The Channels of Economic Growth: A Channel Decomposition Exercise

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Abstract

This paper formally introduces *channel decomposition*, a method that systematically decomposes the channels through which the determinants of growth operate, into the analysis of economic growth. Under channel decomposition, the determinants could affect economic growth through physical capital accumulation, through human capital acquisition, and/or through growth in total factor productivity. Thus, by examining the outcomes of the decomposition, we can test alternative models, as different models often imply different channels of operation for the determinants. Methodologically, channel decomposition combines growth accounting with regression analysis, rather than regarding them as alternative approaches. With this method, it becomes clear that technological catch-up, not factor accumulation, accounts for the widely documented phenomenon of conditional convergence. This finding turns out to be extremely robust. In effect, this finding puts the final nails in the coffin of the Neoclassical growth model, as the model can neither explain cross-country growth, nor can it explain conditional convergence. The method also shows that both rich and poor countries converge mainly through technological catch-up, although richer countries converge much faster than the poor.

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1 Introduction

This paper formally introduces the methodology of *channel decomposition* or *channel accounting* into the analysis of economic growth. This method systematically decomposes the channels through which the determinants of growth operate; 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 capita either by attracting investment in plants and factories, by encouraging further education, or by facilitating innovations and the diffusion of technology. Channel decomposition systematically determines the empirical importance of each of these potential channels.

Understanding the channels of growth is important for two reasons. First, a theoretical model may predict the correct reduced form relationship among aggregate variables, yet postulate the wrong mechanisms underlying this relationship. Such models are spurious, and can only be weeded out by studying the actual mechanisms. Second, since models can be observationally indistinguishable in the reduced form relationships they predict, but differentiable by the mechanisms they postulate, they are empiricially distinguishable by examining the actual channels of operation. Although there were several precursors to the idea of channel decomposition, they have failed to fully exploit this method as a systematic tool of analysis.[1] My study remedies this gap in the literature.

Methodologically, channel decomposition combines a growth accounting exercise with a cross-country regression – the two traditional approaches to the study of economic growth – by applying them sequentially. The growth accounting exercise decomposes observed economic growth into contributions due to factor accumulation and 'total factor productivity' (TFP).[2] On the other

[1] See, for example, Jeffrey A. Frankel and David Romer (1999) and Robert E. Hall and Charles I. Jones (1999).
[2] TFP, also known as 'Solow residual,' is often thought to reflect technological progress and other elements.

hand, cross-country regression attributes the *same* observed economic growth to the impact of determinants, such as government policies, the institutional environment, household preferences, natural resources, and initial conditions. Since both approaches attempt to explain the same object, the determinants must affect economic growth either through factor accumulation or through TFP growth. In practice, channel decomposition consists of two steps: first, decompose economic growth into components due to factor accumulation and TFP growth; next, regress these components on the determinants of growth. Hence, rather than regarding growth accounting and growth regression as alternative approaches to the study of economic growth, this paper stresses that they can be usefully combined to analyze the channels of growth.

Combining Peter J. Klenow and Andres Rodriguez-Clare's (1997) growth accounting methodology with Robert J. Barro's (1997) determinants of growth, channel decomposition reveals that technological catch-up, not factor accumulation, accounts primarily for the widely documented phenomenon of conditional convergence. Furthermore, although richer countries converge much faster than poorer ones, both rich and poor countries converge through the same channel, i.e., through TFP catch-up. The convergence channel through TFP growth is extremely robust to omitted variables, although the result is weaker if the alternative accounting methodology of Hall and Jones (1999) is used instead; in which case, TFP growth continues to drive convergence among the OECD countries, but physical capital accumulation is equally important in bringing about convergence among a larger cross-section of countries.

However, insofar as we care about convergence where its effect is the strongest, these findings essentially put the final nail in the coffin of the Neo-Classical growth model, as the model emphasizes the role of capital accumulation in economic growth. To elaborate, although the Neo-Classical growth model was rejected as an adequate explanation of cross-country growth when the growth accounting literature found a large TFP component in output per capita, it was later salvaged when cross-country regressions found significant conditional convergence, as economists thought convergence was due to diminishing returns to capital accumulation. However, since channel decomposition shows that, for the most part, growth in total factor productivity is what drives conditional convergence, the Neo-Classical growth model loses its appeal.

The remainder of this paper proceeds as follows. Section 2 reviews the growth regression and accounting approaches, followed by a synthesis that leads to channel decomposition. It then reviews the related literature and explains how the existing literature falls short of full-fledged channel decomposition. Section 3 describes the data. Section 4 presents the empirical results from channel decomposition and the robustness checks. Section 5 concludes.

2 The Methodology: A Two-Stage Channel Decomposition Approach

The empirical framework for growth regressions is based on the notion of conditional convergence developed by Robert J. Barro (1991) and N. Gregory Mankiw, David Romer, and David N. Weil (1992). Under that framework, income per capita in a given country converges to that country's steady-state. Since different countries may have different steady states, convergence is observed only after controlling for the determinants of the steady state, such as differences in government policies, political stability, and household preferences. In other words, observed income growth is a function of initial income and the determinants of steady state:

$$g(Y/L) = \alpha + \gamma lny_{i,t} + \theta' X_{i,t} + \epsilon_{i,t}, i = 1, ..., n, \tag{1}$$

where $g(.)$ denotes growth rate, Y income, L labor, $y_{i,t}$ income per capita for country i at time t, $X_{i,t}$ a column vector of variables that control for the determinants of steady-state income per capita, and $\epsilon_{i,t}$ is the disturbance term. Finally, $\beta' = (\alpha, \gamma, \theta')$ is a row vector of parameters of conforming dimensions. An estimated value of $\gamma < 0$ would imply conditional convergence in output per worker.

Under the growth accounting framework, observed economic growth can also be expressed as the sum of the 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, Romer and Weil (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, A is the productivity index, K is the physical capital stock, H is the human capital stock, L is labor, and $g(.)$ denotes the growth rate.[3] More generally, letting $GOUTPUT$, $GCAPITAL$, $GHUMAN$, 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 accumulation, 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 ($lny_{i,t}$ and $X_{i,t}$) – must affect the growth of output per worker ($GOUTPUT$) through three channels: physical capital accumulation, human capital acquistion, and/or TFP growth ($GCAPITAL$, $GHUMAN$ and GA). Substituting the growth

[3] There are two points worth noting about this decomposition methodology, as pointed out by Klenow and Rodriguez-Clare (1997). First, the decomposition is performed on output per capita rather than total output since differences in output per capita are the object of interest. Second, by decomposing the growth of output per capita 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. In addition, along a balanced growth path, the factor intensities are proportional to the investment rate, so that this form of the decomposition has a natural interpretation. Similar principles are adhered to in Hall and Jones (1999).

accounting identity (3) into the formula of a linear estimator of β, it follows that

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

where $\beta_{GOUTPUT}$, for example, denotes the coefficients obtained from regressing GCAPITAL on the determinants.[4] The above identity defines "channel decomposition." It is an identity because it is based on the growth accounting identity. By decomposing the coefficient estimates, I have in effect decomposed the channels of growth because the identity tells us that the effect of any determinant on the growth rate of output per worker ($\beta_{GOUTPUT}$) can be decomposed into the effect through the TFP growth (β_{GA}) and the effect through factor contributions ($\beta_{GCAPITAL}$ and β_{GHUMAN}). Hence, the relative importance of each channel can be measured by the relative magnitude of β_{GA}, $\beta_{GCAPITAL}$ and β_{GHUMAN} with respect to $\beta_{GOUTPUT}$.[5]

As an example, most cross-country studies find conditional convergence in output per worker at the rate of about 2.5 percent per year. The question is how much of this convergence is achieved through technological catch-up, and how much of it is due to aggregate factor accumulation. It turns out that 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 $lny_{i,t}$. 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 technological

[4] For example, consider the simplest linear estimator – the OLS estimator. To simplify the exposition, the intercept term and the initial income term in equation (1) can be suppressed under $X_{i,t}$ without loss of generality. The OLS estimator of $\beta_{GOUTPUT} = (X'X)^{-1}X'(GOUTPUT)$. Substitute the expression for $GOUTPUT$ from equation (3) into the OLS formula above, we get:

$$\begin{aligned}\beta_{GOUTPUT} &= (X'X)^{-1}X'(GCAPITAL + GHUMAN + GA)\\ &= (X'X)^{-1}X'(GCAPITAL) + (X'X)^{-1}X'(GHUMAN) + (X'X)^{-1}X'(GA)\\ &= \beta_{GCAPITAL} + \beta_{GHUMAN} + \beta_{GA}.\end{aligned}$$

[5] Note that the channel accounting identity is valid if and only if the same set of regressors and the same linear estimator are used in all regressions.

improvement rather than factor accumulation, and vice versa.

To perform channel decomposition in practice, I simply apply growth accounting and cross-country regression sequentially. First, I choose a growth accounting methodology to decompose the growth rate of output per worker. Then, I successively regress each component from the growth accounting exercise on the determinants. The coefficient estimates obtained from each regression together constitute channel decomposition, as they satisfy the channel accounting identity (4).

2.1 Related Literature

The idea that different determinants may affect economic growth through different channels is not new. In fact, this idea is arguably implicit in every growth accounting exercise.[6] However, empirical implementation of this idea is surprisingly scarce. I am only aware of four related papers. Barry P. Bosworth, Susan M. Collins, and Yu-Chin Chen (1995) and Jess Benhabib and Mark M. Spiegel (2000) contain ideas similar to channel decomposition, but their methods fail to amount to channel decomposition, as their estimates do not satisfy the channel accounting identity (4). Bosworth, Collins, and Chen (1995) study the effect of macroeconomic stability on aggregate factor growth and TFP growth.[7] 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.[8] Benhabib and Spiegel (2000) differ from the other papers in how factor shares are treated; they are estimated along with other parameters in the model, instead of assumed fixed.

Frankel and Romer (1999) and Hall and Jones (1999) do recognize the channel decomposition

[6] See, for example, Robert J. Barro (1998).

[7] Their main regression results are that orthodox macroeconomic policy, combined with outward oriented trade policies foster economic growth. In particular, they show that larger budget deficits slow growth through reducing capital accumulation, while real exchange rate volatility operates mainly through slower TFP growth. However, outward orientation appears to work through both channels.

[8] They find that the financial development indicators that are correlated with total factor productivity growth differ from those that encourage investment. However, many of their results are sensitive to the inclusion of country fixed effects.

interpretation; their estimates satisfy the channel accounting identity (4). However, in applying the method, both papers focus on only one of many determinants: trade share in the former and social infrastructure in the latter. Because of their focus, they fail to fully explore the method as a systematic approach of decomposing the channels of growth.[9] In addition, since both papers apply the method to level accounting rather than growth accounting, their results may be plagued by the influence of country-specific factors that remain constant over time.[10]

3 The Data

Given any growth accounting methodology and any linear regression estimator, the channel accounting identity will give a parallel decomposition in the channels of growth. In the following sections, I am going to illustrate this approach by applying a version of Barro's (1997) cross-country regression on the growth decomposition by Klenow and Rodriguez-Clare (1997).[11] 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 technological progress, physical capital accumulation, and human capital accumulation respectively? For example, Barro (1997) finds a conditional rate of convergence of 2.5 percent per year. The question is how much of this convergence is achieved through technological catch-up, and how much of it is due to faster physical and human capital accumulation.

The determinants in Barro (1997) include the most common set of determinants used in cross-country regressions. Data for these determinants have been collected from various sources.[12] They

[9] To be fair, one reason why both papers focus on only one determinant is certainly because they use instrumental variable regression. To the extent that they have valid instruments, they can consider the effect of the instrumented variable independently of other explanatory variables. However, the fact remains that they never use channel decomposition beyond showing that the particular determinant that they consider is important in the sense that it affects income through all channels. As a consequence, they fail to exploit the method as a systematic tool to decompose the channels of growth, and to use it to distinguish alternative models.

[10] Hall and Jones (1999) do control for the size of the mining sector, which is one component of the country-specific factors.

[11] The regressions here are cross-sectional, whereas Barro (1997) takes a panel regression approach.

[12] See the appendix for the sources.

correspond closely to the ones used in Barro (1997), except for the measure of initial human capital. To measure initial human capital, I use the average years of schooling in the total population aged 15 and over.[13]

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. They 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).

3.1 The Samples

I consider two samples of countries. The first sample consists of the 23 OECD countries.[14] 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 income convergence among the OECD countries is one of the most well documented phenomena in the literature, for this sample, I focus on the channels of convergence, i.e., whether income convergence is achieved through TFP growth or factor accumulation.

[13]Instead, Barro (1997) uses the average years of schooling for the male population aged 25 and over. While his measure of initial human capital fits his data best, a priori, it does not seem to accurately measure human capital for three reasons. First, it ignores female educational attainment, which tends to overestimate human capital in developing countries where educational opportunity is more uneven. Second, it includes only human capital embodied in persons aged 25 and over, which tends to underestimate the stock of human capital in developing countries where people tend to leave schools at a younger age. Third, it ignores primary education, which tends to underestimate human capital in developing countries. Because of the above reasons, I use a different measure of human capital.

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

The second sample includes 77 countries. It is used to estimate the baseline model, which includes all but three of the determinants found in Barro (1997). The three determinants excluded 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.[15] Thus, including initial life expectancy is likely to induce multicollinearity without adding any information. In any case, I will show that the channels for these three variables are indeed jointly statistically insignificant if they are included.

4 Empirical Results

4.1 Regression Results Using the OECD Sample

Convergence among OECD countries is one of the most well documented phenomena in the empirical growth literature. However, the channels through which this convergence is achieved remain largely unresolved. To analyze the channels of convergence, the log of initial real income per capita and its interaction with initial human capital are included. The interaction term is included because the speed of convergence may depend on the initial absorptive capacity of the economy. Table 1 reports the results from channel decomposition based on the OLS estimator, where convergence is conditional on initial human capital and the total fertility rate over 1960–1984.[16] The regression

[15]Initial life expectancy is often included to reflect better health of the population.

[16]Heteroskedasticity is a potential problem. The usual OLS estimator, while still consistent, becomes inefficient and the standard errors are biased when heteroskedasticity is not taken into consideration. To correct for heteroskedasticity, the bias-adjusted heteroskedasticity-consistent standard errors are used instead. Russell Davidson and James G. MacKinnon (1993) refer to the estimator I use as the HC2 estimator. It is essentially an improved White heteroskedasticity-consistent estimator. Note that an alternative remedy to heteroskedasticity is to use Weighted Least Squares (WLS). WLS is efficient under heteroskedasticity. However, the use of WLS requires some assumptions about the form of heteroskedasticity. For example, Barro (1991) weights the observations in accordance to the levels

estimates clearly satisfy the channel decomposition identity (4); the coefficient estimates in the $GOUTPUT$ regression in Table 1 are indeed the sum of the corresponding estimates in the GA, $GCAPITAL$, and $GHUMAN$ regressions.

The results in Table 1 imply conditional convergence at an annual rate of -2.58 percent for output per worker, -2.39 percent for TFP, and -0.57 percent for the contribution from physical capital accumulation. On the other hand, the contribution from human capital accumulation diverges at the rate of 0.37 percent per year.[17] These results imply that faster TFP growth alone accounts for more than 90 percent of the conditional convergence in output per worker.[18] In contrast, aggregate capital accumulation, i.e., physical and human capital accumulation taken together, contributes little to convergence. Furthermore, these channels of convergence are all statistically significant at the five percent level, except the channel through physical capital accumulation.[19] In short, TFP growth, not factor accumulation, is what drives income convergence among OECD countries.

4.2 Regression Results Using the Sample of 77 (Baseline Model)

The baseline model includes all but three determinants from Barro (1997). The three variables omitted are the change in terms of trade, initial life expectancy at birth and average inflation rate. As argued earlier, these variables have weak theoretical support for inclusion in the first place. The F-statistics testing their joint significance confirm that they are highly insignificant in all four

of per capita GDP. However, Francisco Rodriguez and Dani Rodrik (1999) argue that the errors for poor countries' growth data implied by such a weighting assumption seem to be unreasonably high. Moreover, heteroskedasticity may be a problem in some regressions but not for the others. In that case, only those that suffer from heteroskedasticity need to be adjusted. However, if different weights are used in different regressions, the channel decomposition identity of the two-stage approach will no longer hold. For these reasons, OLS with heteroskedasticity-consistent standard errors, instead of WLS, are used.

[17] Two variables — initial income and its interaction with initial human capital — are used to capture the convergence effect here. The rates of conditional convergence are evaluated at the average years of schooling among the 23 OECD countries in the year 1960, i.e., 6.53 years. For example, the rate of conditional convergence for the growth of output per worker is calculated as [-0.29+(-0.35)(6.53)] = -2.58 percent. I find very similar rates of convergence if I include only one of the two variables in the regression.

[18] This is because simple calculation gives $2.39/2.58 \times 100\% = 92.6$ percent.

[19] In other words, the coefficients on initial income and its interaction with initial human capital are jointly statistically significant at the five percent level in all regressions in Table 1, except the GCAPITAL regression.

Table 1: Channels of Convergence for OECD Countries

Independent Variables:	GOUTPUT	GA	GCAPITAL	GHUMAN
	Dependent Variable: Growth Rates of Output per Worker and its Components 1960–85			
Constant	6.47	6.09	5.17	-4.76
	(3.79)	(3.32)	(4.46)	(2.61)
ln (initial GDP per capita)	-0.29	-0.48	-0.51	0.70
	(0.43)	(0.41)	(0.50)	(0.31)*
Initial human capital	3.01	2.59	0.09	0.34
	(0.65)**	(0.40)**	(0.70)	(0.35)
Interaction term[a]	-0.35	-0.29	-0.01	-0.05
	(0.07)**	(0.05)**	(0.08)	(0.04)
ln (total fertility rate)	-1.33	-0.96	-0.40	0.02
	(0.37)**	(0.43)*	(0.45)	(0.27)
R^2	0.93	0.84	0.33	0.31
$Adj.R^2$	0.91	0.81	0.18	0.16
Rate of Convergence	-2.58	-2.39	-0.57	0.37
F statistic on convergence[b]	38.14	123.71	1.77	3.90

Notes: Number of observations = 23. 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.

[a] Interaction term between ln (initial GDP per capita) and initial human capital.

[b] F statistic testing the joint significance of ln (initial GDP per capita) and the interaction term.

regressions.[20] Table 2 reports the results from channel decomposition for the baseline model, using the OLS estimator. As the channel decomposition identity (4) dictates, the coefficient estimates in the GA, $GCAPITAL$, and $GHUMAN$ regressions in Table 2 indeed add up to the corresponding estimates in the $GOUTPUT$ regression.

All the coefficients in the $GOUTPUT$ regression have the right signs. However, the coefficients on the East Asian dummy, total fertility rate, democracy index and its square are not statistically significant at the ten percent level. The R-squared levels are 0.61, 0.43, and 0.26 in the GA,

[20]When I include these three variables for hypothesis testing, 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. Evaluated at the average level of initial human capital, which is 3.69 years for the full sample of 106 countries, the estimates imply an average rate of convergence of -2.45 percent in output per worker, which is very close to the -2.5 percent estimate found in Barro (1997). Channel decomposition reveals that of the -2.45 percentage points, -2.30 percentage points comes from technological catch-up (convergence), -0.24 percentage points from physical capital accumulation (convergence), and 0.09 percentage points from human capital accumulation (divergence). These estimates imply that TFP growth alone accounts for about 94 percent (=2.3/2.45 × 100%) of the conditional convergence in output per worker. Furthermore, the TFP channel is the only channel of convergence that is statistically significant. Thus, TFP growth is still what drives income convergence.

Table 2: Channel Decomposition - Baseline Regression

Independent Variables:	Dependent Variable: Growth Rates of Output per Worker and its Components 1960–85			
	GOUTPUT	GA	GCAPITAL	GHUMAN
Constant	12.25	12.73	0.40	-0.88
	(3.07)**	(4.17)**	(3.11)	(1.15)
ln (initial GDP per capita)	-1.07	-1.78	0.58	0.13
	(0.39)**	(0.55)**	(0.40)	(0.14)
Initial human capital	1.54	0.45	0.94	0.15
	(0.52)**	(0.67)	(0.48)	(0.19)
Interaction term	-0.18	-0.04	-0.13	-0.02
	(0.06)**	(0.08)	(0.06)*	(0.02)
ln (total fertility rate)	-0.83	-0.56	-0.27	0.00
	(0.53)	(0.66)	(0.40)	(0.16)
Government consumption ratio	-10.19	-7.62	-1.29	-1.30
	(2.87)**	(3.05)*	(2.35)	(1.28)
Rule of law index	1.89	2.31	-0.45	0.03
	(0.66)**	(0.70)**	(0.40)	(0.20)
Democracy index	0.02	1.39	-1.67	0.30
	(0.38)	(0.56)*	(0.41)**	(0.16)
Democracy index squared	-0.02	-0.16	0.18	-0.03
	(0.04)	(0.06)**	(0.04)**	(0.02)
Dummy for Sub-Saharan Africa	-2.02	-1.90	-0.14	0.03
	(0.46)**	(0.60)**	(0.40)	(0.15)
Dummy for Latin America	-1.46	-1.62	0.43	-0.26
	(0.33)**	(0.40)**	(0.26)	(0.09)**
Dummy for East Asia	-0.42	-1.46	1.11	-0.07
	(0.48)	(0.45)**	(0.37)**	(0.20)
R^2	0.70	0.61	0.43	0.26
$Adj.R^2$	0.65	0.54	0.34	0.13
Rate of Convergence	-1.75	-1.92	0.11	0.06
F statistic on convergence[a]	22.37	13.74	2.44	0.52
F Statistic on democracy index and its square[b]	0.95	4.14	8.46	1.81
F Statistic on exclusion[c]	2.17	0.81	1.49	0.40

Notes: Number of observations = 77. 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. [a] F statistic testing the joint significance of ln (initial GDP per capita) and the interaction term. [b] F statistic testing the joint significance of the democracy index and its square. [c] F statistic testing the joint significance of the terms of trade shock, initial life expectancy at birth, and average inflation.

$GCAPITAL$, 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 specific findings from channel decomposition are discussed below.

4.3 Empirical Findings on Channel Decomposition

4.3.1 Initial Income per Capita and the Interaction Term (Convergence)

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 -1.75 percent per year in output per worker, which is close to the estimates of -2 percent found by most studies. Of the -1.75 percentage points, -1.92 percentage points work through TFP growth (convergence), 0.11 percentage points through physical capital accumulation (divergence), and 0.06 percentage points through human capital accumulation (divergence). These channels are statistically significant at the ten percent level, except the channel through human capital acquisition.[21] These estimates indicate that technological catch-up, not factor accumulation, is the principal channel through which conditional convergence in income per worker is achieved. In fact, factor accumulation may actually lead to slight divergence.[22]

4.3.2 Initial Human Capital

A higher level of initial human capital would have two offsetting effects, as reflected by the positive coefficient on initial human capital and the negative coefficient on its interaction with initial income.

[21] In other words, the F statistics – that tests the joint significance of the coefficients on initial income per capita and its interaction with initial human capital – are statistically significant at the ten percent level for all of the regressions in Table 2 except the regression with $GHUMAN$ as the dependent variable.

[22] The above estimates are not sensitive to the inclusion of the interaction term between initial income per capita and initial human capital. Had the interaction term been excluded, the coefficient estimate on the logarithm of initial income per capita would have implied conditional convergence at the rate of -1.71 percent per year in output per worker. Of the -1.71 percentage points, -1.91 percentage points would have worked through TFP growth, 0.14 percentage points through physical capital accumulation, and 0.07 percentage points through human capital accumulation.

For example, consider the regression for output per worker: A higher level of initial human capital in the form of an additional year of average schooling would have two opposing effects; the direct effect would increase the growth rate of output per worker by 1.54 percentage points, while the indirect effect – due to the stronger tendency to converge – would reduce the growth rate of output per worker by 0.18(7.32) = 1.33 percentage points.[23] The net effect would have been an increase in the growth rate of output per worker of 0.21 percentage points.

Similarly, for each of the growth components, a higher level of initial schooling would also have two offsetting effects. Again evaluated at the average initial income per capita, the net effect of an additional year of average schooling in 1960 would be to raise the growth rate of TFP by 0.18 percentage points, the contribution from physical capital accumulation by 0.02 percentage points, and the contribution from human capital accumulation by 0.02 percentage points respectively.[24] Clearly, for the average country, faster technological catch-up is the principal channel through which initial human capital affects growth.

The negative coefficient on the interaction term with initial income implies that poorer countries would benefit more from a higher level of initial human capital. To illustrate, suppose the poorest country in 1960 were endowed with an additional year of schooling: the growth rate of output per worker would have increased by (1.54-(0.18)(5.55)=) 0.53 percentage points, of which 0.25 percentage points would be attributable to faster technological catch-up, while 0.24 percentage points and 0.04 percentage points would be by way of higher contribution from physical and human capital accumulation respectively.[25] Furthermore, note that the physical-capital-accumulation channel is

[23] This is evaluated at the average initial income per capita of the sample for which data is available. At the average, ln (initial GDP per capita) = 7.32.

[24] Had the interaction term been excluded, the coefficient estimate on initial human capital would imply that an additional year of average schooling at the beginning of the period would have raised the growth rates of output per worker and TFP by 0.05 and 0.15 percentage points respectively. On the other hand, it would have reduced the contribution from physical capital and human capital by 0.09 and 0.01 percentage points respectively, which are both economically small and statistically insignificant.

[25] The poorest country in 1960 has log of initial income per capita equal to 5.55.

more important for the poorer countries. In other words, for the poor countries, a more educated population stimulates growth by promoting both technological progress and physical capital accumulation. However, as countries develop and become wealthier, the marginal benefit from having a more educated population comes primarily through faster technological progress.

4.3.3 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. Roughly two thirds of the negative effect works through slower technological catch-up while the rest is 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 0.38 percentage points, the growth rate of TFP by 0.26 percentage points, and the contribution from physical capital accumulation by 0.12 percentage points. It would have no effect on the contribution from human capital accumulation.

4.3.4 Government Consumption to GDP Ratio

My measure of 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 nearly 75 percent of the total effect operating through slower technological progress, the only channel that is statistically significant. 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 0.62 percentage points. Similarly, it would reduce TFP growth by 0.46 percentage points, the contribution from physical capital and human capital accumulation by 0.08 and 0.08 percentage points respectively.

4.3.5 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 to proxy 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 0.32 and 0.39 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 my results imply that its growth rates of output per worker and TFP could have been higher by 0.63 and 0.77 percentage points respectively. Quite surprisingly, the channel through physical capital accumulation is not statistically significant.

4.3.6 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. 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 be spurious, as the scatter plots in Figure 1 in the appendix reveal: 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. What this means is that these missing observations could have distorted the above relationships.[26] Because of this robustness problem, little emphasis is placed on their significance.[27]

4.3.7 Regional Dummies

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 level. This suggests that the countries in sub-Saharan Africa are less developed 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 and statistically significant in both the aggregate and the TFP regressions. TFP again turns out to be the most important channel. However, the coefficient estimate implies that, on average, Latin American countries have a faster physical capital accumulation rate by about 0.43 percentage points, which is partially offset by their lower human capital accumulation

[26]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.

[27]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 Torsten Persson and Guido Tabellini (1994) and Alberto Alesina and Dani 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.

rate by about 0.26 percentage points. Finally, the coefficient estimates in Table 2 suggest that being an East Asian country has no significant effect on aggregate growth performance and human capital accumulation during 1960–1985. However, East Asian countries suffer from a lower TFP growth by about 1.46 percentage points, while experiencing a higher contribution from physical capital accumulation by 1.11 percentage points.

4.4 Robustness to Omitted Variables

I have shown that conditional convergence in income per worker is driven almost entirely by technological catch-up 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?[28]

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

The first robustness check takes the "most robust variables" from Xavier Sala-i-Martin (1997), and enters them one at a time into the baseline regressions.[29] 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. Table 3 reports the implied rates of convergence from this robustness check. It turns out that the TFP-convergence channel is remarkably robust to these perturbations.

Output per worker converges at a rate that ranges between -1.84 to -1.35 percent per year. 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 -2.02 to -1.26 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 often

[28]Clearly, the question of robustness can also be asked in relation to alternative growth accounting methodologies. This issue is taken up later.

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

not statistically significant at the five percent level; the rate of convergence ranges between -0.27 (convergence) to 0.19 percent (divergence) per year. Finally, the contribution to convergence from human capital accumulation is always divergent, though small and statistically insignificant at the five percent level; the rate ranges between 0.04 to 0.18 percent a year.

4.4.2 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. Table 4 reports the implied rates of convergence through each channel. Remarkably, TFP growth still emerges as the most important channel of convergence. Again evaluated at the average level of initial human capital, these coefficient estimates imply that output per worker converges conditionally at -1.28 percent per year, of which -1.48 percentage points work through TFP growth (convergence), -0.10 percentage points through physical capital accumulation (convergence), and 0.30 percentage points through human capital accumulation (divergence). All of these channels are statistically significant at the five percent level.

In summary, the fact that TFP growth drives conditional convergence is extremely robust to the inclusion of omitted variables, whether the 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, their effects are always small.

