of Ottawa. In his lectures, Professor Coulombe introduced me to the major growth models and major studies about convergence. I have also applied the basic techniques to test convergence in cross section economies.

In April 2002, I finished my term paper about the convergence across G7 countries under Professor Coulombe's supervision. I used the same model as that in Coulombe (2000), applied basic analytical techniques, and obtained results based on my own cross section data. Due to the time constraints, the analysis was only superficial, and some interesting results need further study. The term paper included a short survey of the literatures on convergence theory, graphic trends of convergence, a regression model, regression results as well as dynamic simulation. However there was no profound interpretation of these regression results. In addition, political and historical analyses, which are also important, were ignored.

All the reasons above finally lead me to pursue the study about convergence across G7 countries in my major paper.

1.2 The basic definitions of convergence

Since the 1980s, more and more empirical research has focused on the study of economic convergence. The topic of convergence is a key feature of the neoclassical growth framework. After Professor Coulombe's introduction and instruction on this topic, I decided to pursue extended research on convergence. But before that, we should first have a good understanding of the fundamental theories. The concept of convergence should be clarified before I proceed with my empirical application.

There are two major definitions of convergence: unconditional (absolute) convergence and conditional convergence. Barro and Sala-i-Martin (1995) defined absolute convergence as the hypothesis that per capita income levels in poor economies tend to grow faster than in rich ones—without conditioning for any other economic characteristics. Thus, all economies will eventually reach the same steady state. Conditional convergence, however, allows us to drop the assumption that all economies have the same parameters governing economic growth and converge to the same steady state. The hypothesis of conditional convergence is that the further an economy is from its own steady state value, the faster it grows.

Coulombe and Lee (1995), however, provided us another explanation of these two definitions of convergence. They argued that it was important to distinguish between unconditional convergence and conditional convergence. "Unconditional convergence refers to the case where convergence is explained solely by the gap between the initial economic indicators. This analysis supposes the existence of relative similar structure parameters for preferences and technology across regions". As to conditional convergence, they argued that "when structural parameters are significantly different among these countries or regions (owing, perhaps, to variations in natural resource endowments, saving rates, institutions, human and physical capital), initial per capita income/output differences cannot be sufficient to explain differences in the growth rates of these countries (regions). Additional variables are needed to reflect these differences" (p.895).

As many empirical studies have shown, conditional convergence did happen across a broad group of developed and developing countries in the post WWII period. In this paper, I will use the basic techniques to test the absolute convergence hypothesis and conditional convergence trend towards different steady states on a group of observations, namely the G7 countries.

1.3 Research objective

The objective of my own research is to test the convergence across the most developed industrial countries in the world—the so-called G7.

Since 1975, the heads of state or government of the major industrial democracies have been meeting annually to attempt to deal with the major economic and political issues facing their domestic societies and the international community as a whole. The seven countries are France, the United States, the United Kingdom, Germany, Japan, Italy and Canada (joined the summit in 1976). I choose the G7 as the objective in my research for the following three reasons:

1. Why G7 instead of G8? In the 1994 Naples Summit, the G7 and Russia have met as the P8 (Political 8), following each G7 Summit. The 1998 Birmingham Summit witnessed full Russian participation, giving birth to the G8. Although Russia is another industrialized country, it has undergone a long period of centralized economic planning before 1989. So, considering its different economic system during the interval of my data set (1951-1992), and

the long-period shocks that occurred after the privatization of its economy, I excluded Russia from my research.

After that, I planned to include Russia in the empirical research of this paper and make some comparisons. However, as we know, the comparison between economies of very different economic systems does not make too much sense. Furthermore, due to the lack of updated data, up to present I can only obtain the data before 1992 and this fact makes it impossible to do any research on the G8 after 1992. Thus Russia will not be part of my research sample in this paper either.

2. I assume that technology is an exogenous factor in the G7 sample. From the major economic indicators, we can see that G7 countries have been leaders of the world economy after WWII. Compared with the economies of the rest of the world, they have already had their mature market economy system at the beginning of my research period and had a better access to the most developed new technologies in the world. So I can assume that they have the same technology level in the model.

3. What is most important is that the G7 countries have an obvious trend of convergence. The G7 countries come from three different geographic regions—America, Europe and Asia. At the end of WWII, they had completely different initial development levels. In 1950, the relative GDP per capita indicators of former Axis nations in WWII—Japan, Italy and Germany, were 0.32, 0.62 and 0.75 (comparing to the G7 average 1). At the same time, the United States, the most developed country, had a relative GDP per capita as high as 1.90. Canada, with a relative per capita GDP value of 1.36, ranked second in 1950. The gap between the indicators of the richest (U.S.A.) and the poorest (Japan) GDP per capita level was 158%. But in 1992, the gap decreased to only 34%.

Furthermore, the ranking of the G7 sample in relative GDP per capita level shows an interesting change during the 43 years between 1950 and 1992. The weakest development record went to the U.K., which ranked third in 1950 and ended last in 1992. Japan, a country developed from a war-devastated economy, ranked third in 1992 despite being last in 1950. The above findings make me suspect that conditional convergence exists among the G7 countries because of the decreasing gaps in their relative GDP per capita levels.

Table 1. *The evolution of relative GDP per capita of G7 countries*

Year	Canada	France	former West Germany	Italy	Japan	the United Kingdom	The United States	gap
1950	1.36(2)	0.90(4)	0.75(5)	0.62(6)	0.32(7)	1.16(3)	1.90(1)	1.58
1960	1.13(2)	0.94(5)	1.05(4)	0.74(6)	0.48(7)	1.08(3)	1.58(1)	1.10
1970	1.05(2)	1.00(4)	1.03(3)	0.82(6)	0.81(7)	0.90(5)	1.39(1)	0.58
1980	1.19(2)	0.99(4)	1.01(3)	0.86(5)	0.84(7)	0.85(6)	1.27(1)	0.43
1992	1.09(2)	0.95(5)	1.02(4)	0.87(6)	1.03(3)	0.85(7)	1.19(1)	0.34

Note: 1. The data is the relative GDP per capita level which is calculated from the GDP per capita by the unweighted average. 2. The numbers in '()' are the ranks. 3. Sources: Penn World Table. The indicator of GDP per capita level is described in section *3.1*.

1.4 The economic model

The well-known conditional convergence model of Barro and Sala-i-Martin (1995) has been proved to be a classic model to test cross-sectional convergence. Based on this model, Coulombe (2000) showed a practical empirical model about the conditional convergence of Canadian provinces. Using the same model, I obtained satisfactory results from my data set. Among the three variables used as the estimators of steady state in my term paper, two of them (the relative real investment rate and the relative saving rate) are proven to be both empirically and theoretically significant. In this paper, I will still follow the structure of the model of Coulombe (2000). Some modifications are made for my research sample (see section *3.3* for detail).

During the tests, I use the relative GDP per capita levels of G7 countries as dependent variable and the lagged value of their relative GDP per capita levels as one explanatory variable. Three other explanatory variables are used as the estimators of relative per capita GDP level at their steady states for the G7 countries. Some significant dummy variables are also included to show the structural breaks or fixed effect in several countries. The three explanatory variables are the relative real investment rate, the relative saving rate and the relative schooling rate respectively. The dummies are dummy variables for France, the United Kingdom and the United States.

