ABSTRACT

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Chapter 1 analyzes effects of tax-favored savings plans on savings and retirement decisions in a realistically specified life-cycle model. Individuals face mortality risk and stochastic earnings, allocate assets between conventional savings accounts (CSAs) and tax-deferred accounts (TDAs), make endogenous choice of labor supply and retirement, and make a separate decision on claiming Social Security. The simulations reveal that there is a functional division to some degree between CSAs and TDAs, with the former serving mainly for liquidity and the latter for retirement and bequests. There is tremendous heterogeneity. The tax incentives are generally effective in stimulating new savings for the middle and upper income groups. The higher rate of return on TDAs facilitates wealth accumulation, which consequently and perhaps unintentionally encourages early retirement. Impatient and low-income individuals tend to retire and claim Social Security early. They derive less benefit from TDAs since they face lower marginal tax rates and they have limited resources to take advantage of TDAs. For them, the income effect dominates and TDAs fail to induce new savings.

Chapter 2 attempts quantitatively to measure the efficiency of public spending in developing countries. The efficiency is defined as the distance between observed input-output combinations and an efficiency frontier. Both input- and output-efficiencies are estimated for several health and education output indicators by means of the Free Disposable Hull (FDH) and Data Envelopment Analysis (DEA) techniques. This chapter further seeks to verify empirical regularities associated with cross-country efficiency variation. The panel Tobit regressions reveal that countries are more likely to register lower efficiency if they are faced with higher government expenditure levels, larger wage shares in government budget composition, higher ratios of public to private financing in service provision (health), more prevalence of HIV/AIDS epidemic (health), stronger external aid dependency, and/or higher income inequality (education). Though no causality may be inferred from these exercises, they help point at different factors to understand why some countries spend more resources than others to achieve similar educational and health outcomes.

ESSAYS IN PUBLIC FINANCE

By

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CHAPTER 1

TAX-DEFERRED SAVINGS AND EARLY RETIREMENT

Abstract

This chapter analyzes effects of tax-favored savings plans on savings and retirement decisions in a realistically specified life-cycle model. Individuals face mortality risk and stochastic earnings, allocate assets between conventional savings accounts (CSAs) and tax-deferred accounts (TDAs), make endogenous choice of labor supply and retirement, and make a separate decision on claiming Social Security. The simulations reveal that there is a functional division to some degree between CSAs and TDAs, with the former serving mainly for liquidity and the latter for retirement and bequests. There is tremendous heterogeneity. The tax incentives are generally effective in stimulating new savings for the middle and upper income groups. The higher rate of return on TDAs facilitates wealth accumulation, which consequently and perhaps unintentionally encourages early retirement. Impatient and low-income individuals tend to retire and claim Social Security early. They derive less benefit from TDAs since they face lower marginal tax rates and they have limited resources to take advantage of TDAs. For them, the income effect dominates and TDAs fail to induce new savings.

1.1 Introduction

This chapter explores the impact of tax deferred accounts (TDAs) on early retirement decisions and the implication of planned early retirement for the effectiveness of tax incentives at stimulating new savings.

Tax deferred accounts, particularly IRAs and 401(k)s introduced in early 1980s, were intended to stimulate private savings to support retirement and economic growth in the long run. They rapidly became popular. TDA contributions by 1986 exceeded contributions to traditional defined benefit (DB) and defined contribution (DC) plans (Poterba, Venti and Wise (1996)) and have accounted for one-third of private savings ever since (Engen, Gale and Scholz (1994)). [1] Tax deferred programs are also costly. For instance, Gravelle (2003) estimated that the revenue loss from IRA universal coverage would be $66 billion for 5 years. The debate about the effectiveness of tax incentives embedded in TDAs at inducing new savings forms an active strand of research. Venti and Wise (1986, 1987, 1990, 1995) and Poterba, Venti and Wise (1994, 1995, 1996) view large part of TDA contributions as new savings; Engen and Gale (1993) and Engen, Gale and Scholz (1994, 1996) find limited evidence for new savings; Hubbard and Skinner (1996) judge the effectiveness of saving incentives to be somewhere in between; and Benjamin (2003) recently estimates that one half of 401(k) balances are new private savings. [2]

[1] Traditional non-401(k) DC plans are primarily funded by employer contributions. Contributions to 401(k) plans are at the saving choices of participants and are often augmented by employer matching.

[2] The assessment of effectiveness should in the first place exclude forced savings by firms replacing DB pension plans with 401(k)s. Poterba, Venti and Wise (2001) document the shift from employer managed DB plans to employee controlled DC plans over the last two decades. They point out

The effectiveness of tax incentives depends critically on whether TDAs have inspired new savings. The literature shows that personal savings are largely driven by three motives: for liquidity (including precautionary and transaction needs), for retirement preparation and for bequests. Precautionary savings arise when households face uncertainty over earnings, medical expenses or other shocks and face borrowing limits in a world of incomplete markets for lending and insurance. Retirement savings are for life-cycle reasons in order to support consumption absent new flows of labor income. While these factors can explain the lower tail of the wealth distribution, researchers have found that the bequest motive plays an important role in generating wealth-income patterns consistent with the upper tail of wealth. [3] These motives matter when individuals choose the vehicles for savings. Deposits in TDAs are income tax deductible, returns accrue tax-free, and taxes are paid upon withdrawal. This tax structure makes TDAs attractive for long term saving since they provide savers with a higher return than conventional savings (CSAs). In the meantime, the early withdrawal penalty makes TDAs a quite costly source for liquidity financing. It thus makes much sense to make a functional division, allocating savings for liquidity into CSAs and retirement and bequest savings into TDAs.