Table 3: Robustness of Technological Convergence - Including One at a Time

Additional Variable	N	Rates of Convergence GOUTPUT	GA	GCAPITAL	GHUMAN
Baseline	77	-1.74	-1.92	0.11	0.06
Regression		(22.37)***	(13.74)***	(2.44)*	(0.52)
Equipment	68	-1.38	-1.30	-0.25	0.17
Investment		(24.81)***	(11.94)***	(1.23)	(3.07)*
Sachs-Warner	77	-1.67	-1.84	0.06	0.09
Openness Index		(19.34)***	(12.71)***	(2.91)*	(0.60)
Fraction of	77	-1.70	-1.91	0.10	0.10
Confucius		(20.10)***	(12.86)***	(2.44)*	(0.55)
Fraction of	77	-1.77	-2.01	0.15	0.08
Muslim		(22.08)***	(14.29)***	(2.18)	(0.53)
Index of Civil	77	-1.75	-1.94	0.12	0.05
Liberties		(28.52)***	(19.08)***	(1.44)	(0.83)
Revolutions and	77	-1.74	-1.92	0.11	0.05
Coups per year		(22.41)***	(13.22)***	(2.39)	(0.47)
Fraction of GDP	77	-1.67	-1.70	-0.04	0.07
in Mining		(19.98)***	(10.32)***	(2.26)	(0.89)
Sd of Black	75	-1.69	-1.82	-0.03	0.15
Mkt Premium		(23.58)***	(11.21)***	(6.34)***	(1.59)
Primary	76	-1.74	-1.92	0.11	0.05
Exports		(18.51)***	(12.86)***	(1.76)	(0.65)
Type of Econ.	77	-1.73	-1.90	0.10	0.06
Organization		(29.97)***	(19.98)***	(2.19)	(0.48)
Dummy for	77	-1.83	-2.02	0.13	0.05
External War		(26.93)***	(17.55)***	(2.42)*	(0.42)
Non-Equipment	68	-1.34	-1.25	-0.27	0.18
Investment		(17.63)***	(7.91)***	(1.51)	(2.96)*
Absolute	77	-1.75	-1.98	0.18	0.03
Latitude		(23.43)***	(15.46)***	(2.93)*	(0.40)
Real Exchange	77	-1.74	-1.92	0.11	0.06
Rate Distortion		(22.12)***	(13.68)***	(2.31)	(0.54)

Notes: F statistics testing the hypothesis of zero rate of convergence are in parentheses. *Significantly different from zero at the ten percent level. **Significantly different from zero at the five percent level. ***Significantly different from zero at the one percent level.

Table 4: Robustness of Technological Convergence - Including All at Once

Independent Variables:	Dependent Variable: Growth Rates of Output per Worker and its Components 1960–85			
	GOUTPUT	GA	GCAPITAL	GHUMAN
ln (initial GDP per capita)	-0.07	-0.83	0.43	0.33
	(0.45)	(0.50)	(0.32)	(0.16)*
Interaction term	-0.33	-0.17	-0.14	-0.01
	(0.07)**	(0.08)*	(0.05)*	(0.03)
R^2	0.86	0.78	0.62	0.60
$Adj.R^2$	0.78	0.64	0.38	0.35
Rate of Convergence	-1.28	-1.48	-0.10	0.30
F statistic on conditional convergence/divergence[a]	18.06	8.52	3.51	4.07

Notes: Number of observations = 66. 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.
[a] F statistic testing the joint significance of ln (initial GDP per capita) and the interaction term.

4.5 Robustness to Sample Choice – 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.[30] This hypothesis is tested by comparing the fraction of income convergence achieved through each channel in rich and poor countries.

Specifically, the sample of 77 countries is first sorted according to income per worker in 1960 and then split into two halves. The baseline regressions are then re-run on each sub-sample. However, since there are no East Asian and no Sub-Saharan African countries in the richer half of the sample, the respective continent dummies have been dropped from the regressions. In addition, the rate of convergence for each sub-sample is calculated using the initial human capital at its respective sub-sample average: 5.27 years in the richer half and 2.29 years in the poorer half. Table 5 reports the results.

The results indicate that output per worker converges through TFP catch-up in both rich

[30] See, for example, Yujiro Hayami (1998).

Table 5: The Channels of Convergence for Rich and Poor Countries

Independent Variables:	Dependent Variable: Growth Rates of Output per Worker and its Components 1960–85			
	GOUTPUT	GA	GCAPITAL	GHUMAN
A. Convergence for the Richer Half of the 77 Sample (N = 38)				
ln (initial GDP per capita)	-0.28	-1.50	0.99	0.23
	(0.68)	(0.94)	(0.47)	(0.16)
Interaction term	-0.33	-0.14	-0.17	-0.02
	(0.09)	(0.13)	(0.10)	(0.03)
Rate of Convergence[a]	-2.01	-2.23	0.10	0.12
Fraction of Aggregate Convergence	1.00	1.11	-0.05	-0.06
F statistic on convergence[b]	24.84***	25.79***	2.45	1.08
B. Convergence for the Poorer Half of the 77 Sample (N = 39)				
ln (initial GDP per capita)	-0.11	-0.53	0.26	0.16
	(1.05)	(0.80)	(0.78)	(0.37)
Interaction term	-0.22	-0.09	-0.07	-0.06
	(0.37)	(0.32)	(0.27)	(0.16)
Rate of Convergence[c]	-0.60	-0.75	0.11	0.03
Fraction of Aggregate Convergence	1.00	1.25	-0.18	-0.05
F statistic on convergence[b]	0.64	0.82	0.06	0.09

Notes: Heteroskedasticity-consistent standard errors are in the parentheses.

[a] The rates of convergence are evaluated at the average initial human capital in this sub-sample, which is 5.27 years. There are no East Asian and Sub-Saharan African countries in this sub-sample and hence the respective continent dummies have been dropped from the regressions.

[b] F statistic testing the joint significance of ln (initial GDP per capita) and the interaction term. *Significantly different from zero at the ten percent level. **Significantly different from zero at the five percent level. ***Significantly different from zero at the one percent level.

[c] The rates of convergence are evaluated at the average initial human capital in this sub-sample, which is 2.29 years. All three continent dummies are included in the regressions.

and poor countries; indeed, TFP growth accounts for approximately the same fraction of income convergence in both sub-samples: 1.25 in the poorer half, compared to 1.11 in the richer half. However, convergence is much faster and statistically significant only in the rich countries. For example, the rate of convergence in income per worker is -2.01 percent in the richer sub-sample, compared to only -0.60 percent in the poorer sub-sample. Factor accumulations, on other hand, lead to divergence in both rich and poor countries. To summarize, while the tendency to converge is much stronger in the richer countries, it always works through the same channel – the TFP channel.

4.6 Robustness to Alternative Accounting 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 in the real world; 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.[31] With this alternative accounting methodology, TFP growth is still the dominant channel of convergence among the OECD countries, but it ceases to be the only channel in the larger 77-country sample; physical capital accumulation turns out to be equally important in driving convergence among this larger cross-section of countries.

More generally, Hall and Jones (1999) use the Cobb-Douglas approach with standard elasticities. They report that this simple approach yields similar results to Robert M. Solow (1957) and Laurits

[31] There is a minor modification. 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.