1.5 The organization of this paper

The paper is organized as follows:

In section 2, I will do a survey of the major empirical research contributing to cross-country convergence as well as those contributing to cross-province and cross-industry convergence. In section 3, I will introduce the empirical methodology that follows the research results from Coulombe (2000) about convergence of Canadian provinces. The ADF unit root tests are carried out in section 4 to distinguish between trend stationary and difference stationary processes. The empirical results are presented and discussed in section 5. Section 6 provides the simulation results to show in graphs how well my model fits the actual growth paths of my sample and give interpretations for the dummy variables in the model. The last section discusses some interesting findings of the tests and contains the conclusion.

2. The survey of major empirical research on convergence

2.1 The empirical research on cross-country samples

In 1956, Solow and Swan provided their neoclassical form of the production function in their famous Solow-Swan model, which was the basic paradigm for further research on economic growth. One of the key assumptions of the Solow-Swan model, the diminishing returns to capital, caused growth of economy to finally reach its steady state, where indicators such as per capita output grow at a constant rate. Given the same technology level and saving rate, all economies will reach the same steady state when all per capita variables will grow at the given rate of technological progress. This model proved that without conditioning of any other economic characteristics, all economies have the same steady state per capita income levels as well as the same growth rates in their steady states. The lower the starting level of real income of one economy, relative to its long-run steady state, the faster is the growth rate. In 1965, Cass and Koopmans refined the Ramsey growth model (1928) and showed the same implication that all economies would have the same steady states when other economic characteristics were exogenous.

An important prediction of the above models is the conditional convergence. In the Solow-Swan model, the convergence happened conditionally because the steady state level of per capita income depends on the saving rate, the growth rate of population and the form of production function. This prediction has been explored seriously as an empirical hypothesis since the late 1980's. Other key factors such as government policies and the initial stock of human capital have been introduced in the research after Solow and Swan's article. The following ones are some typical arguments presented in these authors' research about conditional convergence, especially in the sample of economies in the after-WWII period.

In his first empirical work on economic growth, Barro (1989) showed that if the differences in the initial level of human capital were controlled, the correlation between the initial level of income and growth rate turned out to be negative. This concept of convergence found its more explicit formulation in Barro and Sala-i-Martin (1992) and Mankiw, Romer and Weil (1992). Their research emphasized the fact that the neoclassical model did not imply that all countries would reach the same level of per capital income. Countries will reach their specific steady states.

With the emergence of comparable cross-section data set such as the Penn World Table provided by Summer and Heston (1991), most empirical work began to focus on conditional convergence and the determination of steady states. Barro (1992) presented evidences of convergence for a sample of 98 countries from 1960-1985. He argued that "We find evidence of convergence for a sample of 98 countries only in a conditional sense, that is, only if we hold constant variables such as initial school enrolment rate and the ratio of government consumption to GDP"(p.246). He interpreted these variables as proxies for the steady state value of output per capita and the rate of technological progress. In Barro (1992), he studied the relationship between growth rate and many variables. He found that the growth rate of per capita output is negatively related to the initial output level, the government consumption ratio, the measure of market distortions, and positively related to the initial human capital stock (measured by the 1960 enrollment of primary and secondary school) and political stability indicators.

Levin and Renel (1992) found a positive and strong correlation between the average growth rate and the investment rate. They also found qualified support for the conditional-convergence hypothesis—a strong, negative correlation between the initial level of income and the growth rate over the 1960-1989 period when the equation included a measure of the initial level of investment in human capital. Their sample was the data of real GDP level as the dependent variable and almost 50 other variables as the explanatory variables. Their research sample includes 118 countries around the world.

St. Aubyn (1999) used time series methods in his research on convergence across industrialized countries. The data set comprises 16 countries and covers the time period 1890-1989. His work centered on the "no convergence" hypothesis that the convergence to the GDP per capita level of the United States did not happen across the other 15 countries. It is interesting that Augmented Dickey Fuller (ADF) test was applied to annual per capita GDP levels of the 16 countries as the method to test the "no convergence" hypothesis. In his test results, St. Aubyn found the hypothesis of "no convergence" was rejected only in the cases of France, Australia, Belgium and Germany before WWII (1890-1939). In the post-war period (1947-1989), the "no convergence" hypothesis was only rejected in the cases of Germany, Italy, and Japan. In the 1890-1989 period, the null hypothesis was rejected for France, Australia, Belgium, the Netherlands and Switzerland.

2.2 The empirical research on regional and other kinds of convergence

The convergence across regions of a country or industries is another hot topic of research at this time. This research needs fewer assumptions than those for a cross-section of countries. Some variables that are considered to be endogenous in cross-national studies can be thought as exogenous in the research about convergence inside one country or region. Different provinces or states in one country or region have almost the same level to technologies, the same saving rate level as well as the same economic system and culture.

Coulombe (2000) did his own empirical research on the convergence among Canadian provinces. The focus of this article was the per capita income levels of the ten Canadian provinces. Coulombe noticed the importance of interregional redistribution in the Canadian economy and set up two sets of per capita income variables — personal income per capita ratios (RPIC) and the personal income per capita net of transfer ratios (RPIT). In Coulombe (2000), the relative urbanization rate was used as the estimator of steady states. For both income indicators, the coefficients for all the explanatory variables were proved significant and the convergence speed was 5% for RPIC and 5.1% for RPIT.

Cordella and Yeyati (2002), two Spanish economists, did a brief survey about research on regional convergence in Spain. They argued that following the pioneering work of Barro and Sala-i-Martin (1990), a large number of authors have investigated the pattern of convergence in different regional samples. Several empirical regularities with potentially important theoretical and policy implications have emerged from their research. They have found that "First, practically all existing studies find evidence of a negative partial correlation between growth and initial income both at the national and regional level…… A second key finding is that the speed of convergence seems to be very low but quite stable across samples."(p.572). They argued that most research found an around 2% convergence speed and the half life of convergence process would be 35 years. In their own research, the dependent variable was output per employed worker, and the convergence speed was estimated at 2.95%. Their sigma-convergence (see p.16 for definition) figure (p.575) also indicated a perfect convergence approach regarding Spain.

Other interesting research has also been carried out on convergence among different industries. Bernard and Jones (1996) reported that manufacturing sectors across countries did not display a pattern of convergence for 14 OECD countries during the 1970–1987 period. Carree, Klomp and Thurik (2000) found evidence that industries with relatively high labor productivity had a low rate of convergence of productivity, using data from 18 OECD countries over the period 1972–1992. Following these articles, Togo (2002) did a brief test for convergence across 12 manufacturing industries of Japan. The target variable for his research is value added per employee. Another method, transition matrix, was used in Togo (2002) instead of regression models. The results also confirmed the conclusion made by Bernard and Jones (1996) and Carree, Klomp and Thurik (2000).

2.3 Mankiw, Romer and Weil's argument about Solow growth model

Besides the empirical research, many economists also provided their viewpoints about the methodology problems on the classic convergence models. The famous one is provided by Mankiw, Romer and Weil (1992). In Solow-Swan model presented in 1956, the saving rate and population growth rate are exogenous, and it is assumed a standard neoclassical production function with decreasing return to capital. These two exogenous variables determined the different steady states value for each economy. Mankiw, Romer and Weil (1992), however, argued that although the directions of the effects of saving rate and population growth rate were good, the magnitudes had not been correctly predicted and appeared too small in the Solow-Swan model. They argued that the first reason for this problem should be the exclusion of human capital accumulation in Solow-Swan model. In their research, they found that "for any given rate of human capital accumulation, higher saving or lower population growth rate leads to a higher level of income and thus a higher level of human capital." The second reason was that human capital accumulation was correlated with saving rate and population growth rate. So “omitting human-capital accumulation biases the estimated coefficients on saving and population growth.” (p.408). In their own modified Solow-Swan model, they included an endogenous proxy for human-capital accumulation as an additional explanatory variable for their cross-country sample.

After the empirical tests, they found that: 1. the accumulation of physical capital had a larger impact on income per capita. 2. The impact of population growth rate to income level also appeared larger than the original Solow-Swan model. Compared to a finding of 17 years in the original Solow-Swan model, the augmented model provided by Mankiw, Romer and Weil showed that the economies reached the half way point to their steady states after 35 years. Thus the convergence speed of their sample will be only half of that derived by the Solow-Swan Model, which is 4%.

The empirical research that I carried out is based on some argument presented in Mankiw, Romer and Weil (1992). A proxy of human capital accumulation, the relative schooling rate, is used as an explanatory variable in my model for the estimation of steady states.

3. Empirical methodology

3.1 The data set

The basic data collected for this paper are the levels of GDP per capita in constant dollars adjusted for changes in terms of trade (1985 international prices for domestic absorption and current prices for exports and imports). Relative GDP per capita level, as the dependent variable in my model, is the GDP per capita levels in each country divided by the unweighted G7 average levels of GDP per capita. The interval of my research is 1950 to 1992 and the data source is Penn World Table provided by Robert Summers and Alan Heston.

The Penn World Table provides a set of national accounts economic time-series covering the major countries of the world. The basic data I use in this paper is obtained from the PWT5.0 on the web site of Penn World Table. I failed to obtain the data for G7 countries after the year of 1992 because it is unavailable. Thus I choose the maximum range of this data set, 1950 to 1992, as the time range of my research.

In my former research, I used the relative urbanization rate, saving rate and real investment rate in the estimation of the steady states. I found that the urbanization rate is not significant as the estimator of the steady state for my sample. The relative saving rate and real investment rate, however, have been proved significant. In this paper, I exclude urbanization rate from my research and try other variables or variable combinations. These variables are relative saving rate (SR_i), relative real investment rate (RI_i) and relative schooling rate (SC_i). All of them are the ratios of the annual value to their unweighted average levels across countries.

The data sources for these three variables are different. The real investment rate is collected from PWT 5.0, as is my GDP per capita data. The relative saving rate data is obtained from *World Development Indicators* provided by the World Bank. The relative schooling rate is collected from the website of UIS (the United Nations Organization for Education, Science and Culture Institute for Statistics).

RI_i, the relative real investment rate is the difference between GDP and consumption divided by GDP. SR_i, the relative saving rate, is the difference between GDP and gross consumption divided by GDP.

Note that in the above definitions, 'consumption' is the expenditure of a nation or individual on consumer goods and services. The 'gross consumption', however, includes both expenditure on consumer and capital goods and services. In an open economy, the difference between investment and saving should be the difference between imports and exports.

SC_i is the relative schooling rate (gross enrollment ratio of eligible people enrolled in primary, secondary and tertiary school). The schooling rate is the number of eligible people enrolled in primary, secondary and tertiary school divided by the total number of eligible people. *Table* 2 shows us the value of relative saving rate, investment rate and schooling rate I use in the tests. The collecting of the value is also presented in this table.

Table 2. *The relative saving rate, real investment rate and schooling rate variables*

	Canada	France	Germany	Italy	Japan	UK	USA
relative saving rate	0.97	1.00	1.08	0.98	1.46	0.76	0.75
relative real investment rate	0.97	1.03	1.12	1.12	1.23	0.68	0.86
relative schooling rate	1.15	1.00	0.95	0.87	0.99	0.93	1.10

Note: 1.G7 average is 1. 2. Relative saving rate data is calculated from the mean value of relative saving rate from the 1950, 1960, 1965, 1970, 1975, 1980, 1985, 1987-1992 data provided by the World Bank. 3. Relative real investment rate is also collected from Penn World Table and calculated from the mean value of relative real investment rate from 1950-1992. 4. Relative schooling rate is the mean value of relative schooling value calculated from the 1970, 1975, 1980-1992 data available at the web site of UIC. Due to data problems, the relative schooling rate for Germany can only be obtained in 1990, 1991and 1992.

3.2 The graphical evidences of convergence

The graphical evidence is one facet of my empirical research. In this paper, I try three methods of graphical analysis to find the convergence trend for my research sample.

Figure 1 shows us the evolution of the relative level of GDP per capita for G7 countries. The vertical axis shows the relative GDP per capita level for each country. As can be seen in this figure, the dispersion of the relative GDP per capita shows a clear tendency to decrease in the 1950 to 1992 period. For those countries with greater dispersions at the initial time, such as the United States, Japan and Germany, the evolutions of their relative GDP per capita levels appear smoother than those countries initially close to the average level. For the case of Japan, initially the poorest country in this group, the evolution of its relative GDP per capita levels shows a very clear tendency of convergence. During the 43 years, the relative level of GDP per capita in Japan has changed from 0.32 to 1.03, a dramatic 200% increase.

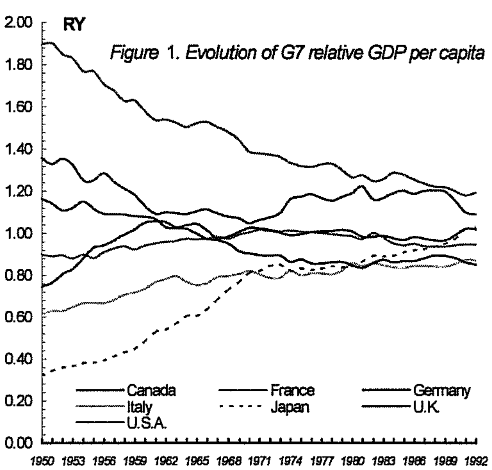


Figure 1. Evolution of G7 relative GDP per capita

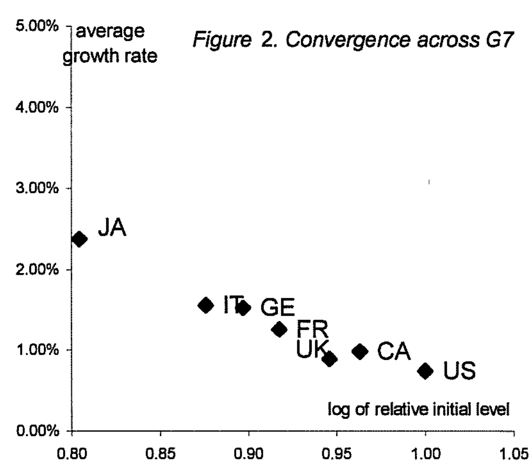
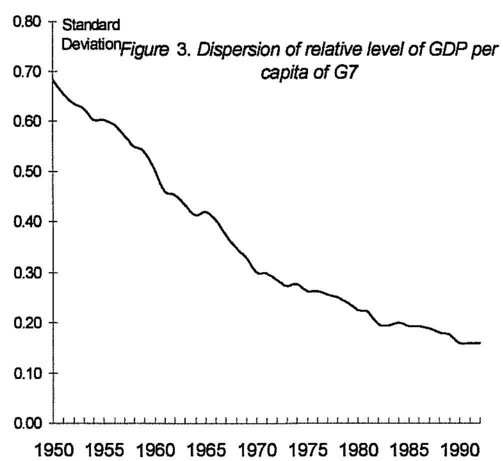


Figure 2. Convergence across G7

Figure 2 shows us the relationship between the initial level of GDP per capita and the average growth rate for G7 countries between 1950 and 1992. This diagram is presented in Barro and Sala-i-Martin (1995). The vertical axis shows the average growth rates for each country, which are calculated by $\frac{1}{t}log(\frac{Y_{i,t}}{Y_{i,0}})$. The $Y_{i,t}$ here is the GDP per capita level for country i in the year of 1992. $Y_{i,o}$ is the GDP per capita level for country i in the year of 1950. t is the number of years in my research period.

In *Figure* 2, I set the log of relative level of GDP per capita (initial value) of the United States as one, and the horizontal axis shows relative logs of initial levels for those six countries. The negative relationship between average growth speed and the initial GDP per capita level is shown clearly in this figure. The average growth rate calculated in this method for Japan is around 2.38%. But for the United States, the growth rate is only 0.74%.

Sigma convergence method is another way to test convergence by measuring the dispersions. In this paper, if the standard deviation of the relative level of the logarithm of per capita GDP declines over time, convergence occurs. *Figure* 3 shows us that the standard deviation of the log of relative GDP per capita levels across G7 countries decreased from 68% in 1950 to 16% in 1992. The above three results suggest that there is a very clear tendency of convergence in my sample studied. My next step is to evaluate the steady states.



3.3 Conditional convergence methodology

The basic equation I use in this model is following the regression model (equation 1) of Barro and Sala-i-Martin (1995), and model (equation 2, 3, 4) of Coulombe (2000). The equations are as the follows:

$$log(Y_{i,t}) = e^{-\beta} log(Y_{i,t-1}) + (1 - e^{-\beta}) log(Y_i^*) \qquad (1)$$

$$log(RY_{i,t}) = e^{-\beta} log(RY_{i,t-1}) + (1 - e^{-\beta}) log(RY_i^*) \qquad (2)$$

$$log(RY_{i,t}) = \gamma_1 log(RY_{i,t-1}) + \gamma_2 log(URi^*) + \gamma_3 A_{i,t} + \gamma_4 Q_{i,t} + \gamma_{5,i} AR(1) + \gamma_{6,i} AR(2) + \varepsilon_{i,t} \qquad (3)$$

Equation (1) shows us that during the transition towards the steady states, the evolution of the log of per capita output level (RY_i in economy i) is determined by its initial level of the log of per capita output level and its long-run equilibrium Y_i^*. In this equation, β is the annual convergence speed towards steady states. The economy will converge to steady state if β is a positive number.

Coulombe and Lee (1995) argued that one could abstract from national shocks for the purpose of testing the convergence hypothesis by measuring provincial economic indicators as deviations from the mean. Thus they presented Equation (2) in their 1995 paper. This equation is derived from equation (1) but relative per capita income level was applied. In Coulombe and Lee (1995), $RY_{i,t}$ represents the relative level of per capita income of province i in time period t.

In order to analyze the convergence of different structures of economic growth across Canadian provinces, Coulombe (2000) estimated the long-run equilibrium ratios of per capita income using a variable based on urbanization ratios and presented equation (3). In equation

(2), β is the annual speed of convergence towards steady state. In equation (3), $\gamma_1=e^{-\beta}$ and UR_i is the relative urbanization ratio. $A_{i,t}$ is the dummy variable for Alberta to show the structural break cased by the first world oil shock since the year of 1973. $Q_{i,t}$ is the dummy variables for Quebec showing the structural break caused by the mass moving out of non-Francophone people from Quebec coupled with the rise of the independent movement.

To make the speed of convergence a more evident symbol in his model, Coulombe (2000) modified equation (3) as equation (4). In equation (3) and (4), Y_i^* has been changed with UR_i as the estimator of steady states levels because UR_i was found to be significant to show different steady state levels of the ten Canadian provinces.

$$log(\frac{RY_{i,t}}{RY_{i,t-1}}) = (1-\gamma_1)log(RY_{i,t-1}) + \gamma_2 log(UR_i^*) + \gamma_3 A_{i,t} + \gamma_4 Q_{i,t} + \gamma_{5,i} AR(1) + \gamma_{6,i} AR(2) + \varepsilon_{i,t} \qquad (4)$$

Equation (3) and (4) also presented us two notions of convergence can be tested. The dependent variable is the log of relative level of per capita output in equation (3) and is the log of growth rate of per capita output in equation (4).

Equation (4) is the final equation used to test the convergence of Canadian provinces when the urbanization rate (UR_i) was proved significant as the estimator of provincial steady states in Coulombe (2000). The empirical results showed the estimated speed of convergence, (γ_1-1), is around 0.05. The estimator of steady state – the urbanization rate, and the dummies showing structural breaks for Alberta and Quebec have all been proved to be significant. As such Professor Coulombe (2000) concluded that that "the conditional convergence model predicts that provinces should converge to their long-run equilibrium based on their relative urbanization rate at a speed of about 5%" (p.720).

Following this model, I modify equation (4) and do my own test for the convergence of G7 cross-country sample. The following is my basic equation used in this paper:

$$log(RY_{i,t}/RY_{i,t-1}) = (1-\gamma_1)log(RY_{i,t-1}) + \gamma_n log(X) + \gamma_m Dummies + \gamma_a AR(1) + \varepsilon_{i,t} \quad (5)$$

In equation (5), $RY_{i,t}/RY_{i,t-1}$ is the growth rate of relative GDP per capita level in time period t. $RY_{i,t-1}$ is the lagged value of relative GDP per capita level. '*X*' works as the proxy of the relative GDP per capita level at its steady state for each economy. '*Dummies*' show structural breaks or fixed effects for several countries. $\varepsilon_{i,t}$ is the disturbance like those in equation (3) and (4).

Equation (5) is the basic model used in this paper. In my research, the '*X*' can be relative real investment rate, relative saving rate, or the combinations of relative real investment rate and relative schooling rate. The '*Dummies*' represents the dummy variables I am using to capture structural breaks in the evolution paths of relative GDP per capita levels. When I use only one variable (the relative real investment rate or the relative real saving rate) as the estimator of steady states, I find that although the variables are significant in my model, the steady state for the United States is too far from its real evolution path of GDP per capita. To solve this problem, I add a dummy variable for the United States and it proves significant. What is more, the dummy variable for the United States equals one all over my research period (fixed effect). When I use the combination of relative real investment rate and relative schooling rate as the estimator of steady states, I find that the dummy variable for the United States fixed effect is still significant and two other dummy variables, for France (equals one after the year of 1973) and the United Kingdom (equals one after the year of 1976), also significant. These results will be presented in section 5.

4. Unit root test

The purpose of unit root test is to distinguish between trend stationary and difference stationary processes. The focus of my unit root test is the log of relative GDP per capita level. The unit root test is based on least-squares estimates of the following equations:

$$D(Y_{i,t}) = \beta_1 + \beta_2 t + \beta_3 Y_{i,t-1} + \varepsilon_{i,t} \qquad (6)$$

$$D(D(Y_{i,t})) = \beta_1 + \beta_2 t + \beta_3 D(Y_{i,t-1}) + \varepsilon_{i,t} \qquad (7)$$

In my research, I found that for some countries, the null hypothesis of β_3 being equal to zero can not be rejected in levels but can be rejected in first difference. So I present both equations for the unit root tests in levels (equation 6) and in first difference (equation 7).

$Y_{i,t}$ in equation (6) and (7) is the log of relative GDP per capita level and D stands for change. $\beta_1+\beta_2 t$ is the trend path and $\varepsilon_{i,t}$ is the disturbance. These two equations also show us two notions of convergence. Equation (6) is used to test the unit root of the evolution of per capita income levels. In equation (7), which is used to test unit root in first difference, the test object changes to be $D(Y_{i,t})$. So equation (7) is actually the method to test the unit root of the change of per capita income levels – the growth rate.

The null hypothesis of the unit root test is β_3 being equal to 0. According to the decision rule, if the null hypothesis is rejected and β_2 is significantly different from zero, then we call $Y_{i,t}$ trend stationary. If the null hypothesis is rejected but β_2 is not significantly different from zero, we call $Y_{i,t}$ stationary. Furthermore, if the test fails to reject the test in levels but rejects the test in first difference, then the series contains one unit root and is integrated of order one.

I carried out both ADF (Augmented Dickey-Fuller) and PP (Phillips-Perron) unit root tests. Only the ADF test results are presented in this paper.

Table 3. *ADF unit root test results for G7 per capita GDP indicators*

		ADF test (tested in levels)		ADF test (tested in first difference)	
		Value	Significant level	Value	Significant level
Canada	ADF test statistic	-2.00		-4.36	***
	β_2	0.00000		0.00372	
	Constant	0.01503		-0.01318	
France	ADF test statistic	-0.97		-4.81	***
	β_2	-0.00018		-0.00042	**
	Constant	0.00269		0.01112	**
Germany	ADF test statistic	-4.12	**	-3.77	**
	β_2	-0.00033		-0.00038	
	Constant	0.01052	***	0.01163	
Italy	ADF test statistic	-2.15		-5.05	***
	β_2	0.00073		-0.00052	*
	Constant	-0.04715		0.02094	**
Japan	ADF test statistic	-0.88		-3.21	*
	β_2	-0.00023		-0.00060	
	Constant	0.02053		0.02989	**
UK	ADF test statistic	-1.01		-5.58	***
	β_2	-0.00026		0.00033	
	Constant	-0.00413		-0.01573	**
USA	ADF test statistic	-2.11		-4.76	***
	β_2	-0.00137		0.00041	*
	Constant	-0.07731		-0.02189	***

Note: In this table and *Table* 4, '***', '**' and '*' means the null hypothesis can be rejected at the 1%,5% and 10% significant level.

If the test statistics is larger (in absolute value) than the MacKinnon critical values in each case, the null hypothesis can be rejected in this one-tail t test. *Table* 3 shows us that, except the case of Germany, the null hypothesis of all the countries cannot be rejected at 10%

significance level. When tested in first difference, for the cases of Canada, France, Italy, the United Kingdom and the United States, the null hypothesis can be rejected at the 1% significant level. For the case of Japan, it can be rejected at the 10% level.

Table 3 also shows us the evolution directions of the relative GDP per capita level for each country. As presented in the ADF results tested in first difference, for the cases of Canada, the United Kingdom and the United States, the constant values are all negative and β_2 values are all positive. These results show us that the growth rates of relative GDP per capita level for Canada, the United Kingdom and the United States are negative initially and increase continuously during my research period. For the evolution paths of France, Germany, Italy and Japan, the directions are just the opposite. This finding in my unit root test matches what I observed in the graphical evidence (p.15) for the convergence across G7 countries.

We can also see from *Table* 3 that the coefficients for trend variable are not significant for Canada, Italy, Germany or the United Kingdom. So the ADF test statistics should be reported with only an intercept and no trend. The following table is an adjusted table for the above four countries. Note that the '***', '**' and '*' in *Table* 4 also means the null hypothesis can be rejected at the 1%, 5% and 10% significant level respectively.

Table 4. *The adjusted ADF unit root test results for Canada, Germany, Italy and the United Kingdom.*

		ADF test (tested in first difference)	
		Value	Significant level
Canada	ADF test statistic	-4.21	***
	constant	-0.00459	
Germany	ADF test statistic	-3.54	**
	constant	0.00226	
Italy	ADF test statistic	-4.58	***
	constant	0.00823	**
UK	ADF test statistic	-5.38	***
	constant	-0.00756	***

From *Table* 3 (p.21) and *Table* 4 (p.22), I can make a brief summary about the unit roots of my sample as follows:

1. Germany is the only case of stationary in my sample.

2. The null hypothesis that β_3 equals zero can be rejected for the other six countries at first difference level. So the series of G7 countries except Germany contains one unit root and are integrated of order one.

3. The null hypothesis that β_2 be equal to zero can not be rejected at the 10% significant level in many cases. So the evolution paths of GDP per capita indicators should have structural breaks in the period between 1950 and 1992.

In the literature, one often uses dummy variables to show the structural breaks in evolution. But the problem is which country's case should include a dummy and from which year the dummy should be equal to one. In my sample, the unit root tests show that in the cases of Canada, Italy, Germany and the United Kingdom, the coefficients of time trend are insignificant. After a great deal of testing, finally I included dummies for France, the United Kingdom and the United States. The break point for each dummy is decided by the time when the dummy turned significant in the model. Thus the final regression model turned out to be the following (equation 8):

$$log(RY_{i,t}/RY_{i,t-1}) = (1-\gamma_1)log(RY_{i,t-1}) + \gamma_2 log(RI_i) + \gamma_3 \log(SC_i) + \gamma_4 D_{fr} + \gamma_5 D_{uk} + \gamma_6 D_{us} + \gamma_7 AR(1) + \varepsilon_{i,t} \quad (8)$$

With:

D_{fr}= 0 for all countries except France,
D_{fr}= 0 for all years before 1973 and equals 1 after the year of 1973.
D_{uk}= 0 for all countries but the United Kingdom,
D_{uk}= 0 for all years before 1976 and equals 1 after the year of 1976.
D_{us}= 0 for all countries except the United States,
D_{us}= 1 for all years between 1950 and 1992.

The RI_i and SC_i in equation (8) (p.23) are the relative levels of real investment rate and schooling rate. D_{fr}, D_{uk} and D_{us} are the dummy variables for France, the United Kingdom and the United States. $\varepsilon_{i,t}$ is the disturbance.

5. Convergence results

This part presents us the major empirical results of my tests on both absolute convergence hypothesis and conditional convergence hypothesis. The results presented in section *5.2* are based on my basic model, equation (5), listed on page 19. The results presented in section *5.3,* however, are based on my specific equation (8).

In carrying out the tests, I used the first-order and the second order serial correlation coefficients (AR (1) and AR (2)) of the residuals $\varepsilon_{i,t}$ to determine if the last AR process (AR (2)) is significant at 5%. The AR (2) has been proved insignificant and rejected. Thus AR (1) is included in my model. What is more, all the empirical results presented in the following tables are tested when I use different AR (1) for each G7 countries.

5.1 The absolute convergence results

Following Coulombe (2000), the absolute convergence hypothesis test is based on the following equation (9). This equation is derived from equation (2) (p.17). When β equals zero, $log\ (RY_{i,t})$ is determined by $log\ (RY_{i,t-1})$ only, and the economy does not converge to RY_i^*.

$$log(RY_{i,t}) = e^{-\beta} log(RY_{i,t-1}) \qquad (9)$$

Table 5. Estimation results for absolute convergence

Sample	Convergence speed	R^2	Durbin-Watson stat.
1950-1992	0.037	0.34	1.98
t-stat	-9.26		
Prob.	0.00		
1950-1970	0.040	0.41	2.01
t-stat	-7.38		
Prob.	0.00		
1971-1992	0.028	0.05	1.95
t-stat	-3.04		
Prob.	0.00		

Note: In this table, the value of convergence speed equals $-e^{-\beta}$ and the "t-stat" value shows the t ratios for $e^{-\beta}$ in equation (9).

In *Table* 5, I show the test results for absolute convergence. The explanatory variable is the log of lagged value of relative GDP per capita level and different AR (1) are used for each country. The coefficients for this lagged relative GDP per capita variable are all positive and significant in the three different intervals, which means convergence speeds are all positive. Thus, the prediction of absolute convergence is not rejected for the G7 countries. What is more, the convergence speed in the 1950-1970 period is much faster than that in the 1970-1992 period. This finding also matches most research on the slowing down convergence speed after the first world oil shock in the post WWII period, that is, the convergence speed will show a dramatically decrease after the first world oil shock.

5.2 Conditional convergence (single variable and dummy included)

The following parts of empirical tests results come from my tests for the prediction of conditional convergence in G7 countries. Note that only a single value for all the relative variable indicators including the real investment rate, saving rate and schooling rate is used in my tests (the collecting of these indicators is presented in *Table* 2 on page14).

In this section, I present empirical results using saving rate and real investment rate independently as the estimator of steady states. A dummy variable for the United States is also included to show fixed effect for the United States. The results are presented in *Table* 6 and *Table* 7.

Table 6. Estimation results for convergence regression equation (log (SR_i) and D_{us} included)

Sample	Convergence speed	$log(SR_i)$	D_{us}	R^2	Durbin-Watson stat.
1950-1992	0.041	0.031	0.012	0.38	1.96
t-stat	-5.68	4.01	3.19		
Prob.	0.00	0.00	0.00		
1950-1970	0.046	0.038	0.017	0.50	1.91
t-stat	-3.95	2.59	2.41		
Prob.	0.01	0.01	0.01		
1971-1992	0.020	0.020	0.004	0.12	1.97
t-stat	-1.53	2.60	0.83		
Prob.	0.12	0.01	0.40		

In *Table* 6, I show that when using the relative saving rate as the estimator of steady states and a fixed effect dummy variable for the United States, γ_2, the coefficient for the relative saving rate variable, are significantly positive for all countries. This result means that the higher the relative saving rate of one economy, the higher its steady state goes. Under this regression model, the relative GDP per capita levels of G7 countries converge to their steady states defined by their saving rate at the speed of 4.1% per year. The convergence speed in the 1950-1970 period is also much higher than that of 1971-1992 period.

Table 7. Estimation results for convergence regression equation (log (RI_i) and D_{us} included)

Sample	Convergence speed	$log(RI_i)$	D_{us}	R^2	Durbin-Watson stat.
1950-1992	0.047	0.033	0.011	0.41	1.96
t-stat	-6.53	5.53	3.47		
Prob.	0.00	0.00	0.00		
1950-1970	0.059	0.108	0.027	0.62	2.03
t-stat	-9.64	8.76	6.39		
Prob.	0.00	0.00	0.00		
1971-1992	0.024	0.022	0.004	0.15	1.95
t-stat	-1.80	3.32	0.77		
Prob.	0.07	0.00	0.43		

In *Table* 7, I show significant results for the case when relative real investment rate is used as the estimator of steady states and a fixed effect dummy variable for the United States is included. All the γ_2 are significant and positive in each sample. This result means that the relative investment rate, as well as the relative saving rate, has a positive correlation with the levels of steady state.

Comparing *Table* 7 with *Table* 6 (p.26), I selected the real investment rate together with a dummy for the United Sates as one objective of my further research because of a larger R^2. The steady states calculated from relative real investment rate and dummy variable for the United States will be presented in section *5.4*.

There is also a very interesting finding in *Table* 6 and *Table* 7. Why does the dummy variable work only for the United States in this model? The dummy variable is only significant when it equals one throughout my research period, that is, there is a fixed effect for the case of the United States. Including the fixed effect, the regression results shows that the steady state of the United States jumped from its original 0.93 to a level as high as 1.21(see *Table* 9 on page 30).

Theoretically, the steady state of each economy indicates the relative level of its GDP per capita to the sample mean of the group. If the real investment rate is significant as the estimator of steady state, the steady state for the United States should be below average because of its lower real investment rate in economy. The significance of the dummy for the United States shows that there is some factor that keeps the relative level of GDP per capita level much higher above the sample mean in the post-WWII period. The analysis will be presented in section 6.

5.3 Conditional convergence (the relative real investment rate, relative schooling rate and dummies included)

This part of empirical results is obtained from the specified equation (8) (p.23) after my study about the research of Mankiw, Romer and Weil (1992).

Mankiw, Romer and Weil (1992) found that although the directions of the effects of saving rate and population growth rate have been properly indicated, the magnitudes appeared too large in Solow-Swan model. They attribute this to the exclusion of human capital accumulation in the classic Solow-Swan model. As the result, in their modified Solow-Swan model, they included a proxy for human-capital accumulation as an additional explanatory variable for their cross-country sample.

I also included a proxy for human capital accumulation—the relative schooling rate in my regression model (equation 8). Adapting a measure different from that in Mankiw, Romer and Weil (1992), the schooling rate in this model is the fraction of eligible people enrolled in primary, secondary and tertiary school. Using this model, I show the results in *Table* 8.

Table 8. Estimation results for convergence regression equation (log (RI_i), log (SC_i) and Dummies included)

Sample	Convergence speed	$log\ (RI_i)$	$log\ (SC_i)$	D_{fr}	D_{uk}	D_{us}	R^2
1950-1992	0.057	0.049	0.056	-0.007	0.013	0.012	0.44
t-stat	-6.63	5.38	2.17	-5.48	2.14	3.31	
Prob.	0.00	0.00	0.03	0.00	0.03	0.00	
1971-1992	0.050	0.035	0.052	-0.006	0.008	0.007	0.20
t-stat	-1.97	3.59	1.41	-4.13	1.90	1.29	
Prob.	0.05	0.00	0.15	0.00	0.05	0.19	

Table 8 shows us the regression results when including the dummies for the United States fixed effect, France and the United Kingdom structural breaks. In the 1950-1992 period, all coefficients for the explanatory variables are significant. But in the 1950-1970 period, I can't get any results because the model is near singular matrix. In the 1971-1992 period, however, the convergence speed decreased while the schooling rate variable and the dummies for the United States and the United Kingdom turn insignificant at the 10% significant level.

5.4 The steady state

Now I have obtained two sets of results using two different regression models. To extend my research further, I should use the regression equation to calculate the steady states for each country. As we know, at the steady state for each country, the relative GDP per capital level will not change after the time it arrives the steady state. So I can calculate the steady state by equation (10) and (11) in these two models:

$$D(log\,(RY_{i,t}^{*})) = -0.057\,log\,(RY_{i,t}^{*}) + 0.049\,log\,(RI_i) + 0.056\,log\,(SC_i) \qquad (10)$$

$$D(log\,(RY_{i,t}^{*})) = -0.05\,log\,(RY_{i,t}^{*}) + 0.033\,log\,(RI_i) + 0.011\,D_{us} \qquad (11)$$

$$-\,0.007\,D_{fr} + 0.0013\,D_{uk} + 0.012\,D_{us}$$

In equation (10) and (11)(p.29), $D\ (log\ (RY_{i,t}^*))$ is the change of relative GDP per capita level at steady state. $RY_{i,t}^*$ is the steady state level of relative GDP per capita. When the economies arrive their steady states, $D\ (log\ (RY_{i,t}^*))$ equals zero. Thus I can calculate the estimated steady states for G7 countries:

Table 9. The estimated steady states for G7 countries

	Steady State (with $log(RI_i)$and D_{us})	Steady State (with $log(RI_i)$, $log(SC_i)$, D_{fr}, D_{uk} and D_{us})	SC_i	RI_i
Canada	0.99	1.05	1.15	0.97
France	1.01	1.01(0.89)	1.00	1.03
Germany	1.04	1.02	0.95	1.12
Italy	1.04	0.98	0.87	1.12
Japan	1.07	1.08	0.99	1.22
UK	0.89	0.84(1.05)	0.93	0.68
US	1.21	1.21	1.10	0.86

Note: 1. Steady state (with $log(RI_i)$and D_{us}) means the steady state calculated using equation (10). Steady state (with $log(RI_i)$, $log(SC_i)$, D_{fr}, D_{uk} and D_{us}) are the steady states calculated by equation (11). 2. The value in brackets shows the steady state for France after the year of 1973 and for the United Kingdom after the year of 1976.

6. Dynamic simulation results

6.1 Simulation results

Dynamic simulation helps us to predict the growth path derived from the convergence model. The simulation part of this paper is based on equation (8) (p.23). In the empirical part of my research, I use real investment rate and schooling rate as the proxies of steady state. After calculating γ_2 and γ_3 in equation (8), I obtain my final regression function and transform it into equation (12):

$$log(RY_{i,t}^{*}) = 0.943log(RY_{i,t-1}^{*}) + 0.049log(RI_i) + 0.056log(SC_i) - 0.007D_{fr} + 0.013D_{uk} + 0.012D_{us} \quad (12)$$

We can see that in equation (12) that in this conditional convergence model, the relative GDP per capita levels of G7 countries converge to their different steady states at the speed of 5.7% per year. This section shows us the simulation results (*Figure* 4) for the relative level of GDP per capita by comparing the observed growing paths in the 1950-1992 period to the paths predicted by my estimated conditional convergence model.

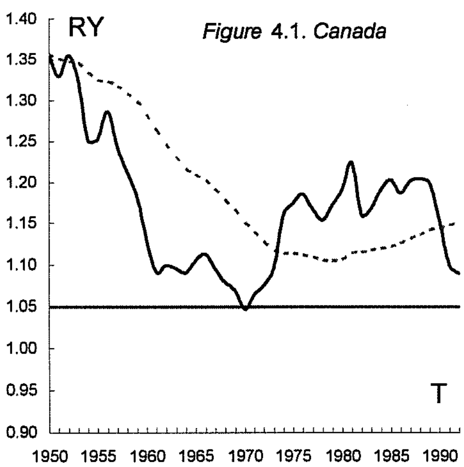


Figure 4.1. *Canada*

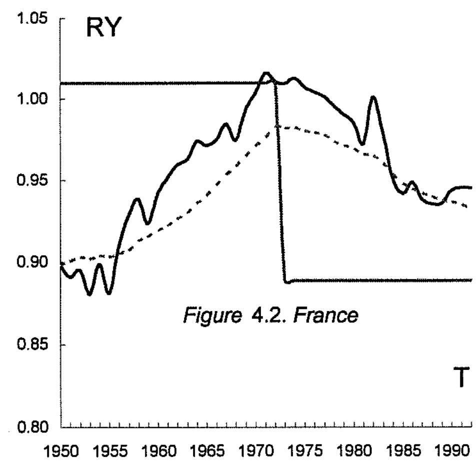


Figure 4.2. *France*

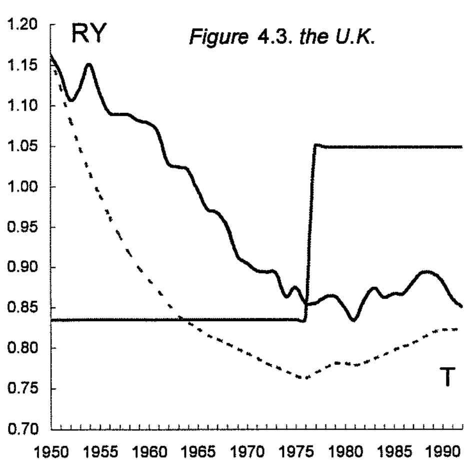


Figure 4.3. *the U.K.*

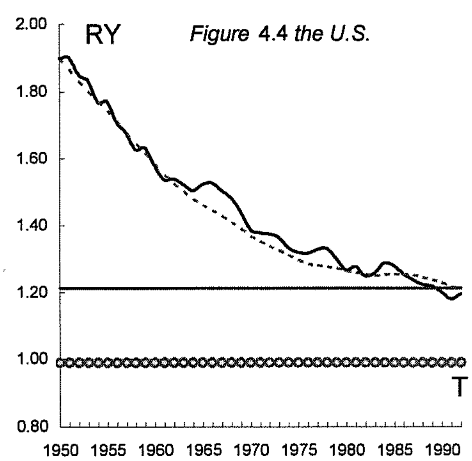


Figure 4.4 *the U.S.*

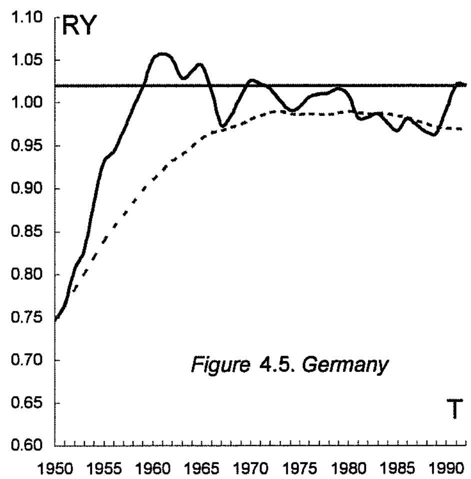


Figure 4.5. *Germany*

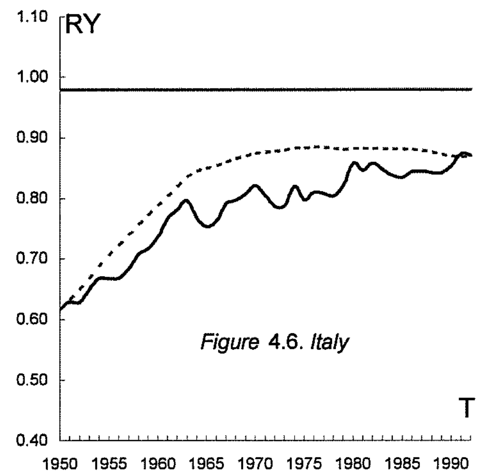


Figure 4.6. *Italy*

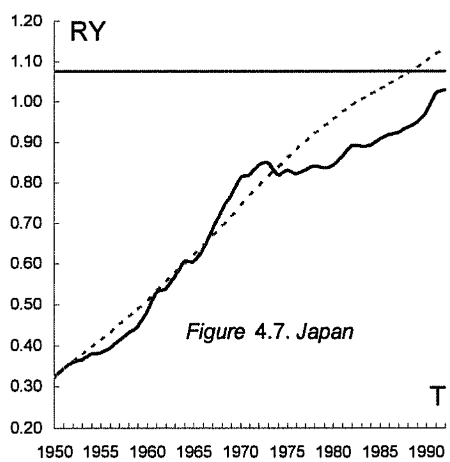


Figure 4.7. *Japan*

Figure 4. *The simulation convergence paths for G7 countries.*

Note: 1.The irregular '—' is the actual evolution paths of the GDP per capita level for each economy. 2. The irregular dashed line is the simulated ways of convergence of each economy. 3. The horizontal lines are the calculated steady state levels for their GDP per capita level. 4. In F*igure* 4.4, the '--o--' is the rejected steady state level without the fixed effect for the United States.