The existing literature on the effectiveness of tax incentives has incorporated these saving motives to some extent, but has not yet captured the complex interactions

that "the micro data show no evidence that the accumulation of 401(k) assets has been offset by a reduction in defined benefit assets." This implies that the popularity of TDAs is largely the choice at employees' discretion.

[3] See, among others, Kotlikoff and Summers (1981), Hurd and Smith (1999), Dynan, Skinner and Zeldes (1996), and De Nardi (2004).

between simultaneous savings and leisure choices. Previous studies treat retirement as an exogenous and mandatory shift at some specific age, which by assumption rules out a potentially important stimulus to save - the possibility of *early* retirement. There is good reason to believe that endogenous retirement choice plays an important role in shaping the savings profile. If always employed until an exogenous retirement age, households will boost current consumption as well as gradually accumulating retirement wealth. With endogenous retirement decisions, however, individuals may depress their consumption growth rate and contribute to TDAs more significantly in the preparation for early retirement. In short, the impact of tax incentives on saving is closely associated with leisure choice and varies at different stages of the life cycle.

Another related strand of research has examined the relationship between wealth and retirement choice. The literature remains divided. Burtless (1986) shows that the unanticipated Social Security benefit increases in 1969-1973 induced retirement, while Krueger and Pischke (1992) find that the reduction in Social Security wealth did not reverse the decline in labor supply of the "notch" generation. Imbens, Rubin and Sacerdote (2001) find that lottery wealth induces retirement. Gustman and Steinmeier (1986) and Samwick (1998) report a small wealth effect on retirement. Hurd and Reti (2001) find no evidence that large stock market gains induce early retirement. An apparent caveat of previous studies is that they mainly focus on wealth change in after-tax accounts, while the omitted wealth in TDAs is substantial for many households and may constitute an important factor determining retirement. With higher rates of return, TDAs offer a more effective means for long-term asset accumulation that may encourage early retirement. However, it is a challenge to empirically identify the wealth effect of TDAs on retirement because of the short exposure to date of retiring cohorts to these tax deferred programs. A structural life-cycle model incorporating TDAs serves as a natural step to tackle the wealth effect on retirement and will shed light on the long-run pattern of labor supply.

This chapter incorporates endogenous labor supply (and thus retirement) decisions as well as all of the above saving motives into a realistically specified life-cycle model. Individuals face stochastic earnings in a world of incomplete markets. Realizations of earnings shocks produce *income* heterogeneity. Differing attitudes toward disutility of work generate *preference* heterogeneity in leisure and retirement choice. The model captures asset allocations between conventional and tax-deferred savings accounts. The presence of liquidity constraints justifies the need for savings in CSAs. Retirement and bequest motives induce households to make optimal allocations into TDAs.

I also carefully introduce a pay-as-you-go Social Security system, for two important reasons. First, Social Security serves as one of the major financing resources for retirement in practice, especially for those with relatively low income. Second, incorporating Social Security helps to avoid overstating the role of TDAs. Individuals make endogenous choices on when to claim Social Security, which are separate from their retirement decisions. This is another contribution of this chapter. Previous studies assuming identical timing of retirement and benefit take-up found that liquidity constrained individuals should retire early to obtain Social Security. My model predicts that high-income individuals may choose to retire earlier than otherwise by virtue of effective wealth accumulation through TDAs, claiming Social Security as a complement, even though they are not facing a shortage of income.

The life-cycle model in this chapter is similar in spirit to those in Engen and Gale (1993) and Engen, Gale and Scholz (1994). The simulations confirm their findings that TDA and CSA assets are imperfect substitutes when savings are mainly for liquidity purpose due to the early withdrawal penalty on TDAs, and that the substitutability increases with age when savings are mainly for retirement. A step further, I introduce important new elements: an intentional bequest motive, a separate decision on Social Security, and particularly endogenous labor supply and retirement decisions for the reasons outlined above. This comprehensive modeling proves to be fruitful, despite considerable computational cost, and yields illuminating findings. The effectiveness of saving incentives varies with income and preference heterogeneity. Tax deferred programs enhance individual welfare and at the same time encourage early retirement, perhaps unintentionally. Allowing for early retirement induces individuals in the model to accumulate more private savings, but with a larger share of asset reshuffling from CSAs to TDAs.