R. Christensen, Dianne Cummings, and Dale W. Jorgensen (1981). They assume a production function $Y = K^{\alpha}(AH)^{1-\alpha}$, where Y is output, K the stock of physical capital, H human capital-augmented labor, and A 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 of physical capital to output ratio, human capital per worker, and productivity:[32]

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

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 George Psacharopoulos (1994), and are the average return in the sub-Saharan Africa, the entire world, and the OECD countries respectively.[33]

4.6.1 Growth Decomposition Based on the Accounting Methodology of Hall and Jones

The above methodology leads to growth decomposition for 95 countries, 92 of which overlap with Klenow and Rodriguez-Clare's 98-country sample. Furthermore, it contains all the countries in the sample of 77. Both methodologies lead to a large TFP component. The components from the two decompositions have a pair-wise correlation coefficient of 0.68 for physical capital accumulation, 0.50 for human capital accumulation, and 0.75 for TFP growth. All of these coefficients are statistically

[32] Hall and Jones (1999) are interested primarily in the levels of economic activities, not growth rates. However, it is straightforward to calculate growth rates from levels.

[33] In contrast, Klenow and Rodriguez-Clare (1997) assume a constant return of 9.5 percent for all educational levels. Both Klenow and Rodriguez-Clare (1997) and Hall and Jones (1999) construct physical capital using the perpetual inventory method.

Table 6: Comparison of Summary Statistics from Alternative Decompositions

Growth rates of output per worker and its components over 1960-1985	Mean	Std. Dev.	Minimum	Maximum
Growth rate of output per worker	2.23	1.59	-1.8	6.85
Contribution from physical capital	0.79	0.90	-1.63	4.07
	0.59	1.40	-3.02	6.46
Contribution from human capital	0.46	0.34	-0.43	1.57
	0.77	0.42	-0.38	1.73
TFP growth	0.98	1.59	-3.26	4.81
	0.86	1.61	-3.90	4.26

Note: The number of observation = 92. The first number refers to the observations from Klenow and Rodriguez-Clare's decomposition while the second one refers to the observations based on Hall and Jones' decomposition.

significant at the 1 percent level.

Table 6 reports the summary statistics for the overlapping 92-country sample from the two decompositions. The average rates of TFP growth from the two decompositions appear to be similar. Klenow and Rodriguez-Clare attribute more growth to contribution from physical capital accumulation.[34] Overall, the resulting growth decompositions seem to be quite insensitive to the specific change in accounting methodology.

4.6.2 Channel Decomposition Based on the Accounting Methodology of Hall and Jones

In this section, I perform channel decomposition using the components of growth based on Hall and Jones's methodology. Table 7 reports the OLS regressions for the OECD countries. It shall be compared to Table 1. As before, output per worker converges conditionally at -2.58 percent per year. Of the -2.58 percentage points, -2.17 percentage points now work through TFP growth (convergence), -0.69 percentage points through physical capital accumulation (convergence), and 0.27 percentage points through human capital accumulation (divergence). All these channels are

[34] This is probably not surprising considering that Klenow and Rodriguez-Clare (1997) assign a higher weight to the physical capital-output ratio. They use $\alpha/(1-\alpha-\beta)$ instead of $\alpha/(1-\alpha)$ although both Klenow and Rodriguez-Clare (1997) and Hall and Jones (1999) set α equal to 0.3 (compare equation (2) to equation (5)).

Table 7: Channels of Convergence for OECD Countries Based on Hall and Jones's Growth Decomposition

Independent Variables:	Dependent Variable: Growth Rates of Output per Worker and its Components 1960–85			
	GOUTPUT	GA	GCAPITAL	GHUMAN
Constant	6.47	7.74	-0.34	-0.94
	(3.79)	(5.17)	(2.78)	(2.10)
ln (initial GDP per capita)	-0.29	-0.51	-0.08	0.30
	(0.43)	(0.61)	(0.32)	(0.26)
Initial human capital	3.01	2.27	0.85	-0.11
	(0.65)**	(0.78)**	(0.56)	(0.28)
Interaction term	-0.35	-0.25	-0.09	-0.01
	(0.07)**	(0.09)*	(0.06)	(0.03)
ln (total fertility rate)	-1.33	-2.34	0.99	0.02
	(0.37)**	(0.68)**	(0.37)*	(0.26)
R^2	0.93	0.75	0.55	0.65
Rate of Convergence	-2.58	-2.17	-0.69	0.27
F statistic on convergence[a]	37.91	29.14	2.73	1.38

Notes: Number of observations = 23. 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.
[a] F statistic testing the joint significance of ln (initial GDP per capita) and the interaction term.

statistically significant at the ten percent level, except the channel through human capital acquisition. Thus, despite the change in accounting methodology, the OECD countries still converge through technological catch-up, not factor accumulation.

Table 8 reports the OLS regressions for the sample of 77 countries based on Hall and Jones's methodology. It shall be compared to Table 2. Evaluated at the average initial schooling of 3.69 years as before, the coefficient estimates imply a convergence rate of -1.75 percent per year in output per worker, conditional on the other determinants in the regression. However, of the -1.75 percentage points, -0.96 percentage points now work through TFP growth (convergence), -1.00 percentage point through physical capital accumulation (convergence), and 0.21 percentage points through human capital accumulation (divergence). All channels, except the channel of human capital accumulation, are statistically significant at the ten percent level. Thus, with the accounting methodology of Hall and Jones (1999), TFP growth and physical capital accumulation turn out to be equally important in driving convergence among the 77 countries. The contribution to convergence from human capital acquisition remains small.

4.7 Final Nail in the Coffin of the Neo-Classical Growth Model

Under the 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.[35] Thus, the two literatures seem to contradict each other concerning the role of capital accumulation and the Neo-Classical growth model which highlights it; while capital accumulation cannot explain much of the variation in the levels and growth rates of incomes, it is thought to *somehow* account for conditional convergence. Although theoretical models that emphasize the role of technological diffusion in conditional convergence have recently emerged (for example, Andrew B. Bernard and Charles I. Jones (1996), Robert J. Barro and Xavier Sala-i-Martin (1997), and Susanto Basu and David N. 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 method of channel decomposition. Large Solow residuals are consistent with conditional convergence because convergence turns out to work through technological catch-up rather than aggregate capital accumulation. This finding is extremely robust to the omitted variables. It is also robust to the alternative accounting methodology by Hall and Jones (1999), if we restrict our attention to convergence among the OECD countries, where the tendency to converge is the strongest. Hence, for the most part, aggregate capital accumulation

[35] See, for example, Mankiw, Romer, and Weil (1992), Robert J. Barro and Xavier Sala-i-Martin (1992), and Robert J. Barro, N. Gregory Mankiw, and Xavier Sala-i-Martin (1995).

Table 8: Channel Decomposition Based on Hall et al.'s Decomposition Baseline Regression

Independent Variables:	Dependent Variable: Growth Rates of Output per Worker and its Components 1960–85			
	GOUTPUT	GA	GCAPITAL	GHUMAN
Constant	12.25	1.03	10.66	0.54
	(3.07)**	(4.65)	(3.61)**	(1.32)
ln (initial GDP per capita)	-1.07	-0.59	-0.70	0.22
	(0.39)**	(0.61)	(0.44)	(0.13)
Initial human capital	1.54	1.02	0.64	-0.13
	(0.52)**	(0.86)	(0.62)	(0.22)
Interaction term	-0.18	-0.10	-0.08	-0.00
	(0.06)**	(0.10)	(0.07)	(0.03)
ln (total fertility rate)	-0.83	-0.46	-0.24	-0.12
	(0.53)	(0.78)	(0.47)	(0.18)
Government consumption ratio	-10.19	-2.68	-5.61	-1.91
	(2.87)**	(3.01)	(2.23)*	(0.96)
Rule of law index	1.89	1.43	0.63	-0.17
	(0.66)**	(0.77)	(0.58)	(0.21)
Democracy index	0.02	2.34	-2.18	-0.14
	(0.38)	(0.55)**	(0.37)**	(0.14)
Democracy index squared	-0.02	-0.26	0.23	0.01
	(0.04)	(0.06)**	(0.04)**	(0.02)
Dummy for Sub-Saharan Africa	-2.02	0.06	-1.79	-0.29
	(0.46)**	(0.72)	(0.57)**	(0.17)
Dummy for Latin America	-1.46	-1.49	0.19	-0.15
	(0.33)**	(0.46)**	(0.31)	(0.09)
Dummy for East Asia	-0.42	-2.04	1.33	0.28
	(0.48)	(0.56)**	(0.46)**	(0.19)
R^2	0.70	0.49	0.56	0.54
Rate of Convergence	-1.75	-0.96	-1.00	0.21
F statistic on convergence[a]	22.43	2.87	5.73	1.90
F Statistic on democracy index and its square[b]	0.96	9.31	17.04	1.37

Notes: Number of observations = 77. 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.

[a] F statistic testing the joint significance of ln (initial GDP per capita) and the interaction term.

[b] F statistic testing the joint significance of the democracy index and its square.

does not account for worldwide economic growth or cross-country income differences, nor does it account for conditional convergence.[36] In this sense, this finding essentially puts the final nail in the coffin of capital accumulation and the Neo-Classical growth model.[37]

5 Conclusion

This paper proposes an intuitive method to study the channels of economic growth. I argue that channel decomposition is useful because it systematically distinguishes alternative models by exploiting the different channels of operation they postulate: whether they operate through physical capital and human capital accumulation, or through total factor productivity growth. This method gives a channel accounting identity which is reminiscent of the growth accounting identity first proposed by Robert Solow more than forty years ago. This should not be surprising, since channel decomposition is in fact built on the growth accounting literature spawned by Solow's original 1957 paper and on the growth regression literature prompted by the advent of large scale cross-country data sets. Specifically, channel decomposition is applied 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, for the most part, contrary to conventional wisdom, convergence is not due to diminishing returns to factor accumulation as the Neoclassical growth model postulates. In fact, the contribution from human capital accumulation tends to lead to divergence, although the effect is almost never statistically significant. Furthermore, the contribution to convergence from physical

[36] However, the speed of convergence does depend on the initial level of human capital, which measures the ability of countries to adopt frontier technology.

[37] The empirical evidence here seems most consistent with the theoretical model by Bernard and Jones (1996). They advocate technology transfer as a potentially important force behind convergence in the framework of a constant returns Solow growth model.

capital accumulation is small and ambiguous in most cases. On the contrary, it is technological catch-up which turns out to drive conditional convergence in income per capita. More generally, although the rate of convergence is faster among richer countries, the channel of convergence is the same for both the rich and poor countries, i.e., both converge through TFP catch-up, not factor accumulation. This finding about TFP convergence is extremely robust to the inclusion of omitted variables, albeit less so when the accounting methodology of Hall and Jones (1999) is used. However, even under this alternative accounting methodology, TFP growth remains as the main channel of convergence among the OECD countries, where convergence is the fastest. In conclusion, these findings about the channels of convergence effectively put the final nail in the coffin of the Neo-Classical growth model, as it cannot explain either cross-country growth or conditional convergence.

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6 Appendix: Sources of Data

The following contains the sources of the variables. Some calculations may have been performed on the raw data to arrive at the variables used in the regressions, e.g., taking averages or logarithms. Except when noted specifically below, the variables for robustness checks come from Sala-i-Martin (1997).

Initial GDP per Capita: Real GDP per capita in constant dollars in 1960 (Penn World Table 5.6).

Initial Human Capital: Average years of schooling in the total population over age 15 (Barro-Lee Data Set).

Total Fertility Rate: Average fertility rate during 1960–84 (Barro-Lee Data Set).

Government Consumption Ratio: The ratio of real government consumption expenditure net of spending on defense and on education to real GDP (Barro-Lee Data Set).

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 Data Set).

Continent Dummies: Barro-Lee Data Set.

Terms of Trade Shock: Growth rate of export prices minus growth rate of import prices over 1960–84 (Barro-Lee Data Set).

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 Data Set).

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 Data Set).

Dummy for External War: Dummy for countries that participated in at least one external war over 1960–85 (Barro-Lee Data Set).

Fraction of GDP in Mining, Type of Economic Organization, and Absolute Latitute: Hall and Jones (1999).

Figure 1: Scatter Plots Between Components of Growth and the Democracy Index ('small circle' indicates that the country is included in the Sample of 77, whereas 'large square' denotes that the country is omitted from the Baseline Regression due to missing values in other explanatory variables in the regression)