# An Accounting Method for Economic Growth

Hongchun Zhao*

PhD student at University of Southern California

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**Abstract**

As Chari et al. (2007) indicate, many growth theories explaining frictions in real economies are equivalent to a competitive economy with some exogenous taxes. Using this idea, I develop an accounting method for identifying fundamental causes of economic growth. A two-sector neoclassical growth model with taxes is used as a prototype economy, and its equilibrium conditions define wedges. These wedges endogenously determine the long run growth rate, which is exogenous and not correlated with any other variables in a one-sector growth model. Furthermore, the importance of wedges in explaining the long-run growth rate can be evaluated through the prototype economy. Applying this method to fifty countries reveals that, among seven wedges, two wedges are important in explaining economic growth.

*Address: 3620 Vermont Ave., KAP 300, Economics Department, University of Southern California, Los Angeles, CA 90089; email address: hongchuz@usc.edu; telephone: 323-229-0922; fax: 213-740-8543. I thank Caroline Betts, Selo Imrohoroglu, Doug Joines, Michael Magill, Jeff Nugent, and Lee Ohanian for useful comments. All errors are my own.

# 1. Introduction

Differences in economic growth across countries have been substantial in history. Since 1950 the industrial countries have either grown at a remarkably stable rate or converged to the stable trend, a few developing countries have experienced rapid growth, yet some other countries grow at only a stagnant rate. Over the last two hundred years the industrial leaders also witness accelerating economic growth: the United Kingdom grew around 1.2% per year from 1820 to 1890; and the United States has a 2% average annual growth rate throughout the twentieth century (use data from Maddison (2003)). What sustains growth over long periods of time? Which country will be the industrial leader in the twenty-first century, and what will its trend growth rate be? In this paper, I extend the "Business Cycle Accounting" framework of Chari et al. (2007) to provide a platform for addressing these questions.[1]

The insight from Chari et al. (2007) is that a neoclassical growth (NCG) model with taxes is a good perspective with which underlying causes of the observed gaps in growth can be analyzed. Wedges associated with a prototype economy's equilibrium conditions can be defined as exogenous variables, and interpreted as taxes, efficiency shifters, and government consumption. Furthermore, specific growth models that can theoretically explain the observed gaps correspond to these wedges too. Compared with the conventional growth accounting method, the whole set of equilibrium conditions, rather than only production functions, are used to decompose economic growth; and the decomposition results can be connected to the fundamental causes of growth more easily. I choose a two-sector NCG model, essentially Rebelo (1991) with different taxes, as the prototype economy, in which the long run economic growth is endogenously driven by the accumulation of the broadly defined human capital.

When the values of the endogenous variables and parameters in the prototype economy are observable, the wedges defined by equilibrium conditions of the prototype economy can be recovered. Substituting these variables and parame-

[1] Kydland and Prescott (1982) unify business cycle and growth theory by arguing that business cycle models should be consistent with the empirical regularities of long-run growth. So growth theories can naturally take advantage of any methodology that proves to be useful in business cycle models.

ters into each equilibrium condition of the prototype economy gives the wedge value associated with that equation. Given the values of individual wedges, their relevance can be evaluated through the prototype economy too. This flexibility allows us to tackle the important question of identifying fundamental causes of the long-term economic growth.

I collect the relevant data for fifty countries, measure various wedges for each country and evaluate the contributions of individual wedges. By assuming that no frictions exist in the US, and using the detailed data for the US during the 1960-2000 period, I calibrate the parameters in the prototype economy. The US is a critical benchmark for this study and the interpretation of the experiment results should be based on the critical assumption, because there may be distortions even in a comparably undistorted country such as the US. The main findings reveal some interesting observations. In accounting for growth performance across countries, on average, the efficiency wedge with the production function for the broadly defined human capital, and the wedge associated with the Euler equation for human capital are of primary importance. The wedge with the labor-leisure trade-off condition and the wedge with the condition of the allocation of labor across sectors are also important, though their effects are smaller. Moreover, these patterns are robust across the sub-samples of countries in and out of the Organization for Economic Co-operation and Development (OECD). These results will help researchers develop quantitative models of economic growth.

This paper relates to a large literature that studies the determinants of the large gaps of economic performance. Some studies deal with proximate causes, such as physical and human capital, or technology changes and adoption (e.g., Lucas (1988), Romer (1990), and Klenow and Rodriguez-Clare (2005)). Others pay more attention to fundamental causes, such as differences in raw materials, geography, preferences, and economic policies (e.g., McGrattan and Schmitz (1999), Cole et al. (2005), Acemoglu et al. (2001) and Rodrik et al. (2004)). [2] Re-

[2] Solow (1957) is an early, but modern, attempt to account for different patterns of economic development, which becomes the cornerstone of the NCG model. Lucas (1988) emphasizes the effects of human capital accumulation; Romer (1990), among others, endogenizes technological change; Klenow and Rodriguez-Clare (2005) address the interaction between open economies. McGrattan and Schmitz (1999) focus on differences in economic policies and review estimates for a wide range of policy variables; Cole et al. (2005) argue that Latin America's failure to replicate Western economic success is primarily due to TFP differences, and that barriers to competition

cently, Hsieh and Klenow (2009) study the misallocation in manufacturing activities with firm-level precision. This is promising in explaining the cross-country efficiency variations, which underlie the exogenous efficiency shifters in my paper. My paper complements this literature by organizing promising stories under a unified framework. In this respect, my work provides a particular response to Lucas (1988), where the author recommended economists: (1) to develop quantitative theories that describe the observed differences across countries and over time, in both levels and growth rates of income per person; (2) to explore the implications of competing theories with respect to observable data; and (3) to test these implications against observation.

The rest of the paper is organized as follows. Section 2. describes the prototype economy, its steady-state equilibrium, and its relationship with a standard one-sector growth model with wedges. Section 3. briefly explains the accounting procedure, presents the raw data sources, the construction of variables, including the broadly defined human capital and its relative price in terms of final goods. Section 4. shows the experiment results. Section 5. concludes.

## 2. The Prototype Economy

In this section, I specify the prototype economy as a two-sector model of endogenous growth with taxes, and describe its steady-state equilibrium.

The prototype economy is a variant of Rebelo's two-sector model (see Rebelo (1991)). One sector produces final goods, which can be either consumed or invested in physical capital; the other sector produces human capital, which enhances labor productivity. Both sectors use Cobb-Douglas aggregate production functions,[3]

$$y(t) = A[v(t)k(t)]^{\alpha}[u(t)h(t)l(t)]^{1-\alpha}, \tag{1}$$

$$x_h(t) = B[(1-v(t))k(t)]^{\alpha}[(1-u(t))h(t)l(t)]^{1-\alpha}, \tag{2}$$

where $y$, $l$, $x_h$, $k$ and $h$ are per person output of final goods, labor input, invest-

are the cause of these differences.

[3]Sturgill (2009) suggests that the inclusion of energy as a further input has a substantial impact on the estimated contribution of TFP on long-run growth. So this widely-used specification of production function deserves a further consideration.

ment in human capital, physical capital stock and human capital stock respectively;[4] $v$ and $u$ represent the fractions of physical capital stock and labor devoted to the final goods sector; $\alpha$ represents the common capital share in both sectors;[5] $A$ and $B$ are two productivity shifters in these two sectors.[6]

Firms face competitive output and factor markets, and thus they take the relative price of human capital in terms of final goods $q$, factor prices of physical capital and labor in the final goods sector ($r_k$, $w_k$) and in the other sector ($r_h$, $w_h$) as given when they make their output decisions. The costs of physical capital and labor in the final goods sector are taxed with rates $\tau_1$ and $\tau_2$. And firms find the capital-labor combinations to maximize their profits,

$$y(t) - (1+\tau_1)r_k(t)v(t)k(t) - (1+\tau_2)w_k(t)u(t)l(t),$$

$$q(t)x_h(t) - r_h(t)(1-v(t))k(t) - w_h(t)(1-u(t))l(t).$$

Let $x_k$ denote per person physical capital investment, $\delta_k$ the depreciation rate of physical capital. Then the law of motion for physical capital is,

$$(1+n)k(t+1) = (1-\delta_k)k(t) + x_k(t), \tag{3}$$

With a depreciation rate for human capital $\delta_h$, the law of motion for human capital can be similarly defined,[7]

$$(1+n)h(t+1) = (1-\delta_h)h(t) + x_h(t). \tag{4}$$

[4]When there is no risk of confusion, I drop time arguments, but whenever there is the slightest risk of confusion, I will err on the side of caution and include relevant arguments.

[5]Capital shares need be sector-specific both conceptually and empirically. However, the lack of reliable data for certain components of human capital makes calibrating the human capital production function considerably more difficult.

[6]These production technologies are labor-augmented $Y = AK^{\alpha}(hL)^{1-\alpha}$, where uppercase variables denote total amounts. The reason why I choose the labor-augmented technology is that any technology consistent with balanced growth can be represented by this form.

[7]If the labor-augmented human capital includes a general technology level that can be "publicly" used, population growth would not dilute the human capital stock per person. Then the law of motion would be $h(t+1) = (1-\delta_h)h(t) + x_h(t)$. Both forms follow Ben-Porath (1967). A different approach is a log-linear law of motion. Chang et al. (2002) use the log-linear approach to analyze learning by doing, Hansen and Imrohoroglu (2009) extend it to study on-the-job training. Both approaches are approximately isomorphic to each other around steady state.

There is a representative household in the model. The physical capital and human capital investment made and the total labor income earned by the household are taxed with after-tax rates $(1+\tau_{xk})(1-\tau_1)$, $(1+\tau_{xh})(1-\tau_l)$ and $(1-\tau_l)$ respectively. The household also receives a lump-sum transfer, whose per person value, $T$, equals all tax revenues minus the government consumption $g$. Assume that $\tau_{xk}\tau_1 = \tau_{xh}\tau_1 = 0$. Then

$$T = \tau_1 r_k k_k + \tau_2 w_k l_k + (\tau_{xk} - \tau_1)x_k + (\tau_{xh} - \tau_l)q x_h + \tau_l[w_k u l + w_h(1-u)l] - g.$$

The household has $N(t)$ members, which grows at a rate of $n$. It maximizes a discounted utility over flows of consumption $c(t)$ and leisure $1-l(t)$. Let $\beta \in (0,1)$ be its discount factor, and $\theta \in (0,1)$ be the consumption share in the period utility function. The household's problem is,

$$\max \sum_{t=0}^{\infty} \beta^t [\theta \ln c(t) + (1-\theta)\ln(1-l(t))]N(t),$$

subject to (a) a budget constraint,

$$\begin{aligned} c(t) + (1+\tau_{xk})(1-\tau_1)x_k(t) + (1+\tau_{xh})(1-\tau_l)q(t)x_h(t) = r_k(t)v(t)k(t) \\ + r_h(t)(1-v(t))k(t) + (1-\tau_l)[w_k(t)u(t)l(t) + w_h(t)(1-u(t))l(t)] + T(t), \end{aligned}$$

(b) factor prices derived from profit maximization problems,

$$(1+\tau_1)r_k(t) = \alpha y(t)/[v(t)k(t)],$$

$$(1+\tau_2)w_k(t) = (1-\alpha)y(t)/[u(t)l(t)],$$

$$r_h(t) = q(t)\alpha x_h(t)/[(1-v(t))k(t)],$$

$$w_h(t) = q(t)(1-\alpha)x_h(t)/[(1-u(t))l(t)],$$

(c) the law of motion for physical capital and human capital, and $x_k(t), x_h(t) \geq 0$.

The competitive equilibrium of the prototype economy is a set of prices and allocations such that they are solutions to firms' and consumers' problems, and satisfy the resources balance,

$$c(t) + x_k(t) + g(t) = y(t). \tag{5}$$

The return to human capital investment is a higher labor income. Notice that the wage rate perceived by the household is $w = \frac{q(1-\alpha)x_h}{(1-u)hl}h$, which equals the human capital stock multiplied by a term that the household takes as given in equilibrium. Then the equilibrium conditions can be derived as follows,

$$(1-\tau_l)\frac{\theta}{c(t)}\frac{(1-\alpha)q(t)x_h(t)}{(1-u(t))l(t)} = \frac{1-\theta}{1-l(t)} \tag{6}$$

$$(1+\tau_1)q(t)x_h(t)v(t) = y(t)[1-v(t)], \tag{7}$$

$$(1+\tau_2)q(t)x_h(t)u(t) = y(t)[1-u(t)], \tag{8}$$

$$\frac{c(t+1)}{c(t)}(1+\tau_{xk}) = \beta[\frac{\alpha y(t+1)}{v(t+1)k(t+1)} + (1-\delta_k)(1+\tau_{xk})] \tag{9}$$

$$\frac{c(t+1)}{c(t)}(1+\tau_{xh}) = \beta\frac{q(t+1)}{q(t)}[\frac{(1-\alpha)x_h(t+1)}{(1-u(t+1))h(t+1)} + (1-\delta_h)(1+\tau_{xh}], \tag{10}$$

together with production functions, laws of motion, and the resources balance. Given the transversality condition, $\lim(\frac{\beta(1+\gamma)}{(1+\gamma)^\theta})^t c(0)^{-\theta}y(0) = 0$, and the initial stocks, $k(0)$, $h(0)$,these equations characterize competitive equilibrium paths of the prototype economy.[8]

[8]Solving the following Bellman equation yields equilibrium conditions,

$$V(k,h) = \max\{U(c,l) + \beta(1+n)V(k',h')\}$$

where $c = r_k vk + r_h(1-v)k + (1-\tau_l)[w_k ul + w_h(1-u)l] + T - (1+\tau_{xk})(1-\tau_1)[(1+n)k' - (1-\delta_k)k] - (1+\tau_{xh})(1-\tau_l)q[(1+n)h' - (1-\delta_h)h]$. Notice that equations (6), (7) and (8) are from first order conditions with respect to $l$, $v$ and $u$,

$$U_c(1-\tau_l)(w_k u + w_h(1-u)) + U_l = 0$$
$$r_k k - r_h k = 0$$
$$(1-\tau_l)(w_k l - w_h l) = 0.$$

Using canonical dynamic programming, we obtain,

$$c'(1+\tau_{xk})(1-\tau_1) = c\beta[r'_k + (1-\delta_k)(1+\tau_{xk})(1-\tau_1)]$$
$$c'(1+\tau_{xh})(1-\tau_l)q = c\beta[(1-\tau_l)(\frac{\partial w'}{\partial h'})l' + q'(1-\delta_h)(1+\tau_{xh})(1-\tau_l)].$$

The prototype economy also has a steady-state equilibrium, whose local properties are now well understood: a unique steady-state equilibrium exists, and it is saddle-path stable (e.g., Mulligan and Sala-i Martin (1993)). In the steady-state equilibrium, the growth rate of every variable is constant.[9] More specifically, $v$, $u$, $l$, and $q$ are constants, and all other endogenous variables grow at the same rate, $\gamma$. As a result, solutions to the steady-state equilibrium are only ratios or rates. There are ten equations that can be used to solve for the ten endogenous variables, $v$, $u$, $l$, $q$, $\gamma$, $h/k$, $y/k$, $c/k$, $x_k/k$, and $x_h/h$.

In later sections, I only use the steady-state equilibrium conditions to derive country-specific wedges. For clarity, the steady-state equilibrium conditions are collected in one place as follows,

$$(1-\tau_l)\frac{1-l}{l}\frac{(1-\alpha)qx_h}{(1-u)h}\frac{h}{k}=\frac{1-\theta}{\theta}\frac{c}{k}, \tag{11}$$

$$(1+\tau_1)v\frac{qx_h}{h}\frac{h}{k}=(1-v)\frac{y}{k}, \tag{12}$$

$$(1+\tau_2)u\frac{qx_h}{h}\frac{h}{k}=(1-u)\frac{y}{k}, \tag{13}$$

$$(1+\gamma)(1+\tau_{xk})=\beta[\frac{\alpha y}{vk}+(1-\delta_k)(1+\tau_{xk})], \tag{14}$$

$$(1+\gamma)(1+\tau_{xh})=\beta[\frac{(1-\alpha)x_h}{(1-u)h}+(1-\delta_h)(1+\tau_{xh})], \tag{15}$$

$$\frac{y}{k}=Av^{\alpha}(ul\frac{h}{k})^{1-\alpha}, \tag{16}$$

$$\frac{x_h}{h}\frac{h}{k}=B(1-v)^{\alpha}((1-u)l\frac{h}{k})^{1-\alpha}, \tag{17}$$

$$\frac{x_h}{h}=\gamma+n+\delta_h, \tag{18}$$

Notice that $r_k=\frac{\alpha y}{(1+\tau_1)vk}$. And the Maclaurin approximation suggests that $(1+\tau_1)^{-1}\approx 1-\tau_1$. Then we have the Euler equations (9) and (10).

[9]To avoid repetition, let $\gamma_a$ be the growth rate of an arbitrary variable $a$ in steady state. Equations (7) and (8) imply that $\gamma_u=\gamma_v=0$, equation (6) implies $\gamma_l=0$, equation (8) implies $\gamma_y=\gamma_{xh}+\gamma_q$, equation (5) implies $\gamma_c=\gamma_{xk}=\gamma_g=\gamma_y$, the law of motion for $h$ implies $\gamma_{xh}=\gamma_h$, the law of motion for $k$ implies $\gamma_{xk}=\gamma_k$, production function (1) implies $\gamma_y=\alpha\gamma_k+(1-\alpha)\gamma_h$, production function (2) implies $\gamma_{xh}=\alpha\gamma_k+(1-\alpha)\gamma_h$. Combining all of these results implies that $v$, $u$, $l$, $q$ are constant, and all the other variables grow at the same rate.

$$\frac{x_k}{k} = \gamma + n + \delta_k, \tag{19}$$

$$\frac{c}{k} + \frac{x_k}{k} + \frac{g}{k} = \frac{y}{k}. \tag{20}$$

I call $\tau_l$ the labor wedge, $\tau_1$ the capital input wedge, $\tau_2$ the labor input wedge, $\tau_{xk}$ the capital investment wedge, $\tau_{xh}$ the human capital investment wedge, $A$ the final goods efficiency wedge, $B$ the human capital efficiency wedge, and $g/k$ the government consumption wedge.

## 2.1. The mapping between a one-sector optimal growth model and the prototype economy

Chari et al. (2007) first define a prototype economy and the associated wedges to address important business cycle questions. The prototype economy that they use is a one-sector stochastic growth model, which has four wedges: the efficiency wedge $A(t)$, the labor wedge $1 - \tau_l(t)$, the investment wedge $1/[1 + \tau_x(t)]$, and the government consumption wedge $g(t)$. Here I compare its deterministic version with the model that I use.

In the model, consumers maximize their utility over per capita consumption $c(t)$ and per capita labor $l(t)$,

$$\max \sum_{t=0}^{\infty} \beta^t [\theta \ln c(t) + (1-\theta) \ln(1 - l(t))] N(t),$$

subject to the budget constraint

$$c(t) + [1 + \tau_x(t)]x(t) = [1 - \tau_l(t)]w(t)l(t) + r(t)k(t) + T(t)$$

and the capital accumulation law

$$(1 + n)k(t + 1) = (1 - \delta)k(t) + x(t)$$

where $k(t)$ denotes per capita capital stock, $x(t)$ per capita investment, $w(t)$ the wage rate, $r(t)$ the rental rate on capital, $\beta$ the discount factor, $\delta$ the depreciation rate of capital, $N(t)$ the population with growth rate equal to $1 + n$, and $T(t)$ per capita lump-sum transfers.

The production function is $y = Ak^{\alpha}((1+\gamma)^t l)^{1-\alpha}$, where $y$ is per capita output, the labor-augmenting technology progress $(1+\gamma)$ is assumed to be constant. Firms maximize profits given by $Ak^{\alpha}((1+\gamma)^t l)^{1-\alpha} - rk - wl$.

The equilibrium of this model is summarized by the following,

$$c(t) + x(t) + g(t) = y(t),$$

$$\frac{1-\theta}{\theta}\frac{c(t)}{1-l(t)} = [1-\tau_l(t)](1-\alpha)\frac{y(t)}{l(t)},$$

$$\frac{c(t+1)}{c(t)}[1+\tau_x(t)] = \beta[\alpha\frac{y(t+1)}{k(t+1)} + (1-\delta)[1+\tau_x(t)]],$$

and the production function.

Notice that in the one-sector model, the labor-augmenting technology $1+\gamma$ is exogenous and not correlated with the four wedges; while in the two-sector model, it is the long-run growth rate, and endogenously determined by exogenous wedges. Thus the underlying causes of growth can be analyzed in a two-sector model, though growth is typically assumed to be constant in business cycle theories.

Suppose that the total consumption in Chari et al. (2007) contains both the final goods consumption and the human capital investment in terms of final goods. Then the consumption in Chari et al. (2007) equals

$$c^{CKM} = c + qx_h,$$

and the output in Chari et al. (2007) equals

$$y^{CKM} = y + qx_h.$$

Substituting the above two equations into the equilibrium conditions of the one-sector model, and comparing them with the equilibrium conditions of the two-sector model in steady state yields the mapping between these two prototype economies. Table 1 summarizes this relationship.

Through this simple illustration, we can see the correspondence between the

| Wedges and Growth | | Variables | |
|---|---|---|---|
| One-sector | Two-sector | One-sector | Two-sector |
| $A^{CKM}$ | $[Av^{\alpha}u^{1-\alpha}+qB(1-v)^{\alpha}(1-u)^{1-\alpha}]$ | $y^{CKM}$ | $y+qx_h$ |
| $1-\tau_l^{CKM}$ | $\frac{1-\tau_l}{1+u\tau_2}\frac{c+qx_h}{c}$ | $c^{CKM}$ | $c+qx_h$ |
| $1+\tau_x^{CKM}$ | $\frac{(1+v\tau_1)(1+\tau_{xk})}{1+\tau_1}$ | $x^{CKM}$ | $x$ |
| $g^{CKM}$ | $g$ | $k^{CKM}$ | $k$ |
| $(1+\gamma^{CKM})^t$ | $h$ | $l^{CKM}$ | $l$ |

Table 1: Equivalence Result for Chari, Kehoe, and McGrattan (2007)

wedges in Chari et al. (2007) and the wedges embedded in Rebelo (1991). The efficiency wedge largely contains efficiency shifters, the labor wedge is largely two labor related wedges, the investment wedge is quite close to the physical capital investment wedge, and the government consumption wedges in these two prototype economies are identical. In the one-sector growth model, wedges are not correlated with the growth $\gamma$, while in the two-sector model, wedges determine the growth. The relative importance of each wedge in explaining growth is the question addressed by the following sectors.

## 3. Method and Data

The accounting method consists of computing wedge values and evaluating the fit of individual wedges. Envisage a world consisting of $j = 1, \ldots, J$ countries. For any country $j$, the economy experiences one event $s_j$, which indexes the state for that country. This state determines country $j$'s economic performance. Assume that endogenous variables in the prototype economy include aggregate variables that characterize a country's economic performance, and that the wedges and population growth in the prototype economy uniquely uncover the event $s_j$. Substituting the country-specific values of endogenous variables into the steady state equilibrium conditions of the prototype economy gives the wedge values across countries.

Notice that despite resembling tax rates, efficiency levels or government consumption in the prototype economy, wedges are clearly not formal tax rates, measures of technological efficiency, or observed government consumption. Rather wedges are the results of policies and institutions that make economic activities more costly or reduce their associated returns. In particular, every wedge in the prototype economy is a measure of overall frictions in the particular market with which it is associated.

To evaluate the importance of wedges in explaining growth, I change each wedge in the favorable direction by 0.1% of its observed values while keeping the rest wedges fixed; and decompose the marginal change of growth and efficiency into the effects of individual wedges.

For example, country $j$'s long-run growth rate $\gamma_j$, a differentiable function of all wedges, can be decomposed as follows,

$$\begin{aligned}\hat{\gamma}_j - \gamma_j \approx & \frac{\partial \gamma}{\partial A}(\hat{A}_j - A_j) + \frac{\partial \gamma}{\partial B}(\hat{B}_j - B_j) \\ & + \frac{\partial \gamma}{\partial \tau_l}(\hat{\tau}_{lj} - \tau_{lj}) + \frac{\partial \gamma}{\partial \tau_1}(\hat{\tau}_{1j} - \tau_{1j}) + \frac{\partial \gamma}{\partial \tau_2}(\hat{\tau}_{2j} - \tau_{2j}) \\ & + \frac{\partial \gamma}{\partial \tau_{xk}}(\hat{\tau_{xkj}} - \tau_{xkj}) + \frac{\partial \gamma}{\partial \tau_{xh}}(\hat{\tau_{xhj}} - \tau_{xhj}) + \frac{\partial \gamma}{\partial (g/k)}[(\frac{\hat{g}}{k})_j - (\frac{g}{k})_j].\end{aligned}$$

Here each variable with a hat is the computed value of growth rate when all wedges are slightly different from their observed values; $\gamma_j$ is the growth rate observed from the data; and $\frac{\partial \gamma}{\partial x}(\hat{x} - x)$ is the difference between the observed value and the computed value of the growth rate when only one wedge $x$ is slightly different from its observed value, but all other wedges are kept at their observed values. It imitates the marginal effect of wedge $x$ on growth rate $\gamma$. Thus the left-hand side of this expression is the comprehensive marginal effect on growth rate $\gamma$; the right-hand side is the sum of individual marginal effects. Dividing the marginal effect of a wedge by the comprehensive effect displays how important this wedge is in explaining the observed value of $\gamma$.

As shown in table 1, efficiency consists of endogenous variables and wedges,

$$\text{Efficiency} = \frac{y + qx_h}{k^\alpha (hl)^{1-\alpha}} = Av^\alpha u^{1-\alpha} + qB(1-v)^\alpha (1-u)^{1-\alpha}.$$

It depends on the resource allocation ($v$ and $u$), the relative price of human capital ($q$), and two efficiency wedges ($A$ and $B$). Wedges $A$ and $B$ can affect it both directly and indirectly, while the effects of other wedges are only indirect through $v$, $u$, and $q$. Similarly, the the marginal change of efficiency can also be decomposed into effects of individual wedges. In practice, I compute the absolute values of partial change for growth and efficiency, and divide each partial effect by the sum of all individual partial effects as normalization.

When preparing the dataset two points are worth noticing: How to divide GDP into final goods and the broadly defined human capital investment and how to measure the relative prices of human capital in terms of final goods. I consider a narrow definition, which only counts education as the proxy for human capital, but neglects other components including experience, health, R&D, and any other factors that may change the production efficiency. One reason to focus on education is because the schooling years are more accurately measured and more available; another is that the relationship between schooling years and labor income is a much studied topic in labor economics. As for the relative prices of the broadly defined human capital, they are not estimated or observed directly, but derived by a few parametric assumptions.

## 3.1. Estimating human capital and its relative price in terms of final goods

Consider the following expression for human capital stock at time $t$,

$$h(t) = h(s) \cdot e^{\gamma(t-s)} \cdot e^{\phi(sch(t))}.$$

It depends on the initial stock $h(s)$, the education stock $e^{\phi(sch(t))}$ and a trend term.

If the initial stock of education, steady state growth rate, schooling years and the function form of $\phi(\cdot)$ are known, then an estimate for the broadly defined human capital stock is available.[10] Notice that the wage rate, by definition, is equal to $(1-\alpha)\text{GDP}/l$. Thus,

$$\ln w(t) = \ln(1-\alpha)\text{TFP} + \alpha \ln \frac{k}{hl} + \ln h(s) + \gamma(t-s) + \phi(sch(t))$$

The average wage rate depends on a constant term, a trend term, and schooling years. Labor economists estimate the following Mincerian regression (see Mincer (1974)), which is informative to construct $\phi(\cdot)$,

$$\ln w = \text{constant} + \phi \cdot \text{sch}.$$

Hall and Jones (1999) assume that $\phi(\cdot)$ is a continuous, piecewise linear function constructed to match the rates of return on education reported in Psacharopoulos (1993). For schooling years between 0 and 4, the return to schooling $\phi'(\cdot)$ is assumed to be 13.4 percent which is an average for sub-Saharan Africa. For schooling years between 4 and 8, the return to schooling is assumed to be 10.1 percent, which is the world average. With 8 or more years, the return is assumed to be 6.8 percent, which is the average for the OECD countries.[11] Then they construct human capital stocks using $h_{HJj} = e^{\phi(sch_j)}$. I use the Hall and Jones (1999) specification to construct $e^{\phi(sch)}$ , with the growth rate in steady state and a guess of education stock in a base year, to construct the human capital stock.

[10]One concern is the impact of quality of years of schooling on growth. Hanushek and Kimko (2000) support the quality of schooling is a major factor for an explanation of long-run growth by using growth regressions. From different perspectives, McGrattan and Schmitz (1999) and Durlauf et al. (2005) both pointed out the potential flaws of growth regressions in establishing causalities. After adjusting the quality of schooling, Caselli (2005) finds that the quality of schooling is not important for explaining cross-country income gaps. Pritchett (2006) summarizes some empirical results of measuring human capital stocks.

[11]McGrattan and Schmitz (1999) summarize popular approaches of measuring human capital stock, including the alternative Mincerian formula used by Klenow and Rodriguez-Clare (1997b),

$$h_{KRCj} = e^{\gamma_1 sch} \sum_i \omega_i e^{\gamma_2 \text{exper}_i + \gamma_3 \text{exper}_i^2},$$

where $sch$ is the average schooling years in the total population over age 25 taken from Barro and Lee (2001), $\text{exper}_i$ is a measure of experiences for a worker in age group $i$ and equal to $(\text{age}_i - s - 6)$, and $\omega_i$ is the fraction of the population in the $i$th age group. The age groups are {25-29, 30-34, ..., 60-64} and $\text{age}_i \in \{27, 32, ..., 62\}$. The coefficients are given by $\gamma_1 = 0.095$, $\gamma_2 = 0.0495$, and $\gamma_3 = -0.0007$, which are averaged estimates of log wages on schooling and experience.

Total GDP includes two parts: final goods output and the human capital investment in terms of final goods. The latter is the value added only in the education sector (ISIC:M),[12] and corresponds to $qx_h$ in the prototype economy. The rest is the final goods output $y$ in the prototype. The partition between final goods and human capital investment may be arbitrary. However, they are consistent with the concepts used in the prototype economy.[13]

When the human capital investment $qx_h$ is known, with the law of motion of human capital in steady state, I construct the human capital stock in terms of final goods as,

$$(qh)_j = \frac{(qx_h)_j}{\gamma_j + n_j + \delta_h}.$$

Dividing this value by $e^{\gamma(s-t)}e^{\phi(sch(t))}$, we have

$$\frac{(qh)(t)_j}{e^{\gamma_j(t-s)}e^{\phi(sch_j(t))}} = \frac{q_j h_j(s) e^{\gamma_j(t-s)} \cdot e^{\phi(sch_j(t))}}{e^{\gamma_j(t-s)}e^{\phi(sch_j(t))}} = q_j h_j(s)$$

Notice that the human capital is broadly defined and equal to the labor augmented technology in the literature. Parente and Prescott (2006) argue that "most of the stock of productive knowledge is public information, and even proprietary information can be accessed by a country through licensing agreements or foreign direct investment".

This statement is, in particular, true by the end of the 20th century. Technological innovations have improved the speed of transportation and communications and lowered their costs. These included jet airplanes and their universal use in transporting people and goods, the containers used in international shipping, the improved road infrastructure that enabled a large share of trade to be carried by

[12]Kendrick (1976) discussed a broad class of capital stocks, including tangible and intangible, human and non-human capital. He categorized physical capital as "tangible non-human capital", child rearing costs as investments in "tangible human capital", research and development (R&D) expenditures as investments in "intangible non-human capital", and outlays of education, training, health, safety, and mobility as investments in "intangible human capital". Ideally human capital should contain all tangible and intangible human capital.

[13]One concern about the definition of human capital investment is that GDP do not include the value of students' time, an important component of education investment. This slippage between model and data affects estimates for $x_h$ and $h$. However, it will not change $x_h/h$ in steady-state. Kendrick (1976) found about half of schooling investment consists of education expenditures which are included in GDP.

freight trucks in Western Europe and North America, and importantly, the personal computer, the cellular phone, the internet, and the World Wide Web that have contributed to profound socio-political and economic transformations.

In addition, changes in production methods, the political developments in 1990s, economic policies towards deregulation, multilateral efforts to liberalize international trade, and to stabilize macroeconomic environment have helped all countries in the world access the most advanced available knowledge. So around 2000, the accessible broadly defined human capital is roughly constant across countries.

I assume that $h_j(2000)$ is constant across countries and rescale the relative price of the broadly defined human capital across countries by assuming that relative price is one in the US. So for any country $j$,

$$q_j = \frac{q_j h_j(2000)}{q_{US} h_{US}(2000)}$$

Consequently, the human capital stock for country $j$ is

$$h_j(t) = (qh)_{US}(t) \cdot e^{(\gamma_j - \gamma_{US})(t-2000)} e^{\phi(sch_j(t)) - \phi(sch_{US}(t))}$$

## 3.2. Data and calibration

Data sources used in this analysis include the Groningen Growth and Development Center (GGDC), the United Nations Statistics Division (UNSD), the International Labor Organization (ILO), the World Bank, the Penn World Table 6.3 and the Barro and Lee (2001) educational attainment dataset.[14]

Some variables are directly observable from data sources, such as the average growth rate for per capita GDP and population, employment-population ratio, the share of workers in the education sector, physical capital investment-GDP ratio, consumption-GDP ratio, and schooling years. Other variables are de-

[14]The sample includes Argentina, Australia, Austria, Belgium, Bangladesh, Bulgaria, Bahrain, Brazil, Canada, Switzerland, Chile, China, Costa Rica, Germany, Denmark, Dominican Republic, Ecuador, Egypt, Spain, Ethiopia, Finland, France, United Kingdom, Greece, Guatemala, Hungary, Ireland, Iran, Iraq, Israel, Italy, Japan, Republic of Korea, Mexico, Malaysia, the Netherlands, Norway, New Zealand, Peru, the Philippines, Poland, Portugal, Romania, Sweden, Thailand, Turkey, Uganda, Uruguay, United States, and Vietnam.

| | | |
|---|---|---|
| capital share | $\alpha$ | 0.3333 |
| depreciation rate of physical capital | $\delta_k$ | 0.0665 |
| depreciation rate of human capital | $\delta_h$ | 0.0518 |
| consumption share | $\theta$ | 0.3908 |
| discount factor | $\beta$ | 0.9457 |

Table 2: Calibrated Values of Parameters

rived from these observable variables under certain assumptions. Appendix A presents the data sources and data construction in detail.

Since no much information of capital used in education across countries is available, I assume that the share of education expenditure in GDP is equal to the share of capital used in the education. Notice that this assumption is equivalent to that the capital input wedge $\tau_1$ is always equal to zero in the prototype economy (see equation (7)).

There are five parameters in the prototype economy: the capital share, $\alpha$, the depreciation rates, $\delta_k$ and $\delta_h$, the discount factor, $\beta$, and the consumption share, $\theta$. Each is assumed to be constant across countries. Online appendix presents the data used in calibration. Table 2 reports their calibrated values. One concern is the heterogeneity of parameters across countries. Gollin (2002) convincingly show that the capital share $\alpha$ is a number between 0.20 to 0.35 for most countries. Appendix B checks the robustness of the findings by changing parameter values in reasonable ranges for the full sample.

Following the literature, I assume that the capital share is 0.3333. For other parameters, I use the national accounts data for the US to calibrate them, by assuming that wedges are zero in the US economy during the 1960-2000 period.

The depreciation rate $\delta_k$ is estimated from the perpetual inventory method (see, for example, Kehoe and Prescott (2007), for a detailed description),

$$K(t+1) = I(t) + (1-\delta)K(t),$$

together with a few restrictions on the initial capital stock and the depreciation rate. The value of $\delta_k$ is chosen to be consistent with the average ratio of depreciation to GDP observed in the data from 1980 to 2004. The initial stock of capital is chosen so that the initial capital-output ratio in 1959 should match the average capital-output ratio over the 1960-1970 period. Using this rule gives the estimate for the depreciation rate $\delta_k$.

The depreciation rate of human capital $\delta_h$ comes from the same procedure, except its value is chosen to be consistent with $\frac{x_h}{h} = \gamma + n + \delta_h$. By comparison, Kendrick (1976)'s estimates imply the depreciation rates of capital, $\delta_k = 0.0616$, of education, $\delta_e = 0.0343$, of health care, $\delta_{hc} = 0.0718$ and of R&D, $\delta_{RD} = 0.0876$.

For the remaining two parameters, standard calibration formulae are available (e.g., an online note for Kehoe and Prescott (2007)). The discount factor $\beta$ stems from the following equation,

$$1 + \text{average growth rate} = \beta[\frac{\alpha \times \text{output-capital ratio}}{\text{1-share of education in GDP}} + 1 - \delta_k].$$

The consumption share $\theta$ is from,

$$\theta = \frac{\text{share of consumption in GDP} \times \text{empl. rate}}{\text{share of consumption in GDP} \times \text{empl. rate} + (1-\alpha) \times (1 - \text{empl. rate})}.$$

# 4. Decomposition Results

A large number of papers study the cross-country economic performance using either growth accounting or level accounting that connects economic performance to inputs and the efficiency with which inputs are used.[15] Despite the large volume of work, results from many studies on a given issue frequently reach opposite conclusions. Moreover, a serious criticism by Acemoglu (2007) says that "at some level to say that a country is poor because it lacks physical capital, human capital and technology is like saying that a person is poor because he does not have money". To satisfactorily understand economic growth requires, not only the contribution of inputs and efficiency to the cross-country income variance, but also an analysis of the reasons making some countries more abundant

[15]Bosworth et al. (2003) is a comprehensive study on growth empirics, including growth accounting. Caselli (2005) is a state-of-the-art study using level accounting.

| Sub-sample | Total | OECD | non-OECD | above median | below median |
|---|---|---|---|---|---|
| Obs | 50 | 26 | 24 | 25 | 25 |
| $\tau_l$ | 15.65% | 14.20% | 17.22% | 12.91% | 18.38% |
| $\tau_2$ | 16.52% | 16.37% | 16.68% | 15.06% | 17.98% |
| $\tau_{xk}$ | 5.98% | 6.44% | 5.48% | 6.81% | 5.15% |
| $\tau_{xh}$ | 21.93% | 22.27% | 21.56% | 23.33% | 20.52% |
| $A$ | 11.91% | 12.22% | 11.59% | 12.66% | 11.17% |
| $B$ | 23.83% | 24.44% | 23.17% | 25.32% | 22.35% |
| $g/k$ | 4.18% | 4.06% | 4.31% | 3.92% | 4.44% |

Table 3: Average Importance of Wedges on Growth Rate

in physical capital, human capital, and technology than others. In this section, I decompose the long-run growth rate and efficiency into effects of individual wedges, which can be linked to fundamental causes of economic growth.

Some interesting findings of the artificial experiments are: (1) when explaining the long-run growth rate, the human capital efficiency and human capital investment wedges play primary roles, while the labor and labor input wedges play secondary roles; (2) in explaining the efficiency, the effect of the final goods efficiency wedge is dominant; and (3) these patterns are robust across the OECD/ non-OECD sub-samples.

Tables 3 and 4 summarize the average importance of each wedge in explaining the long-run growth rate and efficiency for the full sample and across different sub-samples. Note that the median in table 3 refers to the median growth rate of the total sample, while the median in table 4 is the median efficiency. Clearly the effects of wedges on the long-run growth rate scatter more evenly than those on efficiency across wedges. The human capital efficiency wedge and the human capital investment wedge explain 23.83% and 21.93% of the long-run growth rate on average. However, the final goods efficiency wedge alone accounts for 88.86% of efficiency.

| Sub-sample | Total | OECD | non-OECD | above median | below median |
|---|---|---|---|---|---|
| Obs | 50 | 26 | 24 | 25 | 25 |
| $\tau_l$ | 0.62% | 0.76% | 0.49% | 0.74% | 0.52% |
| $\tau_2$ | 6.29% | 6.12% | 6.47% | 5.72% | 6.85% |
| $\tau_{xk}$ | 0.22% | 0.31% | 0.13% | 0.22% | 0.22% |
| $\tau_{xh}$ | 3.07% | 3.44% | 2.66% | 3.35% | 2.78% |
| $A$ | 88.86% | 88.10% | 89.68% | 88.80% | 88.92% |
| $B$ | 0.79% | 1.08% | 0.48% | 0.98% | 0.60% |
| $g/k$ | 0.14% | 0.19% | 0.09% | 0.18% | 0.11% |

Table 4: Average Importance of Wedges on Efficiency

The above result does not contradict previous studies that TFP growth is as important as capital accumulation in explaining growth across countries. In an optimal growth model, the sole driving force of growth is the labor-augmented technology progress, which is not related to cross-country efficiency differences. The TFP growth in a growth accounting exercise includes both stable technology progress and the efficiency's movements. For a large number of countries, the TFP growth is largely the stable technology progress, and drives the accumulation of capital too. This is also consistent with the observation that initial income levels are not systematically correlated with growth performance thereafter, though income levels are largely determined by TFP levels.

Another interesting observation is that the labor and labor input wedges also play a role in accounting for long-run growth rate. So far, there have been many endogenous growth theories addressing the role of education or R&D, which actually exploit the human capital investment wedge. The role of the labor and labor input wedge, and their associated labor market policy implications, on growth are not fully explored and worthy of more attention.[16]

[16]By comparing France and the United States, Prescott (2002) gives an example showing that the labor wedge is responsible for the gap in terms of relative income level between these two countries.

| Normalized values | $\tau_l$ | $\tau_2$ | $\tau_{xk}$ | $\tau_{xh}$ | $A$ | $B$ | $g/k$ |
|---|---|---|---|---|---|---|---|
| Total | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| OECD | 1.07 | 1.21 | -0.53 | 0.69 | 1.15 | 0.50 | 0.63 |
| Non-OECD | 0.95 | 0.79 | 2.67 | 1.33 | 0.85 | 1.54 | 1.38 |
| Fast | 0.79 | 0.79 | 0.20 | 0.91 | 0.90 | 0.93 | 0.75 |
| Slow | 1.24 | 1.24 | 1.80 | 1.09 | 1.12 | 1.56 | 1.25 |

Table 5: Wedges' Values

The aforementioned patterns for the full sample do not change much across sub-samples of countries in and out of the OECD; below and above the median values of respective endogenous variables. This may be due to that most countries in the sample are rich or middle-income countries, whereas extremely poor countries may have different patterns. Another possibility is that these patterns depend more on the NCG structure than the magnitude of the country-specific wedges.

Table 5 presents the values of individual wedges for the total sample and sub-samples, and sheds some light on the above robustness. These values are normalized relative to the sample average. Although wedges differ across sub-samples, they have the same magnitude. Differences of $\tau_{xk}$, $\tau_{xh}$, and $B$ between OECD and non-OECD countries are larger than those between fast and slow growers. But, except for $\tau_{xk}$, all cross-sample normalized values are not far away from one.

What can be learned from these results? First, even if the human capital sector is small in the economy, a biased allocation of the broadly defined human capital over time would change the long run growth very much. Second, frictions that distort the final goods efficiency wedge are less important in changing the long-run growth than those affecting the human capital efficiency wedge. Third, compared with the other wedges, the two efficiency wedges can hardly be microfounded. These wedges seem to reflect everything except for the mechanism suggested by a detailed model. If this is true, then, even after decomposing the efficiency into the effects of seven wedges, it is still mostly a black box, because the final goods efficiency wedge alone takes up nearly 90% of it. As Prescott (1998) points out, a theory of TFP differences is still needed.

## 5. Conclusion

This paper presents a method to account for long-run economic growth across countries. It also sheds light on underlying mechanisms of economic growth. The main findings suggest that endogenous growth theories that are equivalent to the prototype economy with a human capital investment wedge and/or a labor wedge are more consistent with the observed patterns of developing countries.

As Klenow and Rodriguez-Clare (1997a) said, more work should be done to empirically distinguish between theories of endogenous growth; to accomplish this, a quantitative approach avoids misspecification in empirical work and fully exploits the quantitative implications of candidate models. Banerjee and Duflo (2005), moreover, show that even a series of convincing micro-empirical studies is not enough to give an overall explanation for aggregate growth, and that a promising alternative is to build macroeconomic models.

Numerous studies show that the neoclassical growth model with wedges is a useful workhorse in accounting for various macroeconomic events (Cole and Ohanian (2004), McGrattan and Ohanian (2006) and Chen et al. (2007)). These findings suggest that the "Business Cycle Accounting" idea, together with neoclassical models, is a good way to organize the increasingly available data on various dimensions and aspects of economic growth.

**Acknowledgement**: I thank the Economics Department at University of Southern California provides a friendly environment for my writing, and Caroline Betts, Robert Dekle, Selo Imrohoroglu, Doug Joines, Jeff Nugent, and Lee Ohanian for helpful comments.

| Endogenous Variable | Raw Data Used | Data Source |
|---|---|---|
| long-run growth rate | per capital GDP series | Maddison-GGDC |
| employment-pop ratio | employment, population | TED-GGDC |
| capital allocation | value added by industry, | UNSD |
| | public spending on education | WDI |
| labor allocation | employment by industry | ILO |
| investment-capital ratios | population growth | TED-GGDC |
| output-capital ratio | investment share in GDP | PWT 6.3 |
| consumption-capital ratio | consumption share in GDP | PWT 6.3 |
| relative price | education expenditure | UNSD |
| capital-human capital ratio | educational attainments | Barro-Lee 2001 |

Table 6: Data Sources for Endogenous Variables

# A Appendix: variables in the cross-country dataset

This appendix explains how to create relevant variables for the cross-country dataset used in the paper.

The long-run growth rates come from the per capita GDP estimates by Maddison (2003). I compute the annual growth rates for each country year by year from 1951 to 2008, and assume the long-run growth rate equals the average of those annual growth rates. Fifty-eight years are long enough for a country to converge. The long-run population growth rates are from the midyear population estimates of the Total Economy Database. Similarly, I compute the annual growth rates from 1951 to 2008 and take the average. The Total Economy Database also has estimates for employment in the same period. I divide employment by midyear population and take their average as the average employment-population ratios.

As for the shares of employment in the education sector, I divide employment in education by total employment obtained from the ILO, and then take the average. The length of these employment series varies across countries, yet the longest one comes from 1985 to 2008. To compute the shares of education output, I use value added of education and value added of the total economy in constant prices obtained from the National Accounts Official Country Data (Table 2.2) by the United Nations Statistics Division, and the public spending on education as a percentage of GDP is obtained from the World Development Indicators (WDI). I divide value added of education by value added of the total economy, take the average of them, and add it to the average percentage of public spending on education. The longest value added series comes from 1966 to 2008, and the longest public spending share series is from 1970 to 2008.

To construct investment-capital ratios for physical capital, I use the approach in Caselli (2005) $\frac{x_k}{k} = n + \gamma + \delta_k$, together with estimates of growth rates and population growth rates, and calibrated values of depreciation rates. Similarly, $\frac{x_h}{h} = n + \gamma + \delta_h$ can be constructed.

The final goods output-capital ratios are computed by the following formula,

$$\frac{y}{k} = (1 - \frac{\text{Edu VA}}{\text{VA}})\frac{x_k}{k} / \frac{x_k}{\text{GDP}},$$

where $x_k$/GDP is the share of investment in GDP, which is obtained from the Penn World Table 6.3 (CI), Edu VA/VA is the share of education output in the total economy, and $(x_k/k)$ is the investment-capital ratio for capital. The last two variables are both known from previous calculations. Similarly, the final goods consumption-capital ratios can be calculated from the following formula,

$$\frac{c}{k} = \frac{y}{k}[\frac{CC}{GDP} - \frac{\text{Edu VA}}{\text{VA}}]/[1 - \frac{\text{Edu VA}}{\text{VA}}],$$

where (CC)/(GDP) is the share of consumption (CC) in GDP from the Penn World Table 6.3.

The method of estimating human capital and its relative price in terms of final goods is detailed in the text. The data on schooling years are from Barro and Lee (2001). In particular, I use the average schooling years in the total population over age 25.

The physical capital-human capital ratio is derived using the following fomula,

$$\frac{k}{h} = \frac{x_k}{(1-v)GDP}\frac{x_h}{h}\frac{k}{x_k} \cdot q$$

# B Appendix: robustness checks

This section is about the robustness of the findings reported in the text. I change the value of each parameter, holding the remaining parameters fixed to their calibrated values, and see whether the pseudo goodness-of-fit of various wedges changes very much.

## B1. Capital share

The capital share in the US has been rather stable. When it comes to cross-country comparisons, a traditional measure of the capital income is the residual after employee compensation has been taken out from national income. These estimates are generally higher in poor countries than in rich countries. After adjusting the labor income in self-employed and small firms, and some other differences, Gollin (2002) has convincingly shown that for most countries the capital share is in the range of 0.20 to 0.35.

Figure 1 plots the explanatory power of the various wedges on growth as the capital share $\alpha$ moves from 0.20 to 0.35. Clearly, the contribution of the human capital investment wedge $\tau_{xh}$ is quite stable with respect to alternative values of $\alpha$ in this range. The government spending wedge $g/k$ is not important, and also stable. The two labor related wedges $\tau_l$ and $\tau_2$ are always more important than the capital investment wedge $\tau_{xk}$ and two efficiency wedges $A$ and $B$.

## B2. Preferences parameters

Figure 2 shows the contributions of various wedges when changing $\beta$ between 0.90 and 1. The order of various wedges does not change much in this range of $\beta$. Thus the qualitative results in the text do not change at all.

When it comes to the values of the consumption share $\theta$, different studies report different values. McGrattan and Schmitz (1999) reports that the upper

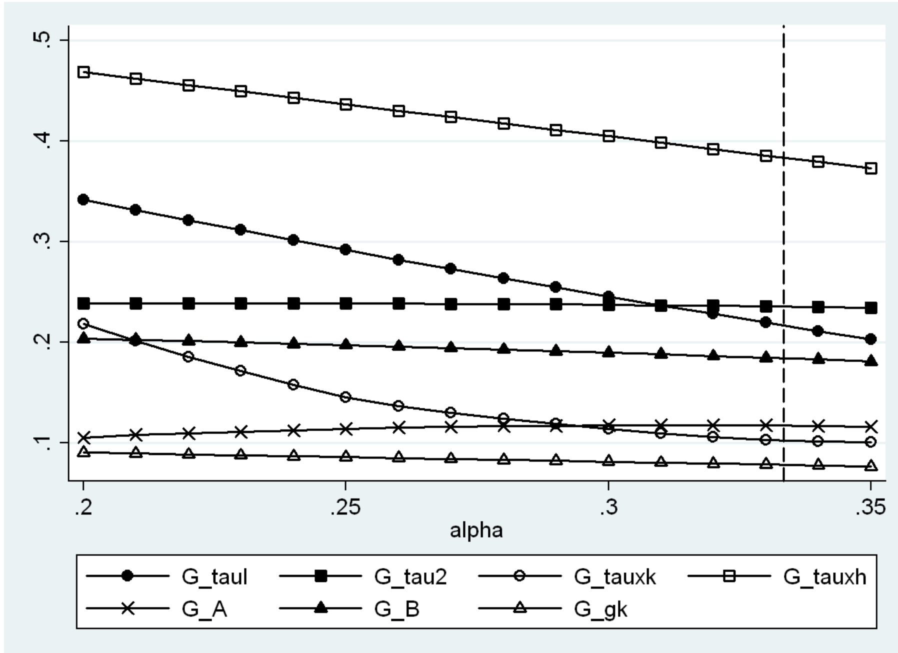


Figure 1: Robustness check with $\alpha$ on growth

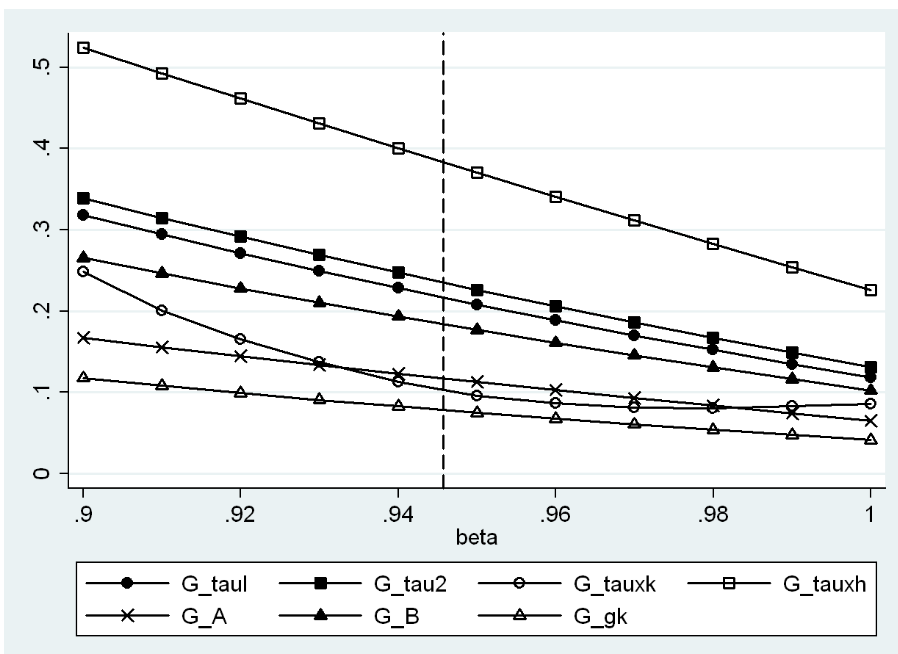


Figure 2: Robustness check with $\beta$ on growth

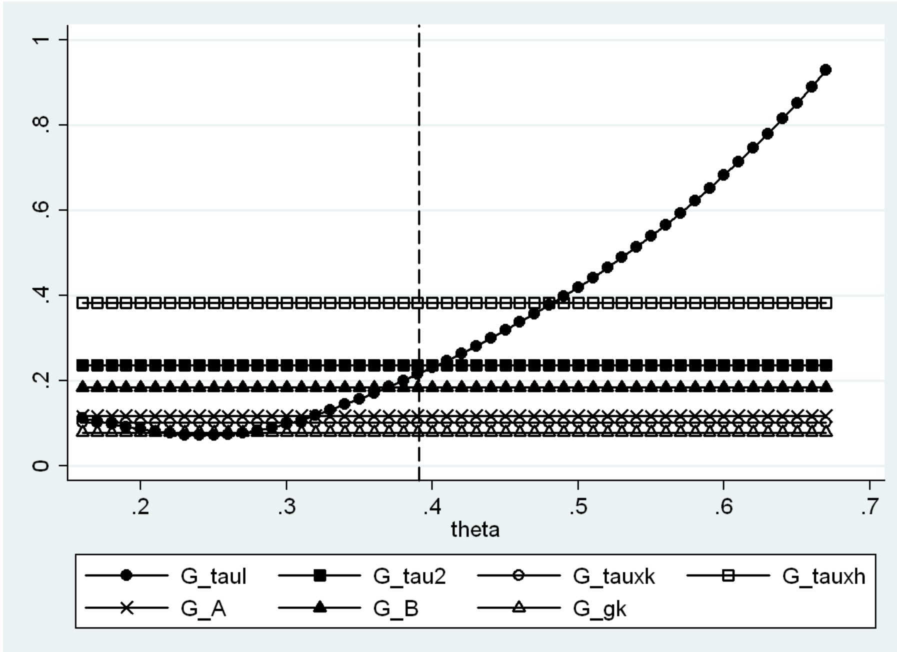


Figure 3: Robustness check with $\theta$ on growth

bound could be 0.67, and the lower bound could be 0.16. Figure 3 plots the contributions of various wedges in explaining growth in this range. Since $\theta$ only affects the labor wedge $\tau_l$, except for the labor wedge, the contributions of all other wedges does not change. The labor wedge, however, is quite sensitive to changes in $\theta$. When $\theta$ is around 0.23, the labor wedge reaches its bottom, and could be the least important factor in accounting for growth. But its explanatory power increases sharply, and it becomes the most important factor when $\theta$ is equal or higher than 0.47. The high sensitivity of $\tau_l$ around the benchmark value of $\theta$ implies that our results about the labor wedge may change non-trivially with more precise measures of the consumption share.

## C Do previous studies contradict this analysis?

Previous quantitative studies on cross-country income variance find that efficiency is at least as important as inputs in explaining both growth and relative income differences. Does the data I collect or the alternative accounting method I

| | Human Capital | Residual |
|---|---|---|
| This Work | $edu \cdot h(0)e^{\gamma t}$ | $A$ |
| Hall and Jones (1999) | $edu$ | $h(0)e^{\gamma t}A$ |
| Klenow and Rodriguez-Clare (1997b) | $edu^{\frac{1-\alpha_1}{\alpha_2}} \cdot h(0)e^{\gamma t} \cdot Al$ | $h(0)e^{\gamma t}A$ |

Table 7: Different Definitions in Growth Accounts

use contradict previous studies? By using Hall and Jones (1999) and Bosworth et al. (2003) as the baseline research for level accounting and growth accounting, I redo these exercises. In the growth accounting case, I use my data set; in the level accounting case, I further impose a constant growth rate by steady state equilibrium. Decomposition results suggest that the alternative method is quite close to previous studies.

Before beginning with the detailed comparison, I would point out the different definitions of human capital and the residual in the growth accounts used by Klenow and Rodriguez-Clare (1997b), Hall and Jones (1999), and me. A general form by Parente and Prescott (2006) can cover these differences,

$$y(t) = k(t)^{\alpha}[h(0)e^{\gamma t} \cdot edu(t) \cdot A(t)l(t)]^{1-\alpha}.$$

Notice that in Klenow and Rodriguez-Clare (1997b), the production function takes the form,

$$y = k^{\alpha_1} h_{KRC}^{\alpha_2} (A_{KRC} l)^{1-\alpha_1-\alpha_2},$$

and in Hall and Jones (1999) it takes the form,

$$y = k^{\alpha}(A_{HJ} h_{HJ} l)^{1-\alpha}.$$

Notice that $A$ is always a residual in any case. My specification follows Hall and Jones (1999), but has a slightly different measure for human capital. Table 7 illustrates definitions of human capital $h$ and the residual $A$ in these three cases in terms of the notations in Parente and Prescott (2006).

Hall and Jones (1999) decompose output per capita of 127 countries in 1988

| Hall and Jones (1999) | Income | Capital | Education | | Residual |
|---|---|---|---|---|---|
| Average (45) | 0.481 | 0.957 | 0.695 | | 0.678 |
| Standard Deviation | 0.283 | 0.194 | 0.165 | | 0.278 |
| Corrlation w/ $Y/L$ (logs) | 1.000 | 0.658 | 0.700 | | 0.812 |
| Corrlation w/ $A$ (logs) | 0.812 | 0.156 | 0.225 | | 1.000 |
| This Work | Income | Capital | Human Capital | Labor | Residual |
| Average (45) | 0.437 | 1.001 | 0.665 | 0.895 | 0.683 |
| Standard Deviation | 0.284 | 0.205 | 0.179 | 0.179 | 0.262 |
| Corrlation w/ $Y/L$ (logs) | 1.000 | 0.788 | 0.771 | 0.394 | 0.785 |
| Corrlation w/ $A$ (logs) | 0.785 | 0.433 | 0.388 | -0.162 | 1.000 |

Table 8: Level Accounting Comparison

into three multiplicative terms: capital intensity $K/Y$, education stock $e^{\phi(sch)}$, and productivity, a residual term. All terms are expressed as ratios to US values. Forty-five countries in their sample overlap the sample I collect. As Hall and Jones (1999) do, table 8 reports each term's comparable averages, standard deviations, and correlations with other terms for the overlapped forty-five countries, from their work and this analysis. Bear in mind that the human capital in my level accounting includes a growth trend imposed by the steady state equilibrium, plus the education stock which is the same as the "human capital" in the baseline study. As a result, the residual in their exercise is different from mine. I also exclude the effect of relative labor participation from the residual term, since this information is available in my dataset.

The comparable characteristics for relative income and capital intensity are quite close to each other, as shown in the second and third column. The capital intensity in my accounting is more correlated with both per capita output and the residual than the baseline study. This is because, in the baseline study, capital

| Bosworth et al. (2003) | Income | Capital | Education | | Residual |
|---|---|---|---|---|---|
| Industrial Countries (22) | 2.2% | 0.9% | 0.3% | | 1.0% |
| China (1) | 4.8% | 1.7% | 0.4% | | 2.6% |
| East Asia less China (7) | 3.9% | 2.3% | 0.5% | | 1.0% |
| Latin America (22) | 1.1% | 0.6% | 0.4% | | 0.2% |
| This Work | Income | Capital | Education | Labor | Residual |
| Industrial Countries (20) | 2.1% | 0.9% | 0.4% | 0.2% | 0.6% |
| China (1) | 4.3% | 2.4% | 0.7% | 0.4% | 0.9% |
| East Asia less China (4) | 3.5% | 1.9% | 0.8% | 0.4% | 0.4% |
| Latin America (9) | 1.8% | 1.1% | 0.5% | 0.3% | -0.1% |

Table 9: Growth Accounting Comparison

is smoothed using the perpetual inventory method. However, in my study it is not smoothed, but comes from the investment-output ratio with a linear transformation.

The education stock in the baseline study and the human capital stock in this work are related, but not identical concepts. Remember that I choose 2000 as the base year, and use the average growth rate to infer human capital stock. If all countries would share the same average growth rates, then the relative human capital would be identical to the education stock in the baseline study. And if a country grows faster than the US, its derived relative human capital would be smaller than its relative education stock. The observation that the average human capital stock is slightly smaller than the education stock confirms that countries in the sample grow slightly faster than the US, on average. It seems that the steady-state equilibrium is not too restrictive to examine cross-country differences in economic performance, at least for countries in this sample.

The labor participation says that, on average, other countries in this sample work less than the US. The residual in the alternative study, not surprisingly, looks similar to the baseline study; given that the human capital stock differs little from the education stock.

In the case of growth accounting, Klenow and Rodriguez-Clare (1997b) use the following formula to decompose growth

$$\Delta \ln \frac{Y}{L} = \Delta \ln A + \frac{\alpha_1}{1-\alpha_1-\alpha_2}\Delta \ln \frac{K}{Y} + \frac{\alpha_2}{1-\alpha_1-\alpha_2}\Delta \ln \frac{H}{Y}$$

where the sum of inputs' contribution can be expressed as $\Delta \ln X$. They also use covariances to measure the contribution of each term to growth,

$$\frac{\text{Cov}(\Delta \ln \frac{Y}{L}, \Delta \ln A)}{\text{Var}(\Delta \ln \frac{Y}{L})} + \frac{\text{Cov}(\Delta \ln \frac{Y}{L}, \Delta \ln X)}{\text{Var}(\Delta \ln \frac{Y}{L})} = 1.$$

Bosworth et al. (2003) use a production function and a definition of human capital that is similar to Hall and Jones (1999), and a more conventional decomposition,

$$\Delta \ln \frac{Y}{L} = \Delta \ln A + \alpha \Delta \ln \frac{K}{L} + (1-\alpha)\Delta \ln h_{HJ}$$

with averages to measure the contribution of each term,[17]

$$\text{Ave}(\frac{\Delta \ln A}{\Delta \ln \frac{Y}{L}}) + \alpha \text{Ave}(\frac{\Delta \ln (K/L)}{\Delta \ln \frac{Y}{L}}) + (1-\alpha)\text{Ave}(\frac{\Delta \ln h_{HJ}}{\Delta \ln \frac{Y}{L}}) = 1.$$

Note that if the steady-state equilibrium were imposed, Klenow and Rodriguez-Clare (1997b) would wholly attribute growth to technology progress and not at all to capital accumulation; and Bosworth et al. (2003) would attribute $\alpha$ of growth to capital accumulation. Growth accounting would not be interesting. So I use Bosworth et al. (2003) as the baseline to account for growth without imposing further restrictions.[18]

Table 9 presents the results from the baseline study in the upper panel and from my calculations in the lower panel. Decompositions are made for four regions: industrial countries, China, East Asia less China, and Latin America.

[17]Covariances are actually weighted averages, with higher weights for larger deviations from the average.

[18]Actually, Klenow and Rodriguez-Clare (1997b) find that at least 85% of economic growth is due to technology growth under different specifications, which verifies that most countries in their sample are close to their steady states.

Notice that mostly, there are fewer countries in my sample. For example, twenty-two Latin American countries are in the baseline, but only nine are in my sample. Another point worth noticing is that the effect of labor participation is excluded from the residual in my calculation, while not in the baseline study.

Bosworth et al. (2003) confirms widely accepted observations across regions: in general, TFP contributes as much as physical capital accumulation and the increase of education explains a relatively small part; East Asia less China accumulates physical capital more rapidly during its miraculous growth in the past than others; and TFP grows slowly in Latin America. My calculations also confirm the baseline. It verifies that the data I have collected is as good (or bad) as the data used by previous studies.

# References

Acemoglu, Daron, "Introduction to Modern Economic Growth," Levine's Bibliography 122247000000001721, UCLA Department of Economics November 2007.

—, Simon Johnson, and James A. Robinson, "The Colonial Origins of Comparative Development: An Empirical Investigation," *American Economic Review*, December 2001, *91* (5), 1369–1401.

Banerjee, Abhijit V. and Esther Duflo, "Growth Theory through the Lens of Development Economics," in Philippe Aghion and Steven Durlauf, eds., *Handbook of Economic Growth*, Vol. 1 of *Handbook of Economic Growth*, Elsevier, December 2005, chapter 7, pp. 473–552.

Barro, Robert J and Jong-Wha Lee, "International Data on Educational Attainment: Updates and Implications," *Oxford Economic Papers*, July 2001, *53* (3), 541–63.

Ben-Porath, Yoram, "The Production of Human Capital and the Life Cycle of Earnings," *Journal of Political Economy*, 1967, *75*, 352.

Bosworth, Barry P., Susan M. Collins, and Georgetown University, "The Empirics of Growth: An Update," *Brookings Papers on Economic Activity*, 2003, *34* (2003-2), 113–206.

Caselli, Francesco, "Accounting for Cross-Country Income Differences," in Philippe Aghion and Steven Durlauf, eds., *Handbook of Economic Growth*, Vol. 1 of *Handbook of Economic Growth*, Elsevier, June 2005, chapter 9, pp. 679–741.

Chang, Yongsung, Joao Gomes, and Frank Schorfheide, "Learning by Doing as a Propagation Mechanism," Macroeconomics 0204002, EconWPA May 2002.

Chari, V. V., Patrick J. Kehoe, and Ellen R. McGrattan, "Business Cycle Accounting," *Econometrica*, 05 2007, *75* (3), 781–836.

Chen, Kaiji, Ayse Imrohoroglu, and Selahattin Imrohoroglu, "The Japanese saving rate between 1960 and 2000: productivity, policy changes, and demographics," *Economic Theory*, July 2007, *32* (1), 87–104.

Cole, Harold L. and Lee E. Ohanian, "New Deal Policies and the Persistence of the Great Depression: A General Equilibrium Analysis," *Journal of Political Economy*, August 2004, *112* (4), 779–816.

— , — , Alvaro Riascos, and James Jr Schmitz, "Latin America in the rearview mirror," *Journal of Monetary Economics*, January 2005, *52* (1), 69–107.

Durlauf, Steven N., Paul A. Johnson, and Jonathan R.W. Temple, "Growth Econometrics," in Philippe Aghion and Steven Durlauf, eds., *Handbook of Economic Growth*, Vol. 1 of *Handbook of Economic Growth*, Elsevier, 2005, chapter 8, pp. 555–677.

Gollin, Douglas, "Getting Income Shares Right," *Journal of Political Economy*, April 2002, *110* (2), 458–474.

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

Hansen, Gary D. and Selahattin Imrohoroglu, "Business cycle fluctuations and the life cycle: How important is on-the-job skill accumulation?," *Journal of Economic Theory*, November 2009, *144* (6), 2293–2309.

Hanushek, Eric A. and Dennis D. Kimko, "Schooling, Labor-Force Quality, and the Growth of Nations," *American Economic Review*, December 2000, *90* (5), 1184–1208.

Hsieh, Chang-Tai and Peter J. Klenow, "Misallocation and Manufacturing TFP in China and India," *The Quarterly Journal of Economics*, November 2009, *124* (4), 1403–1448.

Kehoe, Timothy J. and Edward C. Prescott, *Great depressions of the twentieth century*, Federal Reserve Bank of Minneapolis, 2007.

Kendrick, John W., *The Formation and Stocks of Total Capital*, NBER, 1976.

Klenow, Peter and Andres Rodriguez-Clare, "Economic growth: A review essay," *Journal of Monetary Economics*, December 1997, *40* (3), 597–617.

— and — , "The Neoclassical Revival in Growth Economics: Has It Gone Too Far?," in "NBER Macroeconomics Annual 1997, Volume 12" NBER Chapters, National Bureau of Economic Research, Inc, 1997, pp. 73–114.

— and — , "Externalities and Growth," in Philippe Aghion and Steven Durlauf, eds., *Handbook of Economic Growth*, Vol. 1 of *Handbook of Economic Growth*, Elsevier, June 2005, chapter 11, pp. 817–861.

Kydland, Finn E and Edward C Prescott, "Time to Build and Aggregate Fluctuations," *Econometrica*, November 1982, *50* (6), 1345–70.

Lucas, Robert E., "On the mechanics of economic development," *Journal of Monetary Economics*, July 1988, *22* (1), 3–42.

Maddison, Angus, *The World Economy: Historical Statistics*, OECD Publishing, 2003.

McGrattan, Ellen R. and James Jr. Schmitz, "Explaining cross-country income differences," in J. B. Taylor and M. Woodford, eds., *Handbook of Macroeconomics*, Vol. 1 of *Handbook of Macroeconomics*, Elsevier, June 1999, chapter 10, pp. 669–737.

_ and Lee E. Ohanian, "Does Neoclassical Theory Account for the Effects of Big Fiscal Shocks? Evidence From World War II," NBER Working Papers 12130, National Bureau of Economic Research, Inc April 2006.

Mincer, Jacob A., *Schooling, Experience, and Earnings* number minc74-1. In 'NBER Books.', National Bureau of Economic Research, Inc, 1974.

Mulligan, Casey B and Xavier Sala i Martin, "Transitional Dynamics in Two-Sector Models of Endogenous Growth," *The Quarterly Journal of Economics*, August 1993, *108* (3), 739–73.

Parente, Stephen and Edward Prescott, "What a Country Must Do to Catch Up to the Industrial Leaders," in Leszek Balcerowicz and Stanley Fischer, eds., *Living Standards and the Wealth of Nations*, MIT Press, April 2006, chapter 1, pp. 17–39.

Prescott, Edward C, "Needed: A Theory of Total Factor Productivity," *International Economic Review*, August 1998, *39* (3), 525–51.

Prescott, Edward C., "Prosperity and Depression," *American Economic Review*, May 2002, *92* (2), 1–15.

Pritchett, Lant, *Does Learning to Add up Add up? The Returns to Schooling in Aggregate Data*, Vol. 1 of *Handbook of the Economics of Education*, Elsevier, March

Psacharopoulos, George, "Returns to investment in education : a global update," Policy Research Working Paper Series 1067, The World Bank January 1993.

Rebelo, Sergio, "Long-Run Policy Analysis and Long-Run Growth," *Journal of Political Economy*, June 1991, *99* (3), 500–521.

Rodrik, Dani, Arvind Subramanian, and Francesco Trebbi, "Institutions Rule: The Primacy of Institutions Over Geography and Integration in Economic Development," *Journal of Economic Growth*, 06 2004, *9* (2), 131–165.

Romer, Paul M, "Endogenous Technological Change," *Journal of Political Economy*, October 1990, *98* (5), S71–102.

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

Sturgill, Brad, "Cross-country Variation in Factor Shares and its Implications for Development Accounting," Technical Report 2009.