Fortunately, we can see a good fit between the predicted convergence path and actual data for most countries in *Figure* 4. What is more, the steady states for France, the United Kingdom and the United States are also good considering actual evolution paths of their relative GDP per capita level with the help of dummies. The evolution paths of most cases go much closer to or around their steady states at the end of my research period.

For the cases of the United Kingdom (*Figure* 4.3) and France (*Figure* 4.2), although the evolution paths are not close to their steady states, we can still see clear convergence trends towards their new steady states. In *Figure* 4.4, both the rejected steady states for the United States without fixed effect and with a fixed effect are presented to make a comparison. Clearly, the fixed effect for the United States works very well in my model. Without this fixed effect, the actual evolution path for the relative GDP per capita level of the United States will be too far away form the estimated steady state.

The analysis of my three dummy variables will be presented in the following parts of this section:

6.2 The France dummy variable

In my tests for structural breaks, the dummy variable for France only shows significance after the year of 1973. Clearly this change can be attributed to the world oil shock happened in 1973. After WWII, France experienced a steady and strong evolution path towards the sample average and jumped above at the end of the 1960s. But after the first world oil shock, the relative level of GDP per capita went below average again. In the tests of dummies for other countries such as Germany, Japan, and Italy, the dummies all proved insignificant. So I can conclude that in my sample, France is one of the most negatively affected countries for the first world oil shock.

6.3 The United Kingdom dummy variable

The dummy variable for the United Kingdom seems interesting and only shows significance when the dummy equals one after the year of 1976. I examined much research about the first world oil shock to find out why it is not significant when the dummy equals one from 1973 on. As we know, the United Kingdom is one of the few less affected industrialized counties in the first oil shock because of the rich oil reservation in the North Sea. The United Kingdom and Norway received most benefit from the North Sea oil reservation and survived the oil shock successfully. But the mass production of the oil resources only began in 1977. Before 1976, the United Kingdom still imported almost all the oil needed for its consumption from outside world. Only in a decade, this country became self sufficient in oil production and even more. Comparing to that of 1977, the oil production revenue increases dramatically by 5 times in the year of 1980 (see Montamen (1982)).

6.4 The United States fixed effect

I give more consideration on the fixed effect for the United States. As we know, the United States is one of the largest oil importers of the world. But at the same time, it is also a big oil producer of the world. So the insignificance of the world-oil-shock dummy for the United States is somehow reasonable. For the fixed effect of the United States, it is explained as follows in this paper.

WWII is a milestone for the new world political order as well as the economic order. It is also a milestone for the economic development of the United States. The United States began its strong influence over the world economy after WWII had devastated Europe. The economies of most European countries were shattered after WWII. Poverty and hunger were widespread, and many cities lay in ruins. The United States was then the only country that had the ability to help Europe recover from WWII.

As early as the year of 1944, the delegates from 45 nations met at Bretton Woods and reached an agreement known as the Bretton Woods Agreement to establish a postwar international monetary system of convertible currencies, fixed exchange rates and free trade. In the following decades, the U.S. dollar gained leadership of the world currency. In June 1947, the Secretary of State George Marshall made a dramatic offer to the nations of Europe, which came to be called the Marshall Plan. The purpose of this plan is to help Europe recover from the war with the help of the United States. In those years, most FDI (Foreign Direct Investment) to Europe came from the U.S. and thus this country played the major role in the reconstruction of western European economies. What is more, NATO (North Atlantic Treaty Organization), a military alliance was established in 1949 and the U.S. became its leader. From this time on, the U.S. gained the financial, economic and military leaderships on the nations of the world after WWII and finally became a superpower of the world. The military presence of the U.S. Army all over the world is a good evidence of the leadership position of the United States.

All the actions above helped the United States to assume the leadership of the world economy. After the WWII, the important influence of the United States on the 'game rules' of world economy such as international trade order and the global financial order made American commodities and capital goods enter other economies more easily and with fewer barriers.

With mass revenue from international trade and investment, the R&D industries kept booming in the United States in the post WWII period. Thus most the technique revolutions in this period emanated from the United States. Being the leader of technique development of the world, the United States can easily obtain the leadership in the world economic growth and keep the gap of productivity between itself and other countries around the world. As we have seen in *Table* 1, the relative GDP per capita levels of the United States have been in the first position form 1950 to 1992.

7. Summary and conclusions

In this paper, I presented the regression results of my conditional convergence model for the G7 countries between 1950 and 1992. I used three different groups of variables (the relative saving rate, the relative real investment rate, the relative real investment rate together with relative schooling rate) as the proxies of steady state in my research. Dummy variables for the United States, France and the United Kingdom were also included in my research to show the fixed effects or structural breaks. The coefficients for all the variables are significant at the 10% significant level.

The relative real investment rate with fixed effect dummy variable for the United States (model 1) and the relative real investment rate, schooling rate and fixed effect dummy variable for the United States, dummies for the United Kingdom and France (model 2) are chosen to calculate the steady states for my G7 cross-section sample. Under the basic regression models (equation (5) and equation (8)), I can conclude that G7 countries converge to their long-run steady state level of GDP per capita at a speed of approximately 4.7% per year under model 1 and 5.7% per year under model 2.

Also, as many former research on convergence proved, the convergence speeds vary in sample periods before and after the first world oil shock. As shown in *Table* 10, the convergence speed estimated in 1950-1970 period is much faster than that in 1971-1992 period.

Table 10. *The estimated convergence speed in different time periods*

Variable / Speed	Absolute Convergence	$log(RI_i)$ & D_{us}	$log(SC_i)$ & D_{us}	$log(RI_i), log(SC_i)$, D_{fr}, D_{uk} and D_{us}
Estimated Convergence Speed in 50-70 period	0.040	0.046	0.059	Na
Estimated Convergence Speed in 71-92 period	0.028	0.020	0.024	0.50

The most interesting finding in my research is about the significance of dummy variables in my model. As we know, Canada and the United Kingdom are two countries that benefited form the first world oil shock because of their rich oil reserves in Alberta and the North Sea. But in my model, only the dummy variable for the United Kingdom showed positive significance after the first world oil shock. This means although there is an obvious structural break in the 1970's (see *Figure*1), no significant dummy variable is showing this structural break for the case of Canada in my model.

As far as the negative effect is concerned, Japan used to be thought of as the worst affected country because this second largest economy has to import almost all natural resources, especially oil. It was also observed that the value of GDP per capita of Japan experienced the largest decrease (-412 dollars) among G7 countries in 1973. But the evolution of its relative GDP per capita level went comparatively smooth after the first oil shock and upwards again after the year of 1980. The world-oil-shock dummy variable for this country was also proved to be insignificant in my model. Interestingly, only the dummy variable for France was negatively significant.

A great deal of research was carried out on the convergence across major industrialized countries including G7 countries. The major contribution of this paper is the use of dummy variables to show fixed effect or structural breaks in the sample. But because of the lack of data availability, the research interval was limited to 1950 to 1992. Further research will probably include more up-to-date data and covers longer research interval. Another possible topic of research will include Russia as a member of G8 Summit with the updated data. More interesting findings will probably be observed in further research.

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