CONVERGENCE: A CROSS COUNTRY EMPIRICAL ANALYSIS

Araş. Gör. Dr. Halit YANIKKAYA
Celal Bayar Üniversitesi İ.İ.B.F. İktisat Bölümü, MANİSA

1. INTRODUCTION

In the 1960s, growth theory consisted mainly of the neoclassical model. One of the most important characteristics of this model is that it predicts absolute convergence among the world economies due to the assumption of diminishing returns to physical capital. Thus, all countries should converge to a common level of per capita income and growth. Since economies, however, differ from each other in terms of structural variables –such as, trade policies, infrastructure services, tax rates, the degree of maintenance of property rights, and the rule of law- we would expect only conditional convergence in which every country converges to its steady-state value. While it is hard to support the existence of absolute convergence among world economies, a number of studies report substantial evidence in favor of conditional convergence.

The basic problem with the neoclassical theory is that in the steady state, income growth is mainly driven by the changes in exogenous variables. In other words, the steady state growth rate only depends upon exogenous population growth and technological improvements. As a result, since the early 1980s a large number of studies have developed theoretical models in an attempt to endogenize long-run economic growth. These contributions to the analyses of economic growth and development are called "endogenous" growth theory. This theory provides this missing explanation for long-run growth by identifying a number of channels such as R&D activities, human capital accumulation, externalities, and learning by doing through which economic agents can affect long-run growth.

The outline of this paper is as follows. Section 2 reviews the basic Solow growth model with and without human capital accumulation. This section also presents the equations to assess the speed of convergence quantitatively. Section 3 describes a standard growth equation and the data sources and definitions. Section 4 separately reports the estimation results for all, developing, and developed countries. Finally, Section 5 concludes the paper.

2. MODELS OF ECONOMIC GROWTH

We start by describing the basic Solow growth model with a Cobb-Douglas production function. Although it may seem a very simple model of growth, it is the starting point for almost all economic growth models. After describing the basic Solow model, we then add human capital accumulation to this model and examine the dynamics of the Solow model with human capital. Finally, we describe the conditional convergence in the endogenous growth models.

2.1 The Basic Solow Model[1]

There are only four variables in this model: output (Y), capital (K), labor (L) and technology or the "effectiveness of labor" (A). At any time, economic agents (individuals and governments) use inputs, K and L, to produce final outputs. We assume a Cobb-Douglas production function

$$Y(t) = K(t)^{\alpha}\left(A(t)L(t)\right)^{(1-\alpha)}, \qquad 0 < \alpha < 1 \tag{1}$$

where t denotes time. Easy to show that the Cobb-Douglas function has constant returns to scale, which implies that output can be expressed in intensive form as

$$y(t) = k(t)^{\alpha}, \tag{2}$$

where $y \equiv Y/AL$ is output per unit of effective labor and $k \equiv K/AL$ is the amount of capital per unit of effective labor.

The rest of the assumptions of the model describe how the stocks of labor, knowledge, and capital change over time. Initial levels of these variables are taken as given. L and A are assumed to grow exogenously at rates n and g, respectively.

$$L(t) = L(0)e^{nt}, \tag{3}$$

$$A(t) = A(0)e^{gt}. \tag{4}$$

These equations imply that the number of effective units of labor, A(t)L(t), grows at the rate (n + g). In addition to the exogenously determined population growth and technological changes, this model also assumes that the fraction of output devoted to investment (s) is also exogenous and constant. The net change in the capital stock equals gross investment less depreciation:

$$\dot{K}(t) = sY(t) - \delta K(t), \tag{5}$$

where a dot over a variable denotes a derivative of a variable with respect to time, δ is the rate of capital depreciation, and $0 \le s \le 1$. Since two of the three inputs, L and A, are exogenous, the behavior of the economy is characterized by the behavior of capital. If divide both sides of Eq. (5) by AL, then we get

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[1] This chapter is mostly based on Mankiw et al. (1992), Romer (1996), and Chapter 12 of Barro and Sala-i-Martin (1995a).

$$\frac{\dot{K}(t)}{A(t)L(t)} = sk(t)^{\alpha} - \delta k(t)\,, \qquad (6)$$

where k(t) = K(t)/A(t)L(t). We can write $\dot{K}(t)\big/A(t)L(t)$, as a function of k by using the condition $\left(\dot{K}(t)\big/A(t)L(t)\right) = \dot{k}(t) + (n + g + \delta)k(t)$. If we substitute this expression in Eq. (6) and then rearrange terms, we obtain

$$\dot{k}(t) = sk(t)^{\alpha} - (n + g + \delta)k(t)\,. \qquad (7)$$

This equation is the fundamental equation of the Solow growth model. Since in the steady state, k converges to k^*, the steady state level of capital for each unit of effective labor, it follows that $\dot{k} = 0$. At the steady-state, Eq. (7) implies that k^* can be described as $sk^{*\alpha} = (n + g + \delta)k^*$, or

$$k^* = \left[\frac{s}{(n + g + \delta)}\right]^{\frac{1}{(1-\alpha)}}. \qquad (8)$$

Thus, the steady state capital-labor ratio is positively affected by saving rates and negatively affected by population growth. Given $y^* = k^{*\alpha}$, substituting y^* for $k^{*\alpha}$ in Eq. (8) yields

$$y^* = \left[\frac{s}{(n + g + \delta)}\right]^{\frac{\alpha}{(1-\alpha)}}. \qquad (9)$$

If we take logs and rearrange the terms, then we can get the steady state per capita income

$$\ln\left[\frac{Y(t)}{L(t)}\right] = \ln A(0) + gt + \frac{\alpha}{(1-\alpha)}\ln(s) - \frac{\alpha}{(1-\alpha)}\ln(n + g + \delta)\,. \qquad (10)$$

We assume that g and δ are constant across countries. g represents progress of knowledge, which is not very different across countries. However, the A(0) term not only indicates the level of technology but also resource endowments, economic and political factors, geographical factors, and so on. It may, thus, differ across countries. We assume that ln A(0) = a + ε, where a is a constant and ε is a country-specific shock. Thus, we can rewrite the log per capita income at time t as

$$\ln\left[\frac{Y(t)}{L(t)}\right] = a + \frac{\alpha}{(1-\alpha)}\ln(s) - \frac{\alpha}{(1-\alpha)}\ln(n + g + \delta) + \varepsilon\,. \qquad (11)$$

We can then estimate this equation by OLS, if n and s are uncorrelated with ε. The equation shows that the steady-state income levels in the Solow model are solely determined by exogenous variables. However, examining the behavior of output and capital along the transition path has important implications. The transitional dynamics analyze how a country's per capita income approaches its steady-state position.

Division of both sides of Eq. (7) by k results in the growth rate of k as given by

$$\gamma_k(t) \equiv \frac{\dot{k}(t)}{k(t)} = sk(t)^{(\alpha-1)} - (n + g + \delta), \tag{12}$$

where the symbol γ denotes the growth rate of the variable shown by the subscript, in this case growth of capital per effective worker. We can also examine the behavior of output along the transition. The growth rate of output per effective worker is given by

$$\gamma_y(t) \equiv \frac{\dot{y}(t)}{y(t)} = \frac{\alpha k(t)^{(\alpha-1)}\,\dot{k}(t)}{k(t)^{\alpha}}. \tag{13}$$

Multiplying by k/k and rearranging terms yields

$$\gamma_y(t) \equiv \gamma_k(t)\left[\frac{k(t)\alpha k(t)^{(\alpha-1)}}{k(t)^{\alpha}}\right]. \tag{14}$$

The expression in brackets is usually specified as the "capital share", which is the share of capital income in total income. This equation shows that the relation between γ_y and γ_k relies on the behavior of the capital share. In a Cobb-Douglas production function, share of capital is a constant α, and γ_y mimics the behavior of γ_k. If $k(0) < k^*$, given by Eq. (8), then γ_k is positive. Hence, γ_y will follow the same path and will be positive. Especially, the lower y(0), the higher γ_y will be. Other things equal, smaller values of k are associated with larger values of γ_k. Thus, this implies that economies with lower capital per capita tend to grow faster in per capita terms, which is called as convergence across economies.

Next, we add human capital accumulation to the basic Solow growth model. There are at least two reasons for this modification. First, many economists claim that the basic Solow model is unable to explain the vast international differences in income levels and growth rates. The other reason, closely related to the previous one, is the common consensus that human capital accumulation, which was excluded from the basic model, is an extremely important determinant of economic growth. Thus, inclusion of human capital can certainly help us understand the vast differences in income per capita across nations.

2.2 The Solow Model with Human Capital Accumulation

A number of studies (e.g., Lucas, 1988, Young, 1991) developed theoretical models that have emphasized the role of human capital in long-run economic growth. To include human capital accumulation in the basic Solow model, we make slight changes to the Cobb-Douglas production function presented in the previous section. Thus, output is given by

$$Y(t) = K(t)^{\alpha} H(t)^{\beta} \left(A(t)L(t)\right)^{(1-\alpha-\beta)}, \quad \alpha > 0, \beta > 0, \alpha + \beta < 1, \tag{15}$$

where H is the stock of human capital. L still represents the number of workers and each skilled worker provides 1 unit of L and some amount of H. Note that this equation continues to imply constant returns to scale. We make the same assumptions about the behavior of K, L, and A. Since total savings are now divided between physical and human capital, we respecify Eq. (5) as

$$\dot{K}(t) = s_K Y(t) - \delta K(t), \tag{16}$$

where s_K denotes the fraction of output devoted to physical capital accumulation. Next, human capital accumulation is also characterized in the same way as physical capital accumulation for simplicity.

$$\dot{H}(t) = s_H Y(t), \tag{17}$$

where s_H is the fraction of income invested in human capital accumulation.

The dynamic analysis of this model resembles the analysis of the basic Solow model. In contrast to the basic model, in addition to the examining the behavior of the physical capital, we also now consider the behavior of the human capital. In particular, define k = K/AL, h = H/AL, and y = Y/AL. These definitions along with Eq. (15) imply that

$$y(t) = k(t)^{\alpha} h(t)^{\beta}. \tag{18}$$

We first consider k. The definition of k and equations for the dynamics of K, L, and A imply

$$\dot{k}(t) = \frac{\dot{K}(t)}{\left(A(t)L(t)\right)} - \left[\frac{K(t)}{\left(A(t)L(t)\right)}\right]^2 \left[\dot{A}(t)L(t) + A(t)\dot{L}(t)\right]. \tag{19}$$

By definition K(t)/A(t)L(t) is k(t). From the Eqs. (3) and (4), $\dot{L}(t)/L(t)$ and $\dot{A}(t)/A(t)$ are n and g. Finally, $\dot{K}(t)$ is given by Eq. (16). Substituting these conditions into Eq. (19) yields

$$\dot{k}(t) = s_K y(t) - (n + g + \delta)k(t). \tag{20}$$

We now consider h. Following the same steps used to derive Eq. (19) yields

$$\dot{h}(t) = s_H y(t) - (n + g + \delta)h(t). \tag{21}$$

The initial levels of k and h depend on the initial values of K, H, and L. Then the dynamics of k and h evolve based on Eqs. (20) and (21). If the economy is on the balanced growth path, physical capital per effective unit of labor, human capital per effective unit of labor, and output per effective unit of labor (k, h, and y) are constant. Total physical capital, human capital and output (K, H, and Y) grow at a rate n +g. And physical capital per unit of labor, human capital per unit of labor, and output per unit of labor (K/L, H/L, and Y/L) grow at a rate g. Therefore, as in the basic Solow model, the long-run growth rate per worker is exogenously determined by technological progress.

To understand the behavior of y on the balanced growth path, y^*, let k^* and h^* show the values of k and h on the balanced growth path. Since at the steady state position $\dot{k} = \dot{h} = 0$, Eqs. (20) and (21) imply

$$s_K k^{*\alpha} h^{*\beta} = (n + g + \delta)k^*, \tag{22}$$

$$s_H k^{*\alpha} h^{*\beta} = (n + g + \delta)h^*. \tag{23}$$

If we take the logs of these two equations, we get

$$\ln s_K + \alpha \ln k^* + \beta \ln h^* = \ln(n + g + \delta) + \ln k^*, \tag{24}$$

$$\ln s_H + \alpha \ln k^* + \beta \ln h^* = \ln(n + g + \delta) + \ln h^*. \tag{25}$$

We can then solve these equations for $\ln k^*$ and $\ln h^*$. This implies

$$\begin{aligned} \ln k^* = {} & \frac{(1-\beta)}{(1-\alpha-\beta)} \ln s_K + \frac{\beta}{(1-\alpha-\beta)} \ln s_H \\ & - \frac{1}{(1-\alpha-\beta)} \ln(n + g + \delta) \end{aligned}, \tag{26}$$

$$\begin{aligned} \ln h^* = {} & \frac{\alpha}{(1-\alpha-\beta)} \ln s_K + \frac{(1-\alpha)}{(1-\alpha-\beta)} \ln s_H \\ & - \frac{1}{(1-\alpha-\beta)} \ln(n + g + \delta) \end{aligned}. \tag{27}$$

Finally, Eq. (18) implies that $\ln y^* = \alpha \ln k^* + \beta \ln h^*$. Substituting Eqs. (26) and (27) into this expression and rearranging terms obtains an equation for income per effective worker similar to Eq. (10) above:

$$\begin{aligned} \ln y^* = {} & \frac{\alpha}{(1-\alpha-\beta)} \ln s_K + \frac{\beta}{(1-\alpha-\beta)} \ln s_H \\ & - \frac{(\alpha+\beta)}{(1-\alpha-\beta)} \ln(n + g + \delta) \end{aligned}. \tag{28}$$

This equation implies that income levels are a positive function of physical and human capital accumulation and a negative function of population growth. Mankiw, Romer, and Weil (1992) used both this equation and Eq. (11) to examine the vast international differences in per capita incomes and then compared the explanatory power of these two models. They concluded that inclusion of human capital into the basic Solow model raised the performance of the model substantially. In other words, differences in population growth and the broad measure of capital accumulation (human and physical capital together) have actually accounted for large income differences across countries. Even with human capital accumulation, the Solow model predicts that per capita income growth eventually must cease if there are no technological improvements because in the steady state, k, h, and y are constant. However, this contradicts the fact that positive growth rates can actually persist over a century or more and that these rates have no tendency to decline. Thus, the Solow growth model explains these positive growth rates with exogenous technological improvements. All of the analysis so far is based on the assumption of diminishing returns to capital (either $\alpha < 1$ or $\alpha + \beta < 1$), which is the very same assumption that leads to (conditional) convergence across countries.

2.3 Conditional Convergence and Endogenous Growth Models

We, then, turn our attention to the issue of conditional convergence. The Solow model predicts that countries converge to their steady-state positions that may differ from country to country because of the different levels of s_K, s_H, and n in each country. Thus, the model only predicts conditional convergence once we control for other determinants of growth. Further, the Solow model has quantitative implications with regard to the speed of convergence. In particular, it is possible to show that around the balanced growth path, y approaches y^* according to

$$\frac{d \ln y(t)}{dt} = \lambda\left[\ln y^* - \ln y(t)\right], \tag{29}$$

where $\lambda = (1 - \alpha - \beta)(n + g + \delta)$. Eq. (29) implies that ln y converges to ln y^* exponentially

$$\ln y(t) - \ln y^* = e^{-\lambda t}\left[\ln y(0) - \ln y^*\right], \tag{30}$$

where ln y(0) denotes the value of y at some initial time. Rearranging terms and adding the ln y(0) to both sides of the Eq. (30) yields a following growth equation

$$\ln y(t) - \ln y(0) = (1 - e^{-\lambda t}) \ln y^* - (1 - e^{-\lambda t}) \ln y(0)\,. \tag{31}$$

It is important to note that this equation shows that countries with relatively lower initial income levels compared to their steady-state levels will have higher growth rates. At last, substituting Eq. (28) for ln y^* obtains

$$\ln y(t) - \ln y(0) = (1 - e^{-\lambda t})\frac{\alpha}{(1-\alpha-\beta)}\ln s_K$$
$$+ (1 - e^{-\lambda t})\frac{\beta}{(1-\alpha-\beta)}\ln s_H \tag{32}$$
$$- (1 - e^{-\lambda t})\frac{(\alpha+\beta)}{(1-\alpha-\beta)}\ln(n+g+\delta) - (1 - e^{-\lambda t})\ln y(0).$$

Thus, this equation indicates that the growth of income is a function of initial levels of income and the determinants of the steady-state. As in Mankiw et al. (1992), we actually estimate this equation. While our results provide little evidence for absolute convergence, our results strongly supported the notion of conditional convergence in per capita income growth after controlling for the other determinants of long-run growth.

Since the late 1980s, a number of economists (e.g., Romer, 1986, 1987, and 1990; Grossman and Helpman, 1990; Lucas, 1988; and Young, 1991) have turned their attention to endogenous growth models. This is probably because neoclassical growth models are unable to explain the large international differences in growth rates by other than exogenous technological shocks. The main difference of endogenous growth models is that these models have assumed non-decreasing returns to physical and human capital accumulation together. This has several sources, such as R&D activities, externalities, and learning by doing that are discussed in the growth literature as the cause of constant or increasing returns to capital. For instance, the model in previous sections assumes that $\alpha + \beta < 1$. Changing this assumption such that $\alpha + \beta \geq 1$ has surprisingly important implications for the analysis of the model. Our model then would become an endogenous growth model that predicts ever-increasing growth rates. Thus, in these models permanent increases in saving rates not only cause large differences in income levels but also lead to permanent differences in growth rates.

The implications of endogenous growth models are substantially different from those of the Solow model with regard to convergence among countries. Due to the assumption of non-decreasing returns to capital, there is actually no steady-state level of income. This implies that even if countries have similar initial conditions, the differences across income levels can persist indefinitely. The natural implication of this is therefore (absolute) divergence across nations even if their initial conditions are similar. However, this contradicts the well-established empirical finding that conditional convergence occurs. Thus, to solve this problem "leader-follower models" were introduced.[2] These models combine features of endogenous growth models with the convergence implications of the neoclassical growth model. In the long run, the world's growth rate is driven by discoveries in the technologically leading economies. Follower countries, technologically non-innovative countries, are likely to catch up to leaders, innovative countries, since imitation and implementation of these new technologies are cheaper than innovation itself. As the pool of uncopied ideas or products diminishes, the cost of imitation tends to increase, and the followers` growth rates tend accordingly to decrease. Thus, even without diminishing returns to capital or to R&D, this mechanism can generate conditional convergence. However, it is important to note that while the evidence of convergence has been considered as the support for the neoclassical models, absence of convergence has often been regarded as supportive of endogenous growth theories.

3. MODEL AND DATA

We use the following empirical framework to investigate the issue of convergence in a cross-section of countries. In general form, this model can be characterized as

$$\gamma_{yt} = F\left(y_{t-1}, k_{t-1}, h_{t-1}; Z_{(t)}\right), \tag{33}$$

where γ_{yt} is a country's per capita growth rate in period t, y_{t-1} is initial GDP per capita, k_{t-1} is the initial physical capital stock per person, h_{t-1} is initial human capital stock per person. We use telephone mainlines per worker and life expectancy rates as rough proxies for the stock of physical and human capital, respectively. It is also possible to interpret an initial GDP level as a proxy for the stock of capital for a country. The variable Z represents a vector of control and environmental variables that are primarily determined by decisions of governments or individuals. These variables include two measures of trade and capital flows, black market premium, type of regime, average schooling years in the total population over age 25, the rule of law measure, inflation rates, government consumption, budget surpluses, and regional dummies. This paper also uses two geographical factors; a variable measures whether a country is in a tropical climate and a variable that measures whether a country has access to international waterways.

There are two major sources for real per capita GDP growth rates and levels. The first source is national accounts data, which are based on domestic prices, collected by multinational institutions such as the World Bank (WB) and the IMF. The other source is the Penn World Tables (PWT), widely known as the

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[2] For a complete discussion on these models, see Chapter 8 of Barro and Sala-i-Martin (1995a), and Barro and Sala-i-Martin (1995b).

Summers-Heston (SH) data.[3] The main purpose of the SH data is to produce comparable GDP level estimates using international prices since the differences in exchange rates are not good measures of differences in purchasing power parities. As one might expect, real per capita growth rates calculated from these two sources are considerably different. As discussed in Summers and Heston (1991) and Nuxoll (1994), substantial changes in relative prices over time within the countries are largely responsible for these significant differences between the growth rates from national accounts and the growth rates from the SH data.

Almost all of the empirical growth studies have used the growth rates from the SH data.[4] Nuxoll investigated whether the SH data have been distorted due to data construction techniques. Distortion may occur because changes in relative prices, caused by different rates of technological progress in different sectors within the countries, exert two distinct effects on measured growth rates. First, the "Gerschenkron effect" that is the selection of base prices affects growth rates. The second effect is the spurious-correlation effect that any income index using fixed prices underestimates the growth rates of less developed countries and introduces a spurious correlation between income levels and growth rates.

The Penn World Tables, which are based on the International Comparison Project (ICP), have used international prices. These prices do not depend upon any particular country's relative prices but rather depend on the world structure of relative prices. However, as Nuxoll argued, the Gerschenkron effect suggests that if those prices are similar to the prices of "some moderately prosperous country", then the data using those prices are likely to produce quite misleading numbers.

While Nuxoll did not challenge the argument that the Summers and Heston (1991) method is more reliable than using exchange rates to adjust for differences in purchasing power parities, he claimed that the Gerschenkron effect is quite obvious in the ICP. On the one hand, he (p. 1431) concluded that

> (t)hus, there is some evidence that the relative prices used by the International Comparison Project resemble the prices of Hungary and Yugoslavia. The Gerschenkron proposition implies that the Penn World Tables would overstate the growth rates for countries richer than Hungary and understate the growth rates for less developed countries.

On the other hand, he (p. 1434) concluded that "(c)urrent versions of the Penn World Table do not systematically distort the data, because of the very high level of aggregation." Note that the ICP has price series on about 150 different categories of goods, but the PWT uses only four categories: consumption, investment, government spending, and net exports.

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[3] For a more detailed discussion of the PWT and SH data, see Summers and Heston (1991).

[4] Although they heavily depended on the SH data, Levine and Renelt (1992), King and Levine (1993), and Barro and Sala-i-Martin (1995a) have also used the growth rates from the World Bank database for some cases.

Based on this evidence, Nuxoll suggested that using national accounts for measuring growth rates is more reliable since economic agents actually act according to domestic prices when they face trade-offs. Further, he concluded that growth researchers should use the SH data for income levels because international prices are more reliable to adjust GDP estimates for differences in price levels.

Because of the reasons discussed above, real per capita GDP growth rates (GRWB) used in the next section come from the World Development Indicators 1999 CDROM (WDI 1999). Time series data are available from 1970 through 1997. Another reason why this paper uses the GRWB is that the SH data have not been compiled for years after 1992. Yet, real per capita GDP levels (GDPSH) come from the SH data. The coefficient of the initial GDP level variable is an estimate of the speed of convergence across countries, and the sign of this coefficient is expected to be negative. Although the data construction techniques in the ICP tend to distort the data, Nuxoll argued that growth rates from SH data are not distorted systematically due to the high level of aggregation. However, our results show that convergence coefficients from GRSH differ systematically from convergence coefficients obtained by using national-accounts data.

Many empirical studies of growth suffer from the fact that the researchers include only a subset of related variables. Thus, it is crucial to include a reasonably comprehensive set of independent variables to estimate the underlying relationships. Based on our reading of the literature, we include the following exogenous variables. Data for telephone mainlines (TELPE) and political regime type (REGIME), used to measure the level of democracy in a country, come from Easterly and Lu[5]. Life expectancy figures (LIFE) are taken from WDI 1999. Data for black market premium are taken from the Pick's Currency Yearbook. Data on tropical climate (TROPIC) and physical access to international waters (WATER) are taken from the Sachs and Warner (1995).[6]

We use two measures of trade and capital flows as percentages of GDP. First, the most basic measure of trade flows is the ratio of exports plus imports to GDP (TRADE). Second, foreign direct investment (FDI) is net and includes flows of investment to acquire a lasting management interest (10 percent or more of voting stock) in an enterprise operating in an economy other than that of the investor. It is the sum of equity capital, reinvestment of earnings, other long-term capital, and short-term capital as shown in the balance of payments. Data on these variables are taken from the WDI (1999). To measure the human capital stock in countries, we use the measure of average schooling years in the total population

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[5] They maintain a database called "Global Development Network Growth Database" on the World Bank Web site. (http://www.worldbank.org/research/growth/)

[6] They published their data on the Center for International Development Web site. (http://www.cid.harvard.edu/ciddata/ciddata.html).

over age 25 (SCH). Data are taken from Easterly (1999). The Rule of Law Index (LAW) measures the quality of the bureaucracy, political corruption, the likelihood of government repudiation of contracts, the risk of government expropriation, and the overall maintenance of the rule of law. Data on LAW come from Knack and Keefer (1995).

This paper also employs three measures of macroeconomic variables. First, the overall budget surplus (percentage of GDP) (SURPLUS) is current and capital revenue and official grants received less total expenditure, lending and repayments. The data for this variable are taken from Easterly and Yu. Second, inflation rates (GCPI) are computed annually, in most cases from consumer price indexes (due to data availability, in a few cases the GDP deflator is used to compute annual inflation rates). Third, government consumption (GCON) consists of all current expenditures on purchases of goods and services (including wages and salaries) by all levels of government. Both of these measures are from the WDI (1999). Finally, dummies for Sub-Saharan African countries (AFRICA), East Asian countries (EASIA), and Latin America and Caribbean countries (LATIN) are also used to control the effects of location on a country's growth performance in the cross country regressions.

The cross-country growth regressions apply to a panel of over one hundred developed and developing countries observed from 1970 to 1997. Socialist countries (or formerly socialist) are excluded from the sample as well as the oil exporting countries. The number of countries is actually limited by the availability of data. The system is a three-equation system. The dependent variables are the average growth rates of real per capita GDP over three periods: 1970-1979, 1980-1989, and 1990-1997. The system of equations is estimated by using the seemingly unrelated regression method (SUR) as in Barro (1997).[7]

3. EMPIRICAL RESULTS

One of the most thoroughly studied properties of neoclassical growth theory is the convergence property: poor economies tend to grow faster than rich economies. On the one hand, it is extremely difficult to support absolute convergence among world nations on empirical grounds. On the contrary, there is compelling evidence presented in this study and elsewhere that shows that there has been absolute divergence among world nations. For example, Figure 1 clearly depicts the strong and positive relationship between growth rates and initial GDP levels, which contradicts the absolute convergence predictions of neoclassical

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[7] For a complete discussion on the seemingly unrelated regression technique, see Chapter 15 of Greene (1997).

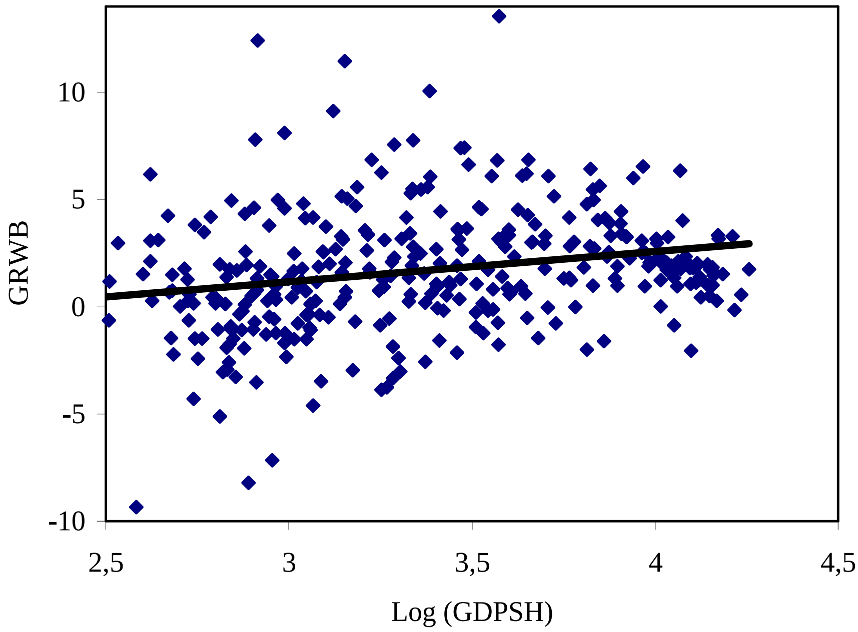

Figure 1: Simple Correlation between Growth and Initial Per Capita GDP Levels

growth theory. Furthermore, if we regress decade averages of growth rates from the World Bank on log of GDPSH in 1970, 1980, and 1990, the coefficient of the log of GDPSH for 114 countries in Table 1 is 1.28 with a t-ratio of 3.41.[8] As can be seen from Table 1, estimating the same regression using the growth rates from Summers and Heston (GRSH) yields identical results. The significant and positive coefficient suggests that countries with higher GDP per capita grow faster than countries with lower GDP per capita. These results and Figure 1 imply that if anything, there is evidence of absolute divergence among world countries. We then estimate the same regressions for developing and developed countries.

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[8] Our country list includes 85 developing and 29 developed countries based on the World Bank classification.

Table 1 Per Capita GDP Growth Rates and Initial Per Capita GDP Levels.

	PANEL I: GRWB		PANEL II: GRSH	
Variable	Log (GDPSH)	R^2, for each eq., (# of obs)	Log (GDPSH)	R^2, for each eq., (# of obs)
All Countries	1.28 (3.41)	.3, .9 .9, (114)	1.42 (3.98)	.10, .10 .04, (114)
Developing Countries	1.48 (2.50)	.4, .01 .10, (85)	0.96 (1.71)	.02, .01 .08, (85)
Low-income Developing C.	0.26 (0.21)	.01, .01 .01, (41)	-0.77 (0.58)	.02, -.01 -.04, (41)
Middle-income Developing C.	-5.03 (2.87)	.05, .22 .02, (27)	-4.55 (2.97)	.02, .27 .01, (27)
High-income Developing C.	-8.02 (3.74)	.42, .31 -.20, (17)	-7.33 (4.25)	.49, .25 -.16, (17)
Developed Countries	-6.50 (5.25)	.49, .38 .17, (29)	-5.30 (4.22)	.10, .37 .16, (29)

Our regressions for developing countries also support the notion of absolute divergence across developing countries. However, further disaggregating the data fundamentally changes the discussion. Although the regression results for low-income developing countries imply neither convergence nor divergence across these countries, our results for the other three groups of countries clearly show 5 to 8 percent annual rate of absolute convergence among each group of countries. Thus, the data actually have shown the existence of "convergence clubs" among world nations. Note that, however, somewhat arbitrary nature of the classification of countries precludes us further contemplating on these results.

On the other hand, a large body of empirical evidence strongly supports the conditional convergence for economies that are similar, except for initial conditions. However, for the large samples of countries, the empirical evidence is highly controversial on the speed of convergence. Although many of the earlier cross-sectional studies reported a 2 percent convergence rate among the worlds' nations, panel data and time series studies suggested that the problems that are common to cross section estimation are the likely causes of low estimated convergence rates. Therefore, recent studies reported a wide range of convergence rates that have varied between zero and 30 percent annually (see, Islam 1995; and Temple 1999).

After controlling for the initial conditions of countries using a number of growth determinants, the negative coefficient on the log of GDPSH indicates conditional convergence. The size of the coefficient also shows the rate of convergence at which countries have been approaching their long-run steady state positions. Empirical results presented in this paper reveal 0 to 7 percent rate of convergence depending on the size of the sample, inclusion of independent variables, and data set used. Even though it has varied within these limits, for all cases it is statistically significant and implies conditional convergence occurring at different levels for different samples of countries. The only exception is reported in column 8 of Table 3, the convergence coefficient, -0.65 (0.66), is still negative but insignificant for 57 developing countries. The significantly negative estimated convergence coefficient in column 1 of Table 2 is -3.82. This implies a 3.8 percent convergence rate per year for 114 countries after controlling for a number of exogenous variables. Furthermore, inclusion of trade shares (TRADE) in the regressions raises the convergence coefficient to 4.3 percent in column 2 of Table 2. Inclusion of FDI also increases the rate of convergence compared to column 1.

Moreover, to test whether relatively open countries, based TRADE and FDI, converge faster than closed economies do, we use interaction terms between GDPSH and these two measures. Both interaction terms have the expected signs but none is statistically significant. Thus, our results not only fail to support the Sachs and Warner view that open economies having higher trade flows converge faster but also provide no evidence for the hypothesis that openness in the form of

Table 2: Regressions for Per Capita GDP Growth Rates for All Countries: Panel of Three Decades (1970 - 1997)

Variable	1	2	3	4	5	6	7	8
log(GDPSH)	-3.82	-4.27	-3.88	-4.12	-4.68	-3.85	-3.83	-3.17
	(5.40)	(6.17)	(5.85)	(4.34)	(6.02)	(5.43)	(5.27)	(4.01)
log(LIFE)	16.99	15.98	16.89	25.50	17.05	18.25	17.05	14.54
	(4.64)	(4.53)	(4.95)	(5.81)	(4.09)	(4.91)	(4.63)	(3.57)
TELPE	0.008	0.009	0.005	0.007	0.007	0.007	0.008	0.006
	(2.19)	(2.48)	(1.65)	(1.84)	(1.77)	(2.13)	(2.17)	(1.64)
TROPIC	-1.41	-1.52	-1.56	-1.73	-1.55	-1.31	-1.41	-0.89
	(2.63)	(2.94)	(3.08)	(3.05)	(2.59)	(2.44)	(2.63)	(1.53)
WATER	-0.46	-0.64	-0.50	-0.49	-0.52	-0.32	-0.46	-0.31
	(1.12)	(1.61)	(1.27)	(1.10)	(1.04)	(0.77)	(1.12)	(0.64)
BLACK	-2.62	-2.33	-2.21	-2.14	-2.52	-2.78	-2.63	-2.45
	(4.90)	(4.39)	(4.04)	(4.11)	4.40)	(4.53)	(4.84)	(3.89)
REGIME	-0.54	-0.49	-0.46	-0.60	-0.83	-0.49	-0.54	-0.55
	(1.90)	(1.77)	(1.71)	(2.06)	(2.67)	(1.73)	(1.89)	(1.77)
TRADE		0.016						
		(4.07)						
FDI			0.55					
			(5.55)					
SCH				-0.14				
				(1.36)				
LAW					1.30			
					(1.94)			
GCPI						-0.00007		
						(0.11)		
GCON							0.002	
							(0.08)	
SURPLUS								0.077
								(3.37)
AFRICA	-0.42	-0.69	-0.46	0.31	-0.58	-0.50	-0.42	-0.90
	(0.68)	(1.16)	(0.82)	(0.50)	(0.82)	(0.81)	(0.68)	(1.34)
LATIN	-0.83	-0.67	-1.10	-0.75	-0.69	-0.84	-0.81	-1.02
	(1.54)	(1.28)	(2.21)	(1.39)	(1.26)	(1.54)	(1.48)	(1.68)
EASIA	1.59	1.39	0.96	1.54	1.57	1.59	1.59	0.66
	(2.91)	(2.65)	(1.84)	(0.57)	(2.88)	(2.94)	(2.89)	(1.08)
R^2, for each	.29, .49	.37, .50	.39, .55	.33, .55	.27, .62	.29, .50	.29, .49	.25, .45
eq., (# of obs	.25,(104)	.29,(104)	.28,(100)	.16,(84)	.20,(84)	.27,(102)	.25,(104)	.26,(82)

Notes: The system has 3 equations, where the dependent variables are the per capita growth rates over each decade. Each equation has a different constant term (not reported here). Other coefficients are restricted to be the same for all periods.

capital mobility can raise the rate of convergence between rich and poor economies. For example, Barro et al. (1995) argued that it is hard to explain all of the empirical findings on convergence by using standard theories of economic growth. For this purpose they provided a model of economic growth with the assumption of partial capital mobility and showed that their version of the open-economy growth model was able to explain the empirical regularities on convergence. Recently Diehl and Gundlach (1999) using the very same model of Barro et al. concluded that openness in the form of capital mobility could have a much larger impact on growth rates depending on three variables, namely the real interest rate, the gap between steady-state and initial income, and the difference between the convergence rates for open and closed economies. The main reason for their result is that open economies will reach their steady-state which is the same for both open and closed economies, faster than closed economies and hence experience higher growth rates. Wang (1990) also showed that since international capital flows (especially the inflow of FDI with advanced technology) promote capital accumulation in developing countries and increase GDP through increasing human capital accumulation, a developing country that starts with an initially low level of capital stock and technology can catch up to the developed countries.

Furthermore, in columns 4-8 of Table 2, we also include a number of other variables to control the initial conditions of countries. Inclusion of all of these variables raises the rate of convergence for all countries except that SURPLUS slightly reduces the convergence rate. For given values of these explanatory variables, our results report negative coefficients on initial GDP for all cases. Thus, the economies tend to approach their long-run steady state positions at the rate of around 4% per year. It is worthwhile to note that the rate of convergence is considerably higher than 2% convergence rate reported in Barro (1991), Barro and Sala-i-Martin (1995a), Barro (1997), and Mankiw et al. (1992).

Figure 2 depicts the relationship between growth rates and initial GDP levels, for given values of the other explanatory variables, as implied by column 2 of Table 2. The horizontal axis shows the log of GDPSH levels in each decade for the countries in regression 2. The vertical axis indicates the corresponding growth rates after removing the parts explained by all independent variables other than initial GDP levels.[9] Thus, the negative slope implies conditional convergence, which is the impact of the log GDPSH on growth after controlling for the other explanatory variables. Contrary to Figure 1 that depicts an absolute divergence, Figure 2 clearly shows conditional convergence and also that this relationship is not determined by a few outliers. The graph also suggests a linear relationship between growth rates and the log of GDPSH.

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[9] Using the same specification as in column 2 of Table 2 without the initial GDP levels, we calculate the residuals and plot them as the log of (GDPSH).

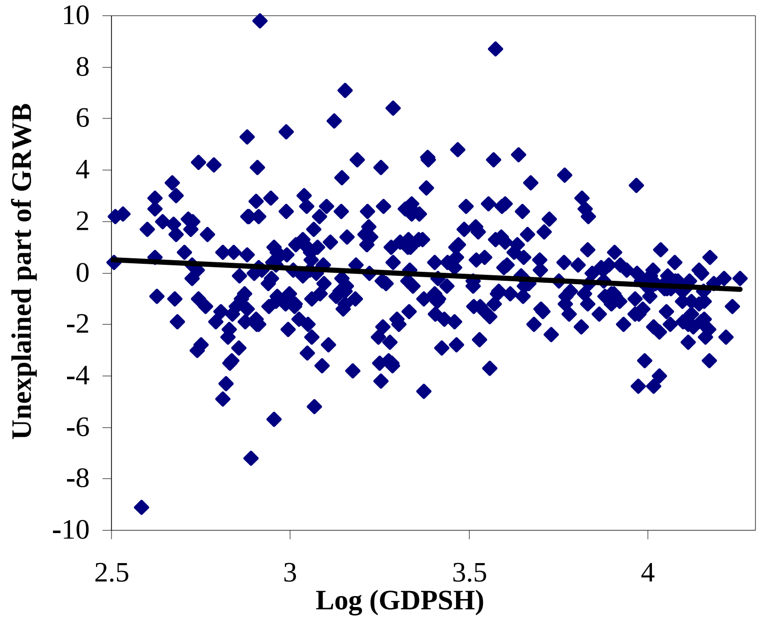

Figure 2: Unexplained Part of Growth and Initial Per Capita GDP Levels

We then separately estimate the regressions in Table 2 for developing and developed countries and report the estimation results in Tables 3 and 4, respectively. Sequential inclusion of the variables also produces same kind of patterns for developing countries. However, for developed countries inclusion of only the schooling and rule of law variables raises the rate of convergence compared to the column 1 of Table 4. These results are consistent with the results presented in Table 1 because there already exist the absolute convergence among developed countries. Thus, there is no need to control the initial conditions of these countries. It is important to note that as can be seen from Tables 2-4, the rates of convergence for all countries are consistently higher than those for developing countries and lower than those for developed countries. For example, the results in column 4 of Table 4 show a considerably higher rate of convergence, 7.1 percent for developed countries. As expected, the convergence rate tends to be high among the relatively more developed countries. These results show that the size of the convergence coefficient is very sensitive to the countries development levels that are included in the regressions.

Finally, to test whether our estimation results are sensitive to the using different data sets, we also estimate the regressions in Tables 2-4 with growth rates from Summers and Heston (GRSH) instead of the World Bank (GRWB). We report the estimation results in Table 5 and the equation numbers in this table refer to the regression numbers in Tables 2-4. As can be seen from Table 5, if we use GRSH instead of GRWB, the estimated convergence coefficients are systematically different from those obtained by using GRWB.[10] On the one hand,

Table 3 Regressions for Per Capita GDP Growth Rates for Developing Countries: Panel of Three Decades (1970 - 1997)

Variable	1	2	3	4	5	6	7	8
log(GDPSH)	-2.13	-2.82	-2.52	-2.40	-2.50	-2.01	-2.24	-0.65
	(2.49)	(3.18)	(3.12)	(2.03)	(2.37)	(2.39)	(2.58)	(0.66)
log(LIFE)	17.28	16.19	18.01	26.88	16.62	18.83	17.65	16.47
	(4.43)	(4.16)	(4.87)	(5.14)	(3.58)	(3.92)	(4.54)	(3.72)
TELPE	0.009	0.011	0.006	0.011	0.006	0.008	0.008	0.008
	(1.29)	(1.58)	(0.73)	(1.54)	(0.87)	(1.24)	(1.27)	(0.87)
TROPIC	-1.36	-1.47	-1.35	-1.60	-1.34	-1.24	-1.36	-0.52
	(2.36)	(2.56)	(2.47)	(2.48)	(1.94)	(2.18)	(2.38)	(0.82)
WATER	-0.31	-0.41	-0.32	-0.21	-0.29	-0.12	-0.31	0.38
	(0.70)	(0.90)	(0.72)	(0.41)	(0.47)	(0.27)	(0.69)	(0.66)
BLACK	-2.46	-2.23	-2.19	-1.83	-2.21	-2.60	-2.52	-1.97
	(4.14)	(3.72)	(3.62)	(2.11)	(3.29)	(3.85)	(4.20)	(2.75)
REGIME	-0.47	-0.36	-0.24	-0.68	-0.74	-0.40	-0.44	-0.42
	(1.33)	(1.02)	(0.69)	(1.78)	(1.68)	(0.35)	(1.24)	(1.07)
TRADE		0.014						
		(2.51)						
FDI			0.52					
			(4.35)					
SCH				-0.26				
				(1.63)				
LAW					1.47			
					(1.31)			
GCPI						-0.0001		
						(0.16)		
GCON							0.024	
							(0.82)	
SURPLUS								0.08
								(3.01)
AFRICA	-0.16	-0.44	-0.38	0.38	-0.49	-0.24	-0.19	-0.90
	(0.25)	(0.68)	(0.62)	(0.54)	(0.60)	(0.38)	(0.30)	(1.25)
LATIN	-1.24	-1.03	21186	-1.23	-1.21	-1.33	-1.18	-1.96
	(1.95)	(1.61)	(2.62)	(1.78)	(1.64)	(2.10)	(1.85)	(2.69)
EASIA	1.81	1.67	1.01	1.61	1.62	1.76	1.78	0.58
	(2.30)	(2.13)	(1.32)	(1.81)	(1.84)	(2.29)	(2.28)	(0.65)
R^2, for each	.32, .43	.38, .41	.40, .48	.34, .53	.28, .57	.34, .45	.34, .42	.28, .38
eq., (# of obs)	.31,(77)	.32,(77)	.32,(74)	.29,(59)	.30,(57)	.33,(75)	.30,(77)	.37,(57)

Note: See Table 2.

10 The simple correlation coefficient between decade averages of GRWB and GRSH is, 0.72, positive and statistically significant.

Table 4 Regressions for Per Capita GDP Growth Rates for Developed Countries: Panel of Three Decades (1970 - 1997)

Variable	1	2	3	4	5	6	7	8
log(GDPSH)	-5.55	-4.85	-4.18	-7.14	-6.64	-5.51	-4.66	-5.50
	(3.30)	(3.61)	(2.62)	(3.15)	(3.74)	(3.26)	(2.68)	(3.77)
log(LIFE)	-33.61	-33.08	-37.45	-19.80	-29.77	-32.78	-32.36	-27.63
	(1.94)	(2.44)	(2.29)	(0.81)	(1.71)	(1.88)	(1.87)	(1.81)
TELPE	0.005	00007	0.007	-0.001	0.007	0.005	0.005	0.005
	(1.26)	(2.02)	(1.70)	(0.19)	(1.84)	(1.29)	(1.30)	(1.44)
TROPIC	-1.91	-3.71	-8.58	-5.44	-1.29	-2.17	-2.35	-3.70
	(0.19)	(0.51)	(0.89)	(0.56)	(0.13)	(0.22)	(0.24)	(0.47)
WATER	-0.27	-1002	-0.80	-0.36	-0.46	-0.34	-0.46	-0.50
	(0.65)	(1.97)	(1.14)	(0.50)	(0.70)	(0.52)	(0.71)	(0.93)
BLACK	-31.92	32.87	-29.64	-33.22	-30.67	-28.97	-26.06	-19.74
	(2.69)	(3.07)	(2.86)	(2.19)	(2.70)	(2.37)	(2.08)	(1.70)
REGIME	-0.70	-0.88	-1.01	-0.68	-0.80	-0.34	-0.67	-0.55
	(2.05)	(3.37)	(3.10)	(1.86)	(2.41)	(0.52)	(2.00)	(2.02)
TRADE		0.014						
		(4.84)						
FDI			0.68					
			(3.81)					
SCH				0.11				
				(0.91)				
LAW					1.76			
					(1.99)			
GCPI						-0.007		
						(1.05)		
GCON							-0.05	
							(1.60)	
SURPLUS								0.13
								(3.26)
R^2, for each	.37, .63	.43, .80	.53, .71	.38, .43	.42, .64	.38, .63	.34, .66	.29, .77
eq., (# of obs)	.37,(27)	.58,(27)	.37,(26)	.28,(25)	.29,(27)	.37,(27)	.42,(27)	.59,(25)

Note: See Table 2.

for all and developing countries the rates of convergence obtained from GRSH are consistently higher than those obtained from GRWB. On the other hand, convergence rates for developed countries are consistently higher from those obtained from GRWB. As discussed in section 3, Nuxoll (1994) argued that the Penn World Tables are likely to overstate the growth rates for developed countries and to understate the growth rates for developing countries. Therefore, our results show that GRSH give different estimates of the convergence rate depending on the development level of countries. Thus, understating (overstating) the growth rates of developing (developed) countries produce higher (lower) convergence rates compared to the GRWB. It is worthwhile to note that estimation results from GRSH do not in anyway change our conclusions about the existence of the convergence (absolute or conditional) across world nations.

4. CONCLUSIONS

On the one hand, our estimation results show the existence of over 1 percent annual rate of absolute divergence for 114 countries. These results therefore contradict the prediction of the neoclassical growth model that poor economies tend to grow faster than rich economies. However, our results also imply that there are so called "convergence clubs" in a way that the data for group of countries similar in terms of income levels tend to show the absolute convergence. On the other hand, even if the absolute divergence exists for world nations, our results depending on both the World Bank data and the Summers and Heston data provide substantial evidence in favor of conditional convergence after controlling for initial conditions of countries. The estimated coefficients on the log of initial GDP levels imply that economies approach to their steady-state positions at the rate of around 4 percent per year for a large sample of countries. Note that our results also indicate that Summers and Heston data consistently tend to create higher (lower) convergence rates for developing (developed) countries than the World Bank data.

Table 5 GRSH Estimates: Panel of Three Decades (1970 - 1997)

Eq. No.	Log (GDPSH)	R^2, for each eq., (# of obs)	Eq. No.	Log (GDPSH)	R^2, for each eq., (# of obs)
2.1	-4.06	.32, .57	3.5	-3.02	.26, .63
	(6.89)	.24, (104)		(3.51)	.29, (57)
2.2	-4.35	.38, .56	3.6	-2.82	.32, .49
	(7.50)	.29, (104)		(3.95)	.32, (75)
2.3	-4.15	.36, .56	3.7	-2.98	.32, .48
	(7.32)	.29, (100)		(3.98)	.30, (77)
2.4	-4.53	.35, .60	3.8	-2.33	.32, .46
	(5.68)	.13, (84)		(2.77)	.33, (57)
2.5	-4.49	.29, .70	4.1	-4.79	.73, .51
	(7.16)	.20, (84)		(3.73)	.40, (27)
2.6	-4.01	.30, .58	4.2	-3.91	.73, .66
	(6.82)	.26, (102)		(3.65)	.59, (27)
2.7	-3.94	.31, .58	4.3	-4.35	.70, .56
	(6.50)	.24, (104)		(3.16)	.46, (26)
2.8	-4.06	.31, .56	4.4	-6.22	.61, .29
	(6.39)	.24, (82)		(3.94)	.31, (25)
3.1	-3.01	.32, .48	4.5	-5.44	.73, .56
	(4.13)	.29, (77)		(4.04)	.34, (27)
3.2	-3.46	.37, .45	4.6	-4.88	.71, .52
	(4.55)	.31, (77)		(3.77)	.40, (27)
3.3	-3.31	.38, .45	4.7	-3.95	.71, .56
	(4.76)	.33, (74)		(2.91)	.44, (27)
3.4	-3.70	.36, .55	4.8	-4.74	.69, .74
	(3.62)	.26, (59)		(4.40)	.57, (25)

Note: See Table 2.

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