Several limitations should be noted. First, this model incorporates the public Social Security system, but assumes no private annuity market nor employer-provided DB pension plans, and abstracts from employer-matching of contributions to 401(k)s, the popular DC plans. The literature has postulated private pensions as an important force manipulating individual retirement behavior, as employees frequently must remain with their employer until some specific age to attain pension eligibility. Second, housing wealth is not explicitly modeled. For many households, home equity accounts for a large part of their total wealth, which may substantially restrict their utilization of TDAs. Third, the model abstracts from medical costs, employer-provided insurance and Medicare programs. Rust and Phelan (1997), Rust (2005), and Blau and Gilleskie (2003) illustrate that private and public insurance programs have significant employment effects. Fourth, the model assumes a deterministic rate of return on savings and does not address the portfolio choice of bonds and equities in CSAs and TDAs (see Huang (2003), Poterba and Samwick (2003), Shoven and Sialm (2003), and Dammon, Spatt and Zhang (2004) along this line). [4]

The remainder of the chapter is organized as follows: Section 1.2 describes the relationship between investment horizon and asset location choice; Section 1.3 outlines the life cycle model featuring asset allocations between CSAs and TDAs, endogenous labor/leisure choice, and separate Social Security decisions in an environment of stochastic earnings with a comprehensive tax system; Section 1.4 provides heuristic findings about consumption, savings and retirement decisions; Section 1.5 reports the findings from numerical simulations; Section 1.6 contains experiments for alternative TDA policy scenarios and reports experiments for the cases of partial myopia and the correlation of mortality with income; and Section 1.7 concludes.

[4] The capital gains tax rate for stocks is typically lower than the marginal tax rate for interest and labor income. The benefit from tax deferral is thus lower for saving in stocks in TDAs. Dammon, Spatt and Zhang (2004) show that individuals should hold in priority the heavily taxed bonds in TDAs. To balance risk exposure, individuals may find it optimal to hold both bonds and stocks in TDAs, in which case the recent capital gain tax reduction may weaken the tax advantage of TDAs.

1.2 Asset Location and Investment Horizon

1.2.1 Tax-Deferred and Conventional Savings Accounts

There are two different types of accounts: conventional savings accounts (CSAs) and tax deferred accounts (TDAs). The former refer to saving vehicles whose funds can be utilized freely at the owner's will. The latter refer broadly to special savings programs, including front-loaded plans such as traditional Individual Retirement Accounts (IRAs), 401(k)s, 403(b)s, and supplemental retirement accounts (SRAs), and back-loaded plans such as Roth IRAs. For front-loaded plans, both income taxes on initial contributions and the taxes on interest and capital gains are deferred, and accumulations are taxed as ordinary income only upon withdrawal. For back-loaded plans, initial contributions are subject to ordinary income tax and there are no taxes on future withdrawals. The following example illustrates that Roth IRAs and other TDAs are similar in nature. Let τ_0 and τ_1 be the current and future income tax rates, respectively. Suppose pre-tax \$1 is invested in a 401(k) and the equivalent after-tax amount $(1-\tau_0)\$1$ in a Roth IRA, and suppose the gross return is R at the terminal date. Then the after-tax value for a Roth IRA investment is $(1-\tau_0)R$ while that for a 401(k) investment is $(1-\tau_1)R$. Clearly each dollar in a Roth IRA is equivalent to $\frac{1-\tau_0}{1-\tau_1}$ dollars in a 401(k). The values are identical under if the tax rate applicable to the individual does not change over time ($\tau_0 = \tau_1$), while the 401(k) is more beneficial within a progressive tax system if the timing of withdrawal puts investors in a lower tax bracket ($\tau_0 > \tau_1$). As illustrated by Burman, Gale and Weiner (2001), the advantage of front-loaded plans lies in the benefit from the much lower tax rate most people face in retirement. Back-loaded plans, on the other hand, give taxpayers larger capacity to shelter funds than front-loaded plans, given equal contribution limits.

Without loss of generality, hereafter, I assume that all TDA contributions are income tax deductible and are capped by an annual limit, that interest accrues tax free, that withdrawals are taxed at the then-prevailing income tax rate, and that early withdrawals are subject to penalty. These assumptions are in line with current regulations.

1.2.2 Asset Locations - Saving for Retirement or for Liquidity

A simple horse race between returns on CSA and TDA investments will help illustrate the impact of the TDA tax structure on asset location decisions. Let r, τ, and τ_w denote the net interest rate, flat income tax rate (for ease of exposition in this section) and penalty rate on early withdrawals, respectively. A pre-tax dollar can be invested either in CSAs or in TDAs. A non-deductible CSA investment has a principal $\$1(1-\tau)$ and accrues at after-tax rate of return $r(1-\tau)$. It yields the following gross return in n years:

$$\$1(1-\tau)[1+r(1-\tau)]^n \tag{1}$$

A tax-deferred TDA investment has the entire dollar as principal and enjoys a pre-tax rate of return on interest. For the same horizon it yields the following gross return, after paying income tax and penalty (if applicable) upon withdrawal:

$$\$1(1+r)^n(1-\tau)(1-\tau_w). \tag{2}$$

It is apparent that TDAs are superior to CSAs if withdrawals are penalