The B.E. Journal of Macroeconomics

Topics

Volume 7, *Issue* 1 2007 *Article* 4

Economic Growth: A Channel Decomposition Exercise

Wei-Kang Wong*

*National University of Singapore, ecswong@nus.edu.sg

Recommended Citation
Wei-Kang Wong (2007) "Economic Growth: A Channel Decomposition Exercise," *The B.E. Journal of Macroeconomics*: Vol. 7: Iss. 1 (Topics), Article 4.
Available at: http://www.bepress.com/bejm/vol7/iss1/art4

Economic Growth: A Channel Decomposition Exercise*

Wei-Kang Wong

Abstract

This paper empirically decomposes the channels through which the determinants of growth operate. Methodologically, channel decomposition combines growth accounting with regression analysis. Under channel decomposition, the determinants could affect aggregate productivity growth through physical capital accumulation, through human capital acquisition, or through growth in total factor productivity (TFP). The results from channel decomposition show that TFP growth is the main channel of operation for most of the determinants. Specifically, TFP growth, not factor accumulation, is what accounts for conditional convergence. This finding is extremely robust. There is also no evidence that rich and poor countries converge through different channels.

KEYWORDS: channel decomposition, channel accounting, channels of growth, conditional convergence, TFP growth

---

*Email: ecswong@nus.edu.sg. I especially thank George Akerlof and David Romer for numerous comments and discussions, the editor (Chad Jones) and two anonymous referees for their thoughtful comments. I also thank J. Brad De Long, Richard Lyons, Barry Eichengreen, James Powell, Maurice Obstfeld, Chris Meissner, Julian di Giovanni, and participants at the Macroeconomics Seminar at UCB for very helpful feedback. I gratefully acknowledge the financial support of research grant FASS-SRSS 2004-2006. A blame accounting exercise confirms that I alone contributed to any remaining errors.

1 Introduction

This paper empirically decomposes the channels through which the determinants of economic growth operate, with a special emphasis on the channels through which conditional convergence is achieved; the determinants, such as initial human capital and maintenance of the rule of law, can affect growth through three channels: physical capital accumulation, human capital acquisition, or growth in total factor productivity. For example, a better educated labor force can lead to advances in income per worker either by attracting investment in plants and factories, by encouraging further education, or by facilitating innovations and diffusion of technology. Methodologically, channel decomposition combines a growth accounting exercise with a growth regression – the two traditional approaches to the study of economic growth – by applying them sequentially: first, decompose economic growth into components due to factor accumulation and TFP growth; next, regress these components on the determinants of growth.

Combining Klenow and Rodriguez-Clare's (1997) growth accounting methodology with Barro's (1997) determinants of growth, channel decomposition reveals that it is TFP growth, not factor accumulation, that accounts for the widely documented phenomenon of conditional convergence. The TFP channel of convergence turns out to be extremely robust to omitted variables, to the alternative accounting methodology of Hall and Jones (1999), to alternative estimation techniques, to different sample periods, and to alternative measures of human capital. Thus, TFP growth not only determines cross-country income differences, but also drives conditional convergence in output per worker. Furthermore, the evidence suggests that TFP growth is the channel of convergence for both rich and poor countries. It is also the channel of convergence for the East Asian economies.

TFP growth also tends to be the most important channel for the other determinants, such as the maintenance of the rule of law and government spending. The only determinant for which TFP growth is not the dominant channel is the total fertility rate. Higher fertility tends to hurt growth through lower physical capital accumulation, not TFP growth or human capital accumulation. However, the effect is generally not statistically significant at the conventional levels.

The rest of the paper proceeds as follows. Section 2 reviews the regression and the accounting approaches to growth before discussing the methodology of channel decomposition and the related literature. Section 3 discusses the data and the empirical results. Section 4 presents the robustness checks. Section 5 concludes.

2 The Methodology of Channel Decomposition

Most convergence regressions are based on the notion of conditional convergence developed by Barro (1991) and Mankiw, Romer, and Weil (1992), where convergence is observed only after controlling for the determinants of the steady state, such as differences in government policies, political stability, and household preferences. Thus, observed income growth is a function of initial income and the determinants of steady state:

$$g(Y/L) = \alpha + \gamma ln y_{i,0} + \theta' X_i + \epsilon_i, i = 1, ..., n, \tag{1}$$

where $g(.)$ denotes growth rate, Y income, L labor, $y_{i,0}$ initial income per worker for country i, X_i a column vector of variables that control for the determinants of steady-state income per worker, and ϵ_i is the disturbance term. Let $\beta' = (\alpha, \gamma, \theta')$ be a row vector of parameters of conforming dimensions. An estimated value of $\gamma < 0$ would imply conditional convergence in output per worker.

On the other hand, growth accounting decomposes observed economic growth into the sum of contributions associated with factor accumulation and a residual, often referred to as the 'total factor productivity' (TFP). For example, given the production function in Mankiw et al. (1992), $Y = K^{\alpha} H^{\beta} (AL)^{1-\alpha-\beta}$, TFP growth can be calculated as a residual from the equation:

$$g(Y/L) \equiv \frac{\alpha}{1-\alpha-\beta} g(K/Y) + \frac{\beta}{1-\alpha-\beta} g(H/Y) + g(A), \tag{2}$$

where Y is output, L is labor, K is the physical capital stock, H is the human capital stock, and A is the productivity index. There are two points worth noting about this decomposition methodology, as pointed out by Klenow and Rodriguez-Clare (1997).[1] First, the decomposition is performed on output per worker rather than total output since differences in output per worker are the object of interest. Second, by decomposing the growth of output per worker into TFP growth and the growth of factor intensities such as K/Y and H/Y, the decomposition gives A "credit" for variations in K and H generated by differences in A. The variations in factor intensity X capture only those variations in K and H not induced by A.

More generally, let $GOUTPUT$, $GCAPITAL$, $GHUMAN$, and GA denote the growth rate of output per worker, the contribution to growth from physical capital accumulation, the contribution to growth from human capital accumu-

[1] Also see Hall and Jones (1999).

lation, and TFP growth respectively. Equation (2) can be rewritten as

$$GOUTPUT \equiv GCAPITAL + GHUMAN + GA. \tag{3}$$

Equations (1) and (3) explain the same object, i.e., observed economic growth $g(Y/L)$. Combining the right hand side of the two equations, one immediately sees that the determinants – initial income and other determinants of steady state ($lny_{i,0}$ and X_i) – must affect aggregate productivity growth ($GOUTPUT$) through three channels: physical capital accumulation, human capital acquisition, or TFP growth ($GCAPITAL$, $GHUMAN$ and GA). With any linear estimator of β, it follows that

$$\beta_{GOUTPUT} \equiv \beta_{GCAPITAL} + \beta_{GHUMAN} + \beta_{GA}, \tag{4}$$

where $\beta_{GCAPITAL}$, for example, denotes the coefficients obtained from regressing GCAPITAL on initial income and the determinants. The above identity defines "channel decomposition" or "channel accounting." It is an identity because it is based on the growth accounting identity. By decomposing the coefficient estimates, it effectively decomposes the channels of growth because it states that the effect of any determinant on aggregate productivity growth ($\beta_{GOUTPUT}$) can be decomposed into the effect through TFP growth (β_{GA}) and the effect through factor contributions ($\beta_{GCAPITAL}$ and β_{GHUMAN}).

As an example, most cross-country studies find conditional convergence in output per worker. The question is how much of this convergence is achieved through TFP growth, and how much of it is due to aggregate factor accumulation. This question can be easily answered by channel decomposition by comparing the relative magnitude of γ_{GA} to $\gamma_{GCAPITAL}$ and γ_{GHUMAN}, where γ is the coefficient estimate on $lny_{i,0}$. For instance, a negative γ_{GA} implies that TFP growth leads to convergence, while a positive γ_{GA} implies divergence. Thus, if γ_{GA} is negative and large in magnitude compared to $\gamma_{GCAPITAL}$ and γ_{GHUMAN}, then conditional convergence in output per worker is attributable to TFP catch-up rather than factor accumulation.

In practice, channel decomposition can be implemented simply by applying growth accounting and growth regression sequentially: first apply growth accounting and then regress each component from the growth accounting exercise on the determinants. It is worth noting that because the regressions in the second step are based on the notion of conditional convergence, the growth accounting exercise employed in the first step should decompose output per worker into capital intensity (that converges) rather than capital per worker (that may increase without

bounds).[2]

Related Literature

It is natural to ask whether different determinants affect economic growth through different channels. For example, Bosworth, Collins, and Chen (1995) study the effect of macroeconomic stability on aggregate factor growth and TFP growth. However, since they decompose output per worker into capital per worker instead of capital intensity, it is unclear how one should interpret their results in the framework of conditional convergence.[3] Benhabib and Spiegel (2000), on the other hand, examine whether financial development affects growth through its contribution to the rates of factor investments or total factor productivity. Instead of assuming fixed factor shares, they estimate factor shares along with other parameters in the model. Most importantly, Frankel and Romer (1999) apply channel decomposition to trade shares, while Hall and Jones (1999) apply it to social infrastructure. What this paper does is to extend their methodology to investigate the channels of growth for the other determinants that are commonly thought to be important, with a special emphasis on the channels of convergence.

This paper is also related to Bernanke and Gürkaynak (2001), who propose a test for the Solow model by essentially running only the TFP-growth regression in a channel decomposition exercise. They argue that if growth were exogenous, then behavioral variables – such as the average investment share and the growth rate of labor – should not enter significantly into the TFP-growth regression.[4] In contrast to Bernanke and Gürkaynak (2001), this paper tests the Solow model by investigating whether convergence is achieved through factor accumulation, due to diminishing returns to physical capital accumulation as the Solow model suggests. Furthermore, while part of their test is based on the assumption that countries are on their balanced growth paths, this paper explicitly considers the possibility that countries may not be in their steady states by adopting the conditional convergence framework in channel decomposition.

[2] Thus, this consideration rules out decomposing aggregate productivity growth the traditional way, into the growth rates of physical capital per worker and TFP.

[3] See also King and Levine (1993).

[4] See Romer (2001) and Caselli (2001) for further discussions of this test.

3 Data and Results

Given any growth accounting methodology and any linear regression estimator, the channel decomposition identity will give a parallel decomposition in the channels of growth. The following section illustrates this approach by applying Barro's (1997) cross-country regressions to the growth decomposition by Klenow and Rodriguez-Clare (1997). This amounts to asking the question: To what extent are the estimated effects of the determinants highlighted in Barro (1997) due to their impacts on TFP growth, physical capital accumulation, and human capital accumulation respectively?

Barro (1997) includes one of the most comprehensive sets of determinants used in cross-country regressions. It turns out that the channels of convergence are extremely robust to the set of determinants used. Data for these determinants have been collected from various sources.[5] They correspond closely to the ones used in Barro (1997).

The growth decomposition in Klenow and Rodriguez-Clare (1997) covers 98 countries over the period 1960–1985, the most popular period for empirical growth regressions. Their decomposition is one of the most sophisticated and careful large-scale growth accounting exercises available. It focuses on the measurement of human capital. Klenow and Rodriguez-Clare (1997) assume a production function for human capital, which is more labor intensive than the production of goods. They calculate the stock of human capital using enrollment rates in primary, secondary, and tertiary levels, assuming a constant return to education of 9.5 percent and incorporating human capital acquired through experience. They also adjust human capital for the failure of national income accounting to include the value of student time. The decomposition takes the form of equation (2), with α set to 0.30 and β set to 0.28, the implied values from Mankiw et al. (1992).

I consider two main samples of countries. The first sample consists of the 23 OECD countries.[6] The quality of the data tends to be better for this sample. However, due to its small sample size, the model fitted has to be parsimonious. Since convergence among the OECD countries is one of the best documented phenomena in the literature, for this sample, I focus on the channels of convergence, i.e., whether convergence in output per worker is achieved through TFP growth or factor accumulation. The second sample contains 77 countries, including the OECD countries. It is used to estimate the baseline model, which includes most of the

[5] See the appendix for the sources.

[6] Luxembourg is excluded because it has no data on educational attainment in the Barro-Lee data set.

determinants found in Barro (1997).

3.1 Channel Decomposition Using the OECD Sample

The finding of convergence used to be regarded as evidence in support of the Solow model because early endogenous growth models generally predict divergence. However, with the development of endogenous growth models that are capable of producing convergence, the interpretation of this finding becomes uncertain. However, because these models predict different channels of convergence – Solow-type models predict convergence through factor accumulation due to diminishing returns, while other models predict convergence through faster TFP growth – channel decomposition can be used to test alternative models.

Table 1 reports the results from channel decomposition using the OECD sample. Unless otherwise noted, the regressions use the OLS estimator with heteroskedasticity-consistent standard error. The estimates in Table 1 imply conditional convergence at an annual rate of 1.94 percent for output per worker, 1.85 percent for TFP, and 0.52 percent for the contribution from physical capital accumulation. On the other hand, the contribution from human capital accumulation diverges at the rate of 0.42 percent per year.[7] This finding means that OECD countries that started out with higher income per worker also tend to experience faster subsequent improvement in human capital accumulation, holding constant the other determinants. As a result, human capital accumulation contributes to divergence. These channels are statistically significant at the five percent level.

These results imply that faster TFP growth alone accounts for more than 95 percent of the conditional convergence in output per worker among OECD countries.[8] In contrast, aggregate capital accumulation, i.e., physical and human capital accumulation taken together, contributes little to convergence. In fact, human capital accumulation leads to divergence. In short, TFP growth, not factor accumulation, is what drives conditional convergence among OECD countries.

[7] Barro (1997) also includes an interaction term between initial human capital and the logarithm of initial output per worker. I find very similar rates of convergence if I include the interaction term: Evaluated at the average level of initial human capital, which is 6.53 years for the OECD sample, the coefficients imply an average rate of conditional convergence of 2.13 percent per year in output per worker. Of the 2.13 percentage points, 2.01 percentage points work through TFP growth (convergence), 0.52 percentage points through physical capital accumulation (convergence), and -0.40 percentage points through human capital accumulation (divergence). These channels of convergence are all statistically significant at the five percent level, except the channel through physical capital accumulation.

[8] This is because $1.85/1.94 \times 100\%$ is greater than 95 percent.

Table 1: Channel Decomposition for OECD Countries

Independent Variable	Dependent Variable: Annual Growth Rates of Output per Worker and its Components 1960–85 (%)			
	GOUTPUT	GA	GCAPITAL	GHUMAN
Constant	22.76	19.78	5.63	-2.6
	(3.33)**	(1.75)**	(2.13)*	(1.40)
ln (Initial Output per Worker)	-1.94	-1.85	-0.52	0.42
	(0.37)**	(0.20)**	(0.23)*	(0.16)*
Initial Human Capital	-0.03	0.06	0.01	-0.1
	(0.07)	(0.05)	(0.04)	(0.03)**
ln (Total Fertility Rate)	-1.96	-1.45	-0.35	-0.16
	(0.80)*	(0.74)	(0.30)	(0.22)
No. of Observations	23	23	23	23
R^2	0.81	0.76	0.36	0.35

Notes: Heteroskedasticity-consistent standard errors are in parentheses. *Significantly different from zero at the five percent level. **Significantly different from zero at the one percent level.

3.2 Channel Decomposition Using the Sample of 77 (Baseline Model)

I next turn to the more comprehensive baseline regression, which includes most of the determinants from Barro (1997).[9] Table 2 reports the results.

[9]The three determinants excluded from the baseline model are the change in terms of trade, initial life expectancy at birth, and average inflation rate. The change in terms of trade and average inflation are excluded because they are better thought of as symptoms of some deeper problems in the economy rather than as fundamental determinants of growth. Initial life expectancy at birth is excluded because another proxy for initial human capital – the average years of schooling – has already been included. Thus, including initial life expectancy is likely to induce multicollinearity without adding any information. If I include these three variables in the regressions, only 58 country-observations remain with complete data. I further omit three observations that are influential: Bolivia (BOL) is influential in the relationships between the components of growth and average inflation, while Israel (ISR) and Bangladesh (BGD) are influential with respect to the terms of trade shocks. Including these three variables does not yield any additional insights. Most of the coefficients have the expected signs, but are not statistically significant. Channel decomposition reveals that of the 1.60 percentage-point convergence in output per worker, 1.77 percentage points come from TFP growth (convergence), 0.03 percentage points from physical capital accumulation (convergence), and -0.20 percentage points from human capital accumulation (divergence). TFP growth is still what drives aggregate productivity convergence.

Table 2: Channel Decomposition – Baseline Regression

Independent Variable	Dependent Variable: Annual Growth Rates of Output per Worker and its Components 1960–85 (%)			
	GOUTPUT	GA	GCAPITAL	GHUMAN
Constant	14.47	11.74	3.76	-1.02
	(2.52)**	(2.77)**	(2.33)	(0.89)
ln (Initial Output per Worker)	-1.33	-1.58	0.11	0.14
	(0.28)**	(0.34)**	(0.29)	(0.09)
Initial Human Capital	0.03	0.14	-0.09	-0.02
	(0.07)	(0.09)	(0.06)	(0.02)
ln (Total Fertility Rate)	-0.48	0.01	-0.45	-0.04
	(0.65)	(0.65)	(0.36)	(0.15)
Government Consumption Ratio	-10.49	-7.95	-1.5	-1.06
	(2.32)**	(2.90)**	(2.28)	(1.27)
Rule of Law Index	1.78	2.3	-0.51	-0.01
	(0.70)*	(0.70)**	(0.43)	(0.20)
Democracy Index	0.55	1.61	-1.4	0.35
	(0.37)	(0.47)**	(0.40)**	(0.14)*
Democracy Index Squared	-0.09	-0.2	0.15	-0.04
	(0.04)*	(0.05)**	(0.04)**	(0.02)*
Dummy for Sub-Saharan Africa	-2.48	-2.31	-0.27	0.1
	(0.53)**	(0.62)**	(0.46)	(0.15)
Dummy for Latin America	-1.29	-1.6	0.56	-0.25
	(0.36)**	(0.39)**	(0.27)*	(0.08)**
Dummy for East Asia	-0.27	-1.49	1.22	0
	(0.49)	(0.49)**	(0.38)**	(0.20)
No. of Observations	77	77	77	77
R^2	0.63	0.59	0.38	0.27
F Statistic on Democracy Index and its Square	3.37	7.79	6.17	3.31

Notes: Heteroskedasticity-consistent standard errors are in the parentheses. *Significantly different from zero at the five percent level. **Significantly different from zero at the one percent level.

There are 77 countries with no missing values. All the coefficients in the $GOUTPUT$ regression have the right signs. The R-squared levels are 0.59, 0.38, and 0.27 in the GA, $GCAPITAL$, and $GHUMAN$ regressions respectively. This means that more of the variation in TFP growth is explained by these determinants than the variations in physical and human capital contributions. The channels of operation for each determinant are discussed below.

3.2.1 Initial Output per Worker

The coefficient in Table 2 implies that output per worker converges conditionally at 1.33 percent per year. Of the 1.33 percentage points, 1.58 percentage points work through TFP growth (convergence), -0.11 percentage points through physical capital accumulation (divergence), and -0.14 percentage points through human capital accumulation (divergence).[10] Only the TFP channel is statistically significant at the conventional levels. These estimates indicate that TFP growth fully accounts for conditional convergence in output per worker. In fact, without TFP growth, factor accumulation would have led to divergence.

3.2.2 Initial Human Capital

The initial human capital has little effect on the growth rate of output per worker. A higher level of initial human capital in the form of an additional year of average schooling would raise the growth rate of output per worker by 0.03 percentage points. None of the coefficients are statistically significant at the conventional levels. Nevertheless, it is worth noting that the greatest impact of initial human capital occurs through TFP growth: An additional year of average schooling would raise TFP growth by 0.14 percentage points.[11]

[10] Again, I find very similar rates of convergence if I include the interaction term between the logarithm of initial output per worker and initial human capital: Evaluated at the average level of initial human capital, which is 3.69 years for the full sample for which data is available, the coefficients imply an average rate of conditional convergence of 1.44 percent per year in output per worker. Of the 1.44 percentage points, 1.61 percentage points work through TFP growth (convergence), -0.04 percentage points through physical capital accumulation (divergence), and -0.13 percentage points through human capital accumulation (divergence).

[11] Given the conditional convergence framework I use, one could interpret the results as follows: Countries that have higher initial human capital have higher TFP in steady state. If a country has low income and high initial human capital, it will have faster TFP growth along the transition to the steady state. One could interpret the results on the other determinants accordingly.

3.2.3 Total Fertility Rate

As expected, a high fertility rate is harmful for growth. However, none of the coefficients are statistically significant at the conventional levels. The negative effect works mainly through slower physical capital accumulation. Higher population growth hurts physical capital accumulation because part of the investment has to be used to provide capital for the new workers, rather than to increase capital intensity. The coefficients imply that a one standard deviation increase in the logarithm of the total fertility rate would reduce the growth rate of output per worker by 0.21 percentage points and the contribution from physical capital accumulation by 0.20 percentage points. It would have essentially no effect on TFP growth and the contribution from human capital accumulation.

3.2.4 Government Consumption to GDP Ratio

Following Barro (1997), government consumption excludes spending on education and national defense because it is intended to approximate that part of government spending that is nonproductive. As expected, a higher government consumption ratio hurts all components of growth, with about 75 percent of the total effect operating through slower TFP growth, the only channel that is statistically significant at the conventional levels. The coefficient estimate on government consumption ratio in Table 2 implies that a one standard deviation increase in government consumption ratio would reduce the growth rate of output per worker by 0.73 percentage points. Similarly, it would reduce TFP growth by 0.56 percentage points, the contribution from physical capital and human capital accumulation by 0.11 and 0.07 percentage points respectively.

3.2.5 Rule of Law

The rule of law variable is a subjective index which was originally measured in seven categories on a scale from zero to six. It has been re-scaled to lie between zero and one, with zero indicating the worst, and one the best. The idea that property rights protection, contract enforcement, and the maintenance of law and order are important to economic growth is deeply rooted in economic thinking. This variable is intended as a proxy for all the above institutions.

The expected effect is confirmed by the positive and statistically significant coefficients in the regressions for both output per worker and TFP. Specifically, a one-rank improvement in the underlying index, corresponding to a rise of 0.167 in the rule of law variable, would increase the growth rates of output per worker

and TFP by 0.30 and 0.38 percentage points respectively. More concretely, if Mexico were to perform as well as the United States in the maintenance of rule of law (corresponding to a two-rank improvement in the underlying index), then the estimates imply that Mexico's growth rates of output per worker and TFP could have been higher by 0.59 and 0.77 percentage points respectively. Quite surprisingly, the channel through physical capital accumulation is not statistically significant.

3.2.6 Democracy

The coefficients on the democracy index and its square imply that if a country were to become more democratic, it would first grow faster in output per worker, due to faster growth in TFP and human capital accumulation.[12] However, beyond certain level of democracy, growth rates would fall with further improvement in democracy. The opposite pattern holds for physical capital accumulation. However, these relationships could have been distorted by missing data in the other determinants. A closer examination of the data reveals that the most undemocratic countries with the least physical capital accumulation have been omitted from the baseline regression because of missing values in the other determinants in the regression. These missing observations could have distorted the above relationships.[13] Because of this robustness problem, little emphasis is placed on their significance.[14]

[12]The democracy index is the average Gastil index of political rights.

[13]Fortunately, the other determinants in the baseline regression do not suffer from the same spuriousness problem, as the observations omitted – due to missing values in the other determinants in the baseline regression – do not appear to be influential.

[14]It is important to highlight this problem because Barro (1997) finds an inverted U-shaped (concave) relation between aggregate economic growth and democracy, i.e., "...growth is increasing in democracy at low levels of democracy, but the relation turns negative once a moderate amount of political freedom has been attained" (Barro, 1997 p. 58). One interpretation of this result is that "...in the worst dictatorships, an increase in political rights tends to increase growth and investment because the benefit from limitations on governmental power is the key matter. But in places that have already achieved a moderated amount of democracy, a further increase in political rights impairs growth and investment because the dominant effect comes from the intensified concern with income redistribution" (Barro, 1997 p. 59). However, income redistribution is often thought to harm growth through distortionary capital taxation (see Persson and Tabellini (1994) and Alesina and Rodrik (1994)). So if Barro's argument were right, then we should expect an inverted U-shaped (concave) relationship between the contribution from physical capital accumulation and democracy. However, I find exactly the opposite pattern. However, as I argued earlier, missing values appear to be influential.

3.2.7 Regional Dummies

It is worth emphasizing that the coefficients on the regional dummies capture any residual variations that are not already explained by the above determinants. The coefficient on the dummy for sub-Saharan Africa is negative and statistically significant in the regressions for aggregate and TFP growth. On the contrary, the channels through factor accumulation are negligible and not statistically significant at the conventional levels. This suggests that the countries in sub-Saharan Africa grow more slowly than the other countries, not because they have less factor accumulation, but because they have much lower TFP growth not accounted for by differences in the above determinants.

Similarly, the coefficient on the dummy for Latin American countries is also negative in both the aggregate and the TFP regressions. TFP again turns out to be the most important channel. However, it turns out that Latin American countries have a faster physical capital accumulation rate by about 0.56 percentage points, which is partially offset by their lower human capital accumulation rate by about 0.25 percentage points. These channels are statistically significant at the 5% level.

Being an East Asian country has no significant effect on aggregate growth performance and human capital accumulation during 1960–1985, once the above determinants have been taken into consideration. However, East Asian countries suffer from a lower TFP growth by about 1.49 percentage points, while experiencing a higher contribution from physical capital accumulation by 1.22 percentage points. The two effects almost completely offset each other.

4 Robustness Checks

4.1 Robustness to Omitted Variables

I have shown that conditional convergence in income per worker is driven almost entirely by TFP growth with very little contribution from factor accumulation. In fact, factor accumulation may be leading to divergence. How robust are these results to the inclusion of omitted variables?

4.1.1 Entering the "Most Robust Variables" One at a Time

The first robustness check takes the "most robust variables" from Sala-i-Martin (1997), and enters them one at a time into the baseline regressions.[15] The "most robust variables" are the variables that are significant at the five percent level in Table 1 of Sala-i-Martin (1997), except the fractions of Protestant, Buddhist and Catholic in the country. Panel A of Table 3 reports the rates of convergence from this robustness check. It turns out that the TFP-growth channel is remarkably robust to these perturbations.

Output per worker converges at a rate that ranges between 1.09 to 1.47 percent per year, depending on the variable added. The effect is always statistically significant at the one percent level. Most importantly, it always converges through TFP growth, at a rate that ranges between 1.04 to 1.72 percent per year, which always turns out to be statistically significant at the one percent level. On the other hand, the contribution to convergence from physical capital accumulation is small, volatile, and never statistically significant at the conventional levels; the rate of convergence ranges between -0.15 (divergence) to 0.29 percent (convergence) per year. Finally, the contribution to convergence from human capital accumulation is always divergent, though small and often not statistically significant at the five percent level; the rate of divergence ranges between 0.12 to 0.24 percent a year.

4.1.2 Entering the "Most Robust Variables" All at Once

The second robustness check includes the "most robust variables" all at once in the baseline regressions. This reduces the 77-country sample to 66 because of missing values in some variables. Panel B of Table 3 summarizes the rates of convergence through each channel. Table 4 reports the full regression results. Remarkably, TFP growth still emerges as the most important channel of convergence. These coefficient estimates imply that output per worker converges conditionally at 1.09 percent per year, of which 1.20 percentage points work through TFP growth (convergence), 0.16 percentage points through physical capital accumulation (convergence), and -0.27 percentage points through human capital accumulation (divergence). All of these channels are statistically significant at the one percent level except for the channel through physical capital accumulation.

[15] Note that the baseline regressions in Table 2 have already included quite a number of the most robust variables.

Table 3: Robustness Check – Omitted Variables

Additional Variable	N	Rates of Convergence (%)) GOUTPUT	GA	GCAPITAL	GHUMAN
A. Including One at a Time					
Baseline Regression	77	1.33**	1.58**	-0.11	-0.14
Equipment Investment	68	1.19**	1.13**	0.28	-0.22*
Sachs-Warner Openness Index	77	1.26**	1.51**	-0.09	-0.16
Fraction of Confucius	77	1.31**	1.56**	-0.11	-0.15
Fraction of Muslim	77	1.33**	1.64**	-0.15	-0.16
Index of Civil Liberties	77	1.33**	1.57**	-0.10	-0.14
Revolutions and Coups per year	77	1.33**	1.57**	-0.10	-0.13
Fraction of GDP in Mining	77	1.34**	1.40**	0.11	-0.16*
Sd of Black Mkt Premium	75	1.17**	1.40**	-0.03	-0.20*
Primary Exports	76	1.31**	1.57**	-0.12	-0.14
Type of Econ. Organization	77	1.32**	1.53**	-0.08	-0.13
Dummy for External War	77	1.47**	1.72**	-0.12	-0.13
Non-Equipment Investment	68	1.09**	1.04**	0.29	-0.24*
Absolute Latitude	77	1.33**	1.60**	-0.15	-0.12
Real Exchange Rate Distortion	77	1.33**	1.57**	-0.10	-0.14
B. Including All at Once					
All	66	1.09**	1.2**	0.16	-0.27**

Notes: 'N' refers to the number of observations. *Significantly different from zero at the five percent level. **Significantly different from zero at the one percent level. The data for the most robust determinants come from Sala-i-Martin (1997).

Table 4: Robustness Check - Enter All Variables at Once

Independent Variable	Dependent Variable: Annual Growth Rates of Output per Worker and its Components 1960–85 (%)			
	GOUTPUT	GA	GCAPITAL	GHUMAN
Constant	12.27	9.37	5.47	-2.55
	[4.33]**	[4.39]*	[2.96]	[0.95]*
ln (Initial Output per Worker)	-1.09	-1.2	-0.16	0.27
	[0.37]**	[0.38]**	[0.27]	[0.08]**
Initial Human Capital	-0.03	0.05	0	-0.09
	[0.08]	[0.08]	[0.05]	[0.03]**
ln (Total Fertility Rate)	-0.48	0.21	-0.73	0.03
	[0.84]	[0.85]	[0.52]	[0.23]
Government Consumption Ratio	-6.45	-5.11	-3.02	1.68
	[4.58]	[5.44]	[2.23]	[0.98]
Rule of Law Index	0.53	0.66	0.4	-0.52
	[0.89]	[0.77]	[0.55]	[0.26]
Democracy Index	0.07	0.44	-0.5	0.14
	[0.62]	[0.57]	[0.37]	[0.14]
Democracy Index Squared	-0.03	-0.09	0.09	-0.03
	[0.06]	[0.06]	[0.04]*	[0.02]*
Dummy for Sub-Saharan Africa	-2.52	-1.81	-0.77	0.06
	[0.90]**	[0.89]*	[0.72]	[0.29]
Dummy for Latin America	-1.01	-0.85	0.24	-0.39
	[0.79]	[0.71]	[0.50]	[0.19]*
Dummy for East Asia	-1.09	-1.11	0	0.02
	[0.64]	[0.75]	[0.50]	[0.20]
Equipment Investment	5.72	4.7	1.32	-0.28
	[7.55]	[7.46]	[3.68]	[2.06]
Sachs & Warner Openness Index	0.6	0.25	0.12	0.22
	[0.64]	[0.60]	[0.49]	[0.16]
Fraction of Confucius	3.9	1.39	0.71	1.8
	[2.30]	[2.68]	[1.00]	[0.33]**
Fraction of Muslim	0.6	1.13	-0.32	-0.2
	[0.63]	[0.68]	[0.46]	[0.22]
Index of Civil Liberties	0.03	0.27	-0.49	0.25
	[0.27]	[0.22]	[0.22]*	[0.09]**
Revolutions and Coups per year	0.27	0.34	0.17	-0.25
	[0.60]	[0.63]	[0.40]	[0.21]
Fraction of GDP in Mining	-2.22	-3.67	-0.31	1.75
	[4.54]	[4.57]	[2.00]	[1.05]
Sd of Black Market Premium	0	0	0	0
	[0.00]	[0.00]	[0.00]**	[0.00]
Primary Exports	0.07	-0.55	0.5	0.11
	[0.88]	[0.84]	[0.53]	[0.17]

Continued on next page

			Continued from previous page	
Type of Economic Organization	0.14	0.15	0	-0.01
	[0.17]	[0.16]	[0.08]	[0.05]
Dummy for Participation in War	-0.57	-0.71	0.11	0.02
	[0.27]*	[0.29]*	[0.20]	[0.10]
Non-Equipment Investment	6.57	9.34	-3.56	0.82
	[3.24]*	[3.88]*	[2.15]	[0.86]
Absolute Latitude	-1.59	-0.47	-1.58	0.46
	[1.35]	[1.46]	[0.93]	[0.51]
Real Exchange Rate Distortion	0	0	0.01	0
	[0.01]	[0.01]	[0.00]	[0.00]
No. of Observations	66	66	66	66
R^2	0.78	0.74	0.56	0.61

Notes: Heteroskedasticity-consistent standard errors are in the parentheses. *Significantly different from zero at the five percent level. **Significantly different from zero at the one percent level.

In summary, TFP growth still drives conditional convergence whether the "most robust variables" are included one at a time or all at once. While human capital accumulation always leads to divergence, physical capital accumulation has a more ambiguous effect; it leads to convergence in some specifications, but divergence in others. Nevertheless, the effects due to capital accumulation are always small.

4.1.3 Including the Investment Rates

One may ask whether omitting investment rates in the capital accumulation regressions could also lead to omitted variable bias. While higher investment rates certainly lead to higher capital stocks (because investment rates – the flows – are used to construct the unobservable capital stocks by applying the perpetual inventory method), they may not necessarily lead to higher growth rates of the capital-output ratio – GCAPITAL and GHUMAN.[16] Moreover, including the investment rates as independent variables may introduce endogeneity bias to the regressions because investment rates are likely to be endogenous.

Nevertheless, to check robustness, I include the average investment-output ratio and the average school enrollment ratios during 1960–1985 as additional ex-

[16] For example, in the Solow model, a higher share of output invested has no effect on the growth rate of the capital-output ratio in the steady state.

planatory variables in the channel decomposition regressions.[17] Table 5 reports the results for OECD countries and Table 6 the results for all countries.

Table 5: Including Investment Rates for OECD Countries

Independent Variable	Dependent Variable: Annual Growth Rates of Output per Worker and its Components 1960–1985 (%)			
	GOUTPUT	GA	GCAPITAL	GHUMAN
Constant	2.42	5.51	-1.55	-1.54
	[3.65]	[6.11]	[3.59]	[3.23]
ln (Initial Output per Worker)	-2	-1.57	-0.81	0.38
	[0.12]**	[0.25]**	[0.18]**	[0.16]*
Initial Human Capital	-0.08	0.06	0.01	-0.14
	[0.04]	[0.05]	[0.03]	[0.04]**
ln (Total Fertility Rate)	-1.34	-1.23	-0.3	0.18
	[0.35]**	[0.62]	[0.34]	[0.21]
Real Investment/GDP	5.84	5.07	-1.36	2.1
	[2.01]*	[3.44]	[1.34]	[1.58]
Primary School Enrollment Ratio	18.47	10.75	9.92	-2.14
	[2.80]**	[5.06]	[3.14]**	[3.84]
Secondary School Enrollment Ratio	1.09	-0.02	0.15	0.95
	[0.66]	[1.19]	[0.65]	[0.43]*
Higher Education Enrollment Ratio	0.67	-1.96	1.46	1.16
	[1.35]	[1.53]	[1.13]	[0.84]
No. of Observations	22	22	22	22
R^2	0.95	0.85	0.68	0.63

Notes: Heteroskedasticity-consistent standard errors are in parentheses. *Significantly different from zero at the five percent level. **Significantly different from zero at the one percent level.
Real Investment/GDP is the average investment-GDP ratio during 1960–85 (Penn World Table 5.6).
School enrollment ratios are the average school enrollment ratios, averaged over 1960, 1965, 1970, 1975, 1980, and 1985 (Barro-Lee cross-country panel data at the NBER's web site: http://www.nber.org/pub/barro.lee/)

[17]The school enrollment ratios are averaged over 1960, 1965, 1970, 1975, 1980, 1985 using data from the Barro-Lee data set. The average investment-output ratio is calculated using data from Penn World Table 5.6.

Table 6: Including Investment Rates for All Countries

Independent Variable	Dependent Variable: Annual Growth Rates of Output per Worker and its Components 1960–1985 (%)			
	GOUTPUT	GA	GCAPITAL	GHUMAN
Constant	12.64	10.87	3.38	-1.6
	[2.72]**	[3.40]**	[2.39]	[0.93]
ln (Initial Output per Worker)	-1.39	-1.49	0.07	0.03
	[0.30]**	[0.39]**	[0.31]	[0.10]
Initial Human Capital	-0.07	0.14	-0.13	-0.08
	[0.06]	[0.08]	[0.06]*	[0.03]**
ln (Total Fertility Rate)	-0.32	-0.21	-0.4	0.28
	[0.63]	[0.73]	[0.37]	[0.16]
Government Consumption Ratio	-6.54	-5.67	-1.11	0.23
	[2.79]*	[4.01]	[2.62]	[1.18]
Rule of Law Index	0.67	1.49	-0.64	-0.18
	[0.68]	[0.74]*	[0.45]	[0.16]
Democracy Index	0.25	1.33	-1.47	0.39
	[0.34]	[0.50]*	[0.42]**	[0.13]**
Democracy Index Squared	-0.04	-0.16	0.16	-0.04
	[0.04]	[0.06]**	[0.04]**	[0.01]**
Dummy for Sub-Saharan Africa	-1.91	-2.2	0.03	0.26
	[0.55]**	[0.72]**	[0.51]	[0.17]
Dummy for Latin America	-0.71	-1.25	0.63	-0.09
	[0.37]	[0.51]*	[0.35]	[0.11]
Dummy for East Asia	-0.06	-1.3	1.27	-0.04
	[0.46]	[0.53]*	[0.44]**	[0.20]
Real Investment/GDP	6.85	6.11	0.15	0.61
	[3.00]*	[3.65]	[1.70]	[0.83]
Primary School Enrollment Ratio	1.19	0.19	0.68	0.33
	[1.30]	[1.53]	[0.89]	[0.36]
Secondary School Enrollment Ratio	1.57	-0.31	0.49	1.39
	[1.47]	[1.82]	[1.06]	[0.46]**
Higher Education Enrollment Ratio	-1.87	-2.4	-0.21	0.75
	[1.93]	[1.96]	[0.99]	[0.49]
No. of Observations	72	72	72	72
R^2	0.72	0.63	0.42	0.47

Notes: Heteroskedasticity-consistent standard errors are in parentheses. *Significantly different from zero at the five percent level. **Significantly different from zero at the one percent level.
Real Investment/GDP is the average investment-GDP ratio during 1960–85 (Penn World Table 5.6).
School enrollment ratios are the average school enrollment ratios, averaged over 1960, 1965, 1970, 1975, 1980, and 1985 (Barro-Lee cross-country panel data at the NBER's web site: http://www.nber.org/pub/barro.lee/)

It turns out that TFP growth remains as the main channel of convergence. Most of these investment rates are not statistically significant in the capital accumulation regressions. In a few cases where they are statistically significant, they enter the capital accumulation regressions positively. Because the main results are robust to their inclusion and because of the above considerations, I do not include them in the regressions that follow.

4.2 The Channels of Convergence in Rich and Poor Countries

This section investigates whether convergence works through different channels in rich and poor countries. Some believe that richer countries converge through TFP growth, while the poorer ones rely on factor accumulation.[18] This hypothesis is tested by comparing the fraction of aggregate productivity convergence achieved through each channel in rich and poor countries.

The sample of 77 countries is first sorted according to output per worker in 1960 and then split into two halves. I create a dummy variable that equals one if the country belongs to the richer half of the sample, and zero otherwise. I then interact this dummy with the logarithm of initial output per worker and re-estimate the baseline regression including this interaction term. Panel A of Table 7 reports the results.

The evidence shows no difference in the channels of convergence for rich and poor countries. The coefficient on the interaction term between the dummy and the logarithm of initial income per worker is negligible in all regressions even though it is statistically significant at the five percent level in the $GHUMAN$ regression. Panels B and C of Table 7 report the results if the dummy variable is defined instead for the richest 25% and the richest 75% of the sample respectively. The coefficient on the interaction term is negligible in all cases. So the conclusion is quite robust to different ways of splitting the data. In short, TFP growth is what drives conditional convergence in both rich and poor countries.

In light of the ongoing AK debate related to the East Asian economies, an issue of particular interest is whether the East Asian countries converge through TFP growth or factor accumulation.[19] To investigate this issue, I interact the East Asian dummy with the logarithm of initial output per worker and re-estimate the baseline regression including this interaction term. Panel D of Table 7 reports the results.

[18] See, for example, Hayami (1998).

[19] For example, see Young (1995) and Hsieh (2002).

Table 7: The Channels of Convergence for Rich and Poor Countries

	Dependent Variable: Annual Growth Rates of Output per Worker and its Components 1960–85 (%)			
Independent Variables:	GOUTPUT	GA	GCAPITAL	GHUMAN
A. Richer Half of the Sample				
ln (Initial Output per Worker)	-1.16	-1.47	0.01	0.3
	(0.38)**	(0.45)**	(0.33)	(0.11)**
ln (Initial Output per Worker)	-0.04	-0.02	0.02	-0.03
× Dummy for the Richer Half	(0.05)	(0.06)	(0.03)	(0.01)*
B. Richest 25% of the Sample				
ln (Initial Output per Worker)	-1.02	-1.37	0.17	0.18
	(0.35)**	(0.41)**	(0.30)	(0.10)
ln (Initial Output per Worker)	-0.09	-0.06	-0.02	-0.01
× Dummy for Richest 25%	(0.05)	(0.05)	(0.04)	(0.01)
C. Richest 75% of the Sample				
ln (Initial Output per Worker)	-1.64	-1.68	-0.13	0.16
	(0.27)**	(0.37)**	(0.32)	(0.12)
ln (Initial Output per Worker)	0.13	0.04	0.1	-0.01
× Dummy for Richest 75%	(0.07)	(0.07)	(0.05)*	(0.03)
D. East Asian Countries				
ln (Initial Output per Worker)	-1.36	-1.59	0.09	0.14
	(0.28)**	(0.35)**	(0.29)	(0.09)
ln (Initial Output per Worker)	0.8	0.57	0.33	-0.1
× Dummy for East Asia	(0.58)	(0.55)	(0.53)	(0.48)
F-Statistic[a]	11.54**	10.67**	0.31	1.12
No. of Observations	77	77	77	77

Notes: Heteroskedasticity-consistent standard errors are in the parentheses. The regressions in this table contain other controls in the baseline regressions.
*Significantly different from zero at the five percent level. **Significantly different from zero at the one percent level.
[a] This is the F-statistic testing for the joint significance of the logarithm of initial output per worker and its interaction with the East Asian Dummy.

The point estimate suggests that there is some evidence that convergence via TFP growth may have been less important in East Asia. However, there is no evidence that physical capital accumulation contributes more to convergence in East Asia. In fact, the point estimate indicates that it may have led to divergence in these countries. The F statistics testing the joint significance of the logarithm of initial output per worker and its interaction with the East Asian dummy show that only the TFP channel is statistically significant at the conventional levels. Nevertheless, given the large standard errors, the evidence is merely suggestive.

4.3 Robustness to Alternative Decomposition Methodology

This section assesses robustness with respect to the growth accounting methodology used. Much of the disagreement on what constitutes the appropriate accounting methodology arises because physical and human capital are concepts not directly observable; they need to be constructed. Since Klenow and Rodriguez-Clare's methodology differs from other works mainly in how they construct their measure of human capital, an accounting methodology that measures human capital differently – that of Hall and Jones (1999) – is used to test its robustness.[20] With this alternative accounting methodology, it turns out that TFP growth still emerges as the main channel of convergence.

More generally, Hall and Jones (1999) use the Cobb-Douglas approach with standard elasticities. They report that this simple approach yields similar results to Solow (1957) and Christensen, Cummings, and Jorgensen (1981). They assume a production function $Y = K^{\alpha}(AH)^{1-\alpha}$, where Y is output, K is the stock of physical capital, H is human capital-augmented labor, and A is labor-augmenting productivity. With this production function, differences in growth rates of output per worker in each country can be decomposed into differences in the growth rates

[20]There is a minor modification from the approach of Hall and Jones (1999). I did not deduct value added in the mining industry from GDP before decomposing it to various components for two reasons. First, I want to focus on the change in how human capital is constructed. Second, because Hall and Jones are interested in income levels, they have to worry about the influence of country specific factors which remain constant over time, such as natural resource endowments. In contrast, this paper is concerned with growth rates. Differencing in growth rate calculation should have accounted for them.

of physical capital to output ratio, human capital per worker, and productivity:[21]

$$g(Y/L) \equiv \frac{\alpha}{1-\alpha} g(K/Y) + g(H/L) + g(A). \tag{5}$$

Specifically, they construct the aggregate stock of human capital in country i as $H_i = e^{\phi(E_i)} L_i$, where E_i is the average years of schooling in country i, L_i the number of workers, and $\phi'(.)$ the private return to education in a Mincerian wage regression, with $\phi(0) = 0$. They assume diminishing returns to education. In particular, they assume a rate of return of 13.4 percent for the first four years of education, 10.1 percent for the next four years, and 6.8 percent beyond the eighth year; these rates come from Psacharopoulos (1994), and are the average return in the sub-Saharan Africa, the entire world, and the OECD countries respectively.[22]

Hall and Jones (1999) assign a lower weight to physical capital accumulation. They use $\alpha/(1-\alpha)$ instead of $\alpha/(1-\alpha-\beta)$.[23] Although both Klenow and Rodriguez-Clare (1997) and Hall and Jones (1999) construct the stock of physical capital using the perpetual inventory method, they estimate their initial capital stock differently. In particular, Klenow and Rodriguez-Clare (1997) estimate the initial capital-output ratio as

$$(K/Y)_0 = \frac{(I/Y)}{g_y + n + \delta}, \tag{6}$$

where I/Y is the investment rate, g_y is the average growth rate of output per worker, n is average population growth rate. δ, the rate of depreciation, is set to 3%. On the other hand, Hall and Jones (1999) use

$$(K/Y)_0 = \frac{(I/Y)}{g_I + \delta}, \tag{7}$$

where g_I is the average growth rate of investment, and δ is set to 6%. Both

[21] The component for human capital accumulation now takes the form of human capital per worker rather than human capital-output ratio. A priori, it is not clear whether it is human capital per worker or human capital-output ratio that is convergent. However, it is plausible that years of formal schooling per worker – Hall and Jones's (1999) measure of human capital accumulation – converges in the steady state, since there is increasing opportunity cost to more formal schooling and life is finite.

[22] Recall that Klenow and Rodriguez-Clare (1997) assume a constant return of 9.5 percent for all educational levels.

[23] Compare equation (5) to equation (2). Hall and Jones (1999) also set α equal to 1/3 while Klenow and Rodriguez-Clare (1999) set α equal to 0.30.

then calculate the subsequent capital stocks using the perpetual inventory relation: $K(t+1) = K(t) + I(t) - \delta K(t)$, where $K(t)$ is the stock of physical capital at time t, $I(t)$ is the flow of gross investment during period t, and δ is again the depreciation rate.

The initial estimates from equations (6) and (7) need not be close. However, subsequent capital stocks calculated from the recursive relation typically become less sensitive to the initial guesses after some iterations. To prevent the initial estimates of capital stock from influencing my results, in what follows, I ensure that there are at least five iterations in the perpetual inventory relation before I use the constructed capital stocks in my channel decomposition exercise.

Specifically, I calculate the initial capital stocks in 1950, 1955, and 1960 using equation (7), where g_I is the growth rate of investment over the next ten years. I then iterate the perpetual inventory relation from the *first available estimate* of initial capital stock to calculate capital stocks in all subsequent years.[24] I use two samples to perform channel decomposition. In the first sample, I restrict the sample to those countries with investment data going back to at least 1955. The restriction reduces the sample size to 63. I use this sample to estimate the channels of growth during 1960–1985. In the second sample, I include all countries with investment data going back to at least 1960. This results in the same sample of 77 countries used in the baseline regression. I use this sample to consider conditional convergence during 1965–1985, keeping the other determinants in the baseline regression. It turns out that both samples lead to similar conclusions.

Table 8 reports the summary statistics from the decomposition of Klenow and Rodriguez-Clare (1997) and the decomposition based on the methodology of Hall and Jones (1999). It appears that Hall and Jones's (1999) methodology attributes more growth to the contribution from human capital accumulation and less to the contribution from physical capital accumulation. Their methodology also leads to more variation in human capital accumulation.

OECD Convergence Revisited

Table 9 reports channel decomposition for the OECD countries based on the accounting methodology of Hall and Jones (1999). Of the 1.94 percentage points conditional convergence in output per worker among the OECD countries, 1.38 percentage points now work through TFP growth (convergence), 0.85 percentage points through physical capital accumulation (convergence), and -0.29 percentage

[24]For example, if a country has investment data beginning in 1955, then I calculate its capital stock in 1955 and iterate the recursive formula from 1955 onwards.

Table 8: Summary Statistics for Alternative Decompositions During 1960–1985

Annual Growth Rates of Output per Worker and Its Components over 1960-1985 (%)	Mean	Std. Dev.	Minimum	Maximum
Growth Rate of Output per Worker	2.09	1.44	-1.80	5.37
TFP Growth	0.81	1.54	-3.26	3.53
	0.61	1.50	-3.72	4.12
Contribution from Physical Capital	0.76	0.80	-0.78	4.07
	0.70	0.95	-3.19	2.86
Contribution from Human Capital	0.51	0.31	-0.13	1.57
	0.77	0.40	-0.26	1.73

Note: The number of country-observations = 67. The first number refers to Klenow and Rodriguez-Clare's decomposition while the second refers to Hall and Jones's decomposition.

Table 9: Channel Decomposition for OECD Countries – Hall and Jones's Accounting Methodology

Independent Variable	Dependent Variable: Annual Growth Rates of Output per Worker and its Components 1960–85 (%)			
	GOUTPUT	GA	GCAPITAL	GHUMAN
Constant	22.78	14.11	9.67	-1
	[3.34]**	[2.53]**	[1.78]**	[1.27]
ln (Initial Output per Worker)	-1.94	-1.38	-0.85	0.29
	[0.37]**	[0.32]**	[0.21]**	[0.13]*
Initial Human Capital	-0.03	0.15	-0.02	-0.16
	[0.08]	[0.09]	[0.04]	[0.03]**
ln (Total Fertility Rate)	-1.96	-0.88	-1.07	-0.01
	[0.80]*	[0.95]	[0.32]**	[0.24]
No. of Observations	23	23	23	23
R^2	0.81	0.39	0.62	0.68

Notes: Heteroskedasticity-consistent standard errors are in parentheses. *Significantly different from zero at the five percent level. **Significantly different from zero at the one percent level.

points through human capital accumulation (divergence). All these channels are statistically significant at the five percent level. The estimates imply that nearly seventy percent of the tendency to converge in output per worker can be accounted for by TFP growth. However, physical capital accumulation appears to contribute

more to convergence among the OECD countries with the change in accounting methodology. Nevertheless, TFP growth is still the most important channel of convergence.

World Convergence Revisited

Table 10 reports channel decomposition for all countries for the period 1960-85 based on the accounting methodology of Hall and Jones (1999). The estimate implies a convergence rate of 1.52 percent per year in output per worker, conditional on the other determinants in the baseline regression. Of the 1.52 percentage points, 1.45 percentage points now work through TFP growth (convergence), 0.39 percentage points through physical capital accumulation (convergence), and -0.32 percentage points through human capital accumulation (divergence). All channels, except the channel through physical capital accumulation, are statistically significant at the one percent level. More importantly, TFP growth remains as the most important channel of convergence, accounting for more than 95 percent of the tendency to converge. I obtain very similar results using the sample of 77 countries for the period 1965–85.

4.4 Robustness to Alternative Measures of Human Capital

The above analyses use schooling data from the Barro-Lee data set. Recently, De la Fuente and Doménech (2006) and Cohen and Soto (2006) argue that the Barro-Lee's schooling data exhibit implausible patterns over time, which suggest that the data may contain significant measurement error, particularly for changes in average schooling years over time. Both have constructed their own measures of schooling. With these data, they show that human capital is more economically and statistically significant in growth regressions than previous research suggests. It is natural to ask whether the results from channel decomposition are sensitive to the choice of schooling data. To check robustness, I redo growth accounting and regressions, replacing Barro-Lee's measure of the average years of schooling with these alternative measures. I continue to use the accounting methodology of Hall and Jones (1999).

Table 11 reports channel decomposition for the OECD countries based on De la Fuente and Doménech's (2006) measure of the average years of schooling. The results suggest that for the OECD countries, of the 2.22 percentage points conditional convergence in output per worker, 1.35 percentage points work through TFP growth (convergence), 0.91 percentage points through physical capital accumulation (convergence), and -0.05 percentage points through human capital ac-

Table 10: Channel Decomposition for All Countries – Hall and Jones's Accounting Methodology

Independent Variable	Dependent Variable: Annual Growth Rates of Output per Worker and its Components 1960–85 (%)			
	GOUTPUT	GA	GCAPITAL	GHUMAN
Constant	16.65	9.26	8.35	-0.97
	[3.35]**	[4.48]*	[3.66]*	[0.91]
ln (Initial Output per Worker)	-1.52	-1.45	-0.39	0.32
	[0.32]**	[0.45]**	[0.34]	[0.08]**
Initial Human Capital	0.04	0.32	-0.11	-0.17
	[0.08]	[0.10]**	[0.06]	[0.03]**
ln (Total Fertility Rate)	-0.7	-0.04	-0.54	-0.12
	[0.78]	[0.84]	[0.44]	[0.19]
Government Consumption Ratio	-10.93	-11.61	0.76	-0.08
	[4.34]*	[6.34]	[3.44]	[0.97]
Rule of Law Index	1.72	1.81	-0.06	-0.03
	[0.91]	[1.02]	[0.53]	[0.21]
Democracy Index	0.3	1.52	-1.21	0
	[0.51]	[0.74]*	[0.56]*	[0.12]
Democracy Index Squared	-0.05	-0.17	0.12	0
	[0.05]	[0.08]*	[0.06]	[0.01]
Dummy for Sub-Saharan Africa	-2.8	-0.06	-2.7	-0.04
	[0.73]**	[1.07]	[0.72]**	[0.21]
Dummy for Latin America	-0.98	-0.6	-0.17	-0.2
	[0.47]*	[0.49]	[0.36]	[0.09]*
Dummy for East Asia	-0.12	-1.21	0.57	0.51
	[0.73]	[0.61]	[0.38]	[0.23]*
No. of Observations	63	63	63	63
R^2	0.65	0.52	0.52	0.59

Notes: Heteroskedasticity-consistent standard errors are in parentheses. *Significantly different from zero at the five percent level. **Significantly different from zero at the one percent level.

cumulation (divergence). All these channels are statistically significant at the one percent level, except the channel through human capital accumulation. Again, countries that begin with higher average years of schooling tend to experience slower growth in human capital accumulation. Higher fertility is especially bad for physical capital accumulation and the effect is statistically significant at the one percent level.

Similarly, Table 12 reports channel decomposition for the OECD countries

Table 11: Channel Decomposition for OECD Countries - De la Fuente and Doménech's Data Set

Independent Variable	Dependent Variable: Annual Growth Rates of Output per Worker and its Components 1960–85 (%)			
	GOUTPUT	GA	GCAPITAL	GHUMAN
Constant	24.32	13.28	10.2	0.85
	[3.43]**	[2.71]**	[1.27]**	[0.60]
ln (Initial Output per Worker)	-2.22	-1.35	-0.91	0.05
	[0.41]**	[0.34]**	[0.16]**	[0.07]
Initial Human Capital	0.01	0.05	0.02	-0.06
	[0.10]	[0.10]	[0.04]	[0.02]*
ln (Total Fertility Rate)	-1.02	0.59	-1.37	-0.24
	[0.61]	[0.73]	[0.32]**	[0.17]
No. of Observations	21	21	21	21
R^2	0.85	0.53	0.61	0.38

Notes: Heteroskedasticity-consistent standard errors are in parentheses. *Significantly different from zero at the five percent level. **Significantly different from zero at the one percent level.

Table 12: Channel Decomposition for OECD Countries - Cohen and Soto's Data Set

Independent Variable	Dependent Variable: Annual Growth Rates of Output per Worker and its Components 1960–1990 (%)			
	GOUTPUT	GA	GCAPITAL	GHUMAN
Constant	23.49	13.84	8.41	1.24
	[2.30]**	[2.39]**	[0.92]**	[0.49]*
ln (Initial Output per Worker)	-2.08	-1.25	-0.87	0.04
	[0.31]**	[0.36]**	[0.12]**	[0.06]
Initial Human Capital	0.01	0.01	0.1	-0.09
	[0.08]	[0.11]	[0.05]	[0.02]**
ln (Total Fertility Rate)	-1.68	-0.91	-0.6	-0.17
	[0.95]	[1.53]	[0.48]	[0.20]
No. of Observations	22	22	22	22
R^2	0.85	0.5	0.55	0.69

Notes: Heteroskedasticity-consistent standard errors are in parentheses. *Significantly different from zero at the five percent level. **Significantly different from zero at the one percent level.

Table 13: Channel Decomposition for All Countries - Cohen and Soto's Data Set

Independent Variable	Dependent Variable: Annual Growth Rates of Output per Worker and its Components 1960–1990 (%)			
	GOUTPUT	GA	GCAPITAL	GHUMAN
Constant	22	14.9	6.7	0.4
	[3.19]**	[4.54]**	[3.95]	[1.18]
ln (Initial Output per Worker)	-2.02	-1.88	-0.21	0.07
	[0.30]**	[0.42]**	[0.35]	[0.10]
Initial Human Capital	0	0.12	-0.08	-0.05
	[0.08]	[0.12]	[0.09]	[0.03]
ln (Total Fertility Rate)	-1.34	-1.51	-0.14	0.31
	[0.75]	[0.79]	[0.53]	[0.27]
Government Consumption Ratio	-10.69	-9.24	-0.41	-1.04
	[3.77]**	[6.51]	[3.75]	[0.79]
Rule of Law Index	2.27	2.3	-0.12	0.08
	[0.79]**	[1.23]	[0.75]	[0.17]
Democracy Index	-0.09	1.27	-1.41	0.04
	[0.62]	[0.88]	[0.73]	[0.24]
Democracy Index Squared	0	-0.13	0.13	-0.01
	[0.06]	[0.09]	[0.07]	[0.02]
Dummy for Sub-Saharan Africa	-3.04	0.15	-2.83	-0.36
	[0.88]**	[0.86]	[0.67]**	[0.35]
Dummy for Latin America	-0.7	-0.09	-0.35	-0.26
	[0.53]	[0.53]	[0.39]	[0.21]
Dummy for East Asia	0.15	-0.21	0.16	0.21
	[0.71]	[0.59]	[0.44]	[0.27]
No. of Observations	57	57	57	57
R^2	0.8	0.67	0.51	0.58

Notes: Heteroskedasticity-consistent standard errors are in parentheses. *Significantly different from zero at the five percent level. **Significantly different from zero at the one percent level.

and Table 13 for all countries with complete data using Cohen and Soto's (2006) measure of the average years of schooling.[25] Because Cohen and Soto's data set does not report schooling data for 1985, I change the sample period to 1960–1990 instead. The results suggest that for the OECD countries, of the 2.08 percentage points conditional convergence in output per worker, 1.25 percentage points work through TFP growth (convergence), 0.87 percentage points through physical

[25] I thank Marcelo Soto for sharing the data set. I use the average years of schooling for population aged 15-64 who is not studying, denoted as TY1564 in the data set.

capital accumulation (convergence), and -0.04 percentage points through human capital accumulation (divergence). Again, all these channels are statistically significant at the one percent level, except the channel through human capital accumulation. Again, countries that begin with higher average years of schooling tend to experience slower growth in human capital accumulation.

For the larger cross-section of countries, of the 2.02 percentage points conditional convergence in output per worker, 1.88 percentage points work through TFP growth (convergence), 0.21 percentage points through physical capital accumulation (convergence), and -0.07 percentage points through human capital accumulation (divergence). The TFP channel is statistically significant at the one percent level, while the channels through factor accumulation are not.

In conclusion, the evidence suggests that TFP growth is still the main channel of convergence with the new measures of schooling by De la Fuente and Doménech (2006) and Cohen and Soto (2006).

4.5 Other Robustness Checks

In results not shown here, I perform two more robustness checks. First, to ensure that the negative correlation between initial output and subsequent growth is not due to temporary measurement errors in output levels, I rerun the regressions using instrumental variables (IV). I use lagged outputs per worker between 1960–1964 as instruments for initial output per worker in 1965. The IV estimates yield essentially the same rates of convergence as the OLS estimates. Thus, it is unlikely that my findings on conditional convergence are due to temporary measurement errors in output levels.

Second, I check robustness using the panel regression approach. Islam (1995) proposes an alternative way to control for omitted variable bias, essentially by including country fixed effects in the panel regression. He shows that this procedure typically leads to faster rate of convergence. Thus, I re-estimate the channels of convergence for both the OECD countries and the broad set of countries using a simple fixed-effects model – the within regression. I use the data for 1960–1990 and I divide the data into six five-year intervals. While the rates of convergence do increase when I use panel regression, the results show that TFP growth is still what drives conditional convergence in output per worker for both the OECD countries and the broad set of countries. In fact, aggregate factor accumulation leads to divergence and the effect is always statistically significant at the one percent level for human capital accumulation.

In summary, TFP growth always emerges as the most important channel of

convergence. This conclusion is extremely robust to different ways of controlling for the omitted variable bias, different growth accounting methodology, different sample periods, different schooling data sets, and different estimation techniques.

The Implications of the Channels of Convergence

According to conventional wisdom, the finding of a large Solow residual from growth accounting exercises appears to be at odds with the finding of significant conditional convergence from cross-country regressions. On the one hand, large Solow residuals clearly indicate that variation in capital accumulation cannot account for a significant part of either worldwide economic growth or cross-country income differences. On the other hand, conditional convergence was often thought to result from diminishing returns to capital accumulation.[26] Thus, the two literatures seem to contradict each other concerning the role of capital accumulation; while capital accumulation cannot explain much of the variation in the levels and growth rates of incomes, it is thought to account for conditional convergence. Although theoretical models that emphasize the role of technological diffusion in conditional convergence have emerged (for example, Bernard and Jones (1996), Barro and Sala-i-Martin (1997), and Basu and Weil (1998)), there is no direct evidence on the relative contributions of total factor productivity and factor accumulation to convergence.

This apparent inconsistency is resolved by the findings of channel decomposition. Large Solow residuals are consistent with conditional convergence because convergence turns out to work mostly through TFP growth rather than aggregate capital accumulation.

5 Conclusion

It is natural to ask whether different determinants affect economic growth through different channels. A number of papers – such as Frankel and Romer (1999) and Hall and Jones (1999) – empirically investigate the channels through which a specific determinant affects aggregate labor productivity. This paper extends their approach to study the channels of convergence and the channels of growth for the other determinants that are commonly found to be important for aggregate productivity growth.

[26] See, for example, Mankiw, Romer, and Weil (1992), Barro and Sala-i-Martin (1992), and Barro, Mankiw, and Sala-i-Martin (1995).

In the framework of channel decomposition, each determinant can affect growth through three channels: physical capital accumulation, human capital accumulation, and TFP growth. In practice, channel decomposition can be implemented by first decomposing economic growth into various components in a growth accounting framework, and then regressing each component from the growth accounting exercise on the determinants of growth.

With this method and the accounting methodology by Klenow and Rodriguez-Clare (1997), I show that contrary to conventional wisdom, the largest contribution to convergence is not due to diminishing returns to aggregate factor accumulation. In fact, the contribution from human capital accumulation always leads to divergence, although the effect is almost never statistically significant. The contribution to convergence from physical capital accumulation is small and ambiguous. On the contrary, TFP growth always contributes to convergence and always emerges as the most important channel.

The evidence also shows that TFP growth is what accounts for conditional convergence in both rich and poor countries. It is also what drives conditional convergence in the East Asian countries. This finding about the channels of convergence is extremely robust. It is robust to different specifications, to different ways of controlling for the omitted variable bias, to the alternative accounting methodology of Hall and Jones (1999), to different sample periods, and to different measures of human capital and schooling. The most important channel always turns out to be TFP growth, not factor accumulation. The TFP channel also tends to be the most important channel for most of the other determinants that are often found to be important in cross-country regressions.

Future research should be directed at identifying the specific elements in TFP that contribute to these findings. More micro level studies are needed to provide a better picture of the missing pieces at the macro level. More theoretical works are needed to explain the mechanisms by which TFP growth generates convergence.

6 Appendix: Sources of Data

The following contains the sources of the variables. Except when noted specifically below, the variables for robustness checks come from Sala-i-Martin (1997).
Initial Output per Worker: Real GDP per worker in 1960 (Penn World Table 5.6).
Real Investment: Constructed from real investment as a percentage of GDP (I), real GDP per capita (RGDPCH), and total population in thousands (POP):

RGDPCH*POP*1000*I/100 (Penn World Table 5.6).

Number of Worker: Constructed from real GDP per capita (RGDPCH), real GDP per worker (RGDPW), and total population in thousands (POP):
RGDPCH*POP*1000/RGDPW (Penn World Table 5.6).
Initial Human Capital: Average years of schooling of the total population over age 15 in 1960 (Barro-Lee data set). Years of schooling of population 15-64 who is not studying in 1960 (Cohen-Soto data set). Average years of schooling of the adult population in 1960 (De la Fuente-Doménech data set, downloadable at http://iei.uv.es/ rdomenec/human/human.html).
Total Fertility Rate: Average fertility rate during 1960–84 (Barro-Lee cross-country panel data. See NBER's web site: http://www.nber.org/pub/barro.lee/)
Government Consumption Ratio: The average ratio of real government consumption expenditure net of spending on defense and on education to real GDP during 1960-84 (Barro-Lee cross-country panel data).
Rule of Law Index: The rule of law index (Sala-i-Martin (1997))
Democracy Index: Gastil index of political rights, averaged over 1972–84 (Barro-Lee cross-country panel data).
Continent Dummies: Barro-Lee cross-country panel data.
Terms of Trade Shock: Growth rate of export prices minus growth rate of import prices over 1960–84 (Barro-Lee cross-country panel data).
Average Inflation: Average inflation rate over 1960–85 (Bruno and Easterly (1998)).
Life expectancy at birth: Life expectancy at age zero in 1960 (Barro-Lee cross-country panel data).
Equipment Investment and Non-Equipment Investment: De Long and Summers (1993).
Index of Civil Liberties: Gastil index of civil liberties, averaged over 1972–84 (Barro-Lee cross-country panel data).
Dummy for External War: Dummy for countries that participated in at least one external war over 1960–85 (Barro-Lee cross-country panel data).
Fraction of GDP in Mining, Type of Economic Organization, and Absolute Latitude: Hall and Jones (1999).

References

[1] Alesina, Alberto and Dani Rodrik, "Distributive Politics and Economic Growth," *Quarterly Journal of Economics*, May 1994, 109(2), 465–490.

[2] Barro, Robert J., "Economic Growth in a Cross Section of Countries," *Quarterly Journal of Economics*, May 1991, 106(2), 407–443.

[3] Barro, Robert J., *Determinants of Economic Growth: A Cross-Country Empirical Study*, 1997, The Lionel Robbins Lecture, Cambridge: The MIT Press.

[4] Barro, Robert J. and Jong Wha Lee, "International Measures of Schooling Years and Schooling Quality," *American Economic Review*, May 1996, 86(2), 218–223.

[5] Barro, Robert J., N. Gregory Mankiw, and Xavier Sala-i-Martin, "Capital Mobility in Neoclassical Models of Growth," *American Economic Review*, March 1995, 85(1), 103–115.

[6] Barro, Robert J. and Xavier Sala-i-Martin, "Convergence," *Journal of Political Economy*, April 1992, 100(2), 223–251.

[7] Barro, Robert J. and Xavier Sala-i-Martin, "Technological Diffusion, Convergence, and Growth," *Journal of Economic Growth*, March 1997, 2(1), 1–26.

[8] Basu, Susanto and David N. Weil, "Appropriate Technology and Growth," *Quarterly Journal of Economics*, November 1998, 113(4), 1025–1054.

[9] Benhabib, Jess and Mark M. Spiegel, "The Role of Financial Development in Growth and Investment," *Journal of Economic Growth*, December 2000, 5(4), 341–360.

[10] Bernanke, Ben S. and Refet S. Gürkaynak, "Is Growth Exogenous? Taking Mankiw, Romer, and Weil Seriously," *NBER Macroeconomics Annual 2001*.

[11] Bernard, Andrew B. and Charles I. Jones, "Technology and Convergence," *Economic Journal*, July 1996, 106(437), 1037–1044.

[12] Bosworth, Barry P., Susan M. Collins, and Yu-Chin Chen, "Accounting for Differences in Economic Growth," *Brookings Discussion Papers in International Economics No.115*, 1995.

[13] Bruno, Michael, and William Easterly, "Inflation Crises and Long-Run Growth," *Journal of Monetary Economics*, February 1998, 41(1), 3–26.

[14] Caselli, Francesco, "Comment" on Ben S. Bernanke and Refet S. Gürkaynak, "Is Growth Exogenous? Taking Mankiw, Romer, and Weil Seriously," *NBER Macroeconomics Annual 2001*, eds. Ben Bernanke and Kenneth S. Rogoff, MIT Press, Cambridge, MA, 2002.

[15] Christensen, Laurits R., Dianne Cummings, and Dale W. Jorgensen, "Relative Productivity Levels, 1947–1973: An International Comparison," *European Economic Review*, May 1981, 16(1), 61–94.

[16] Cohen, Daniel, and Marcelo Soto, "Growth and Human Capital: Good Data, Good Results," *Working Paper*, July 2006.

[17] Davidson, Russell and James G. MacKinnon, *Estimation and Inference in Econometrics*, New York: Oxford University Press, 1993.

[18] De la Fuente, Angel, and Rafael Doménech, "Human Capital in Growth Regressions: How Much Difference Does Data Quality Make?" *Journal of the European Economic Association*, March 2006, 4(1), 1–36.

[19] De Long, J. Bradford and Lawrence H. Summers, "How Strongly Do Developing Countries Benefit from Equipment Investment?" *Journal of Monetary Economics*, December 1993, 32(3), 395–415.

[20] Frankel, Jeffrey A. and David Romer, "Does Trade Cause Growth?" *American Economic Review*, June 1999, 89(3): 379–399.

[21] Hall, Robert E. and Charles I. Jones, "Why Do Some Countries Produce So Much More Output Per Worker than Others?" *Quarterly Journal of Economics*, February 1999, 114(1), 83–116.

[22] Hayami, Yujiro, "Toward an East Asian Model of Economic Development," in Hayami, Yujiro, and Masahiko Aoki, ed., *The Institutional Foundations of East Asian Economic Development*, 1998, Proceedings of the IEA (International Economic Association) Conference held in Tokyo, Japan. Britain: MacMillan Press Ltd.

[23] Hsieh, Chang-Tai, "What Explains the Industrial Revolution in East Asia? Evidence from the Factor Markets," *American Economic Review*, June 2002, 92(3), 502–526.

[24] Islam, Nazrul, "Growth Empirics: A Panel Data Approach," *Quarterly Journal of Economics*, 110(4), November 1995, 1127–1170.

[25] King, Robert G. and Ross Levine, "Finance, Entrepreneurship, and Growth: Theory and Evidence," *Journal of Monetary Economics*, December 1993, 32(3), 513–542.

[26] Klenow, Peter J. and Andres Rodriguez-Clare, "The Neoclassical Revival in Growth Economics: Has It Gone Too Far?" in Bernanke, Ben, and Julio Rotemberg, eds. *NBER Macroeconomics Annual 1997*, Cambridge: MIT Press.

[27] Kremer, Michael, "Population Growth and Technological Change: One Million B.C. to 1990," *Quarterly Journal of Economics*, Aug 1993, 108(3), 681–716.

[28] Mankiw, N. Gregory, David Romer, and David N. Weil, "A Contribution to the Empirics of Economic Growth," *Quarterly Journal of Economics*, May 1992, 107(2), 407–437.

[29] Persson, Torsten and Guido Tabellini, "Is inequality Harmful for Growth?" *American Economic Review*, June 1994, 84(3), 600–621.

[30] Psacharopoulos, George, "Returns to Investment in Education: A Global Update," *World Development*, September 1994, 22(9), 1325–1343.

[31] Rodriguez, Francisco, and Dani Rodrik, "Trade Policy and Economic Growth: A Skeptic's Guide to Cross-National Evidence," in Bernanke, Ben and Kenneth S. Rogoff, eds. *Macroeconomics Annual 2000*, Cambridge: MIT Press.

[32] Romer, David, "Comment" on Ben S. Bernanke and Refet S. Gürkaynak, "Is Growth Exogenous? Taking Mankiw, Romer, and Weil Seriously," in Bernanke, Ben and Kenneth S. Rogoff, eds. *NBER Macroeconomics Annual 2001*, Cambridge: MIT Press.

[33] Sachs, Jeffrey D. and Andrew M. Warner, "Economic Reform and the Process of Global Integration," *Brookings Papers on Economic Activity*, 1995, 1–95.

[34] Sala-i-Martin, Xavier, "I Just Ran Four Million Regressions," *NBER Working Paper No. 6252*, 1997.

[35] Solow, Robert M., "Technical Change and the Aggregate Production Function," *Review of Economics and Statistics*, August 1957, 39(3), 312–320.

[36] White, Halbert, "A Heteroskedasticity-Consistent Covariance Matrix Estimator and a Direct Test for Heteroscedasticity," *Econometrica*, May 1980, 48(4), 817–838.

[37] Young, Alwyn, "The Tyranny of Numbers: Confronting the Statistical Realities of the East Asian Growth Experience," *Quarterly Journal of Economics*, August 1995, 110(3), 641–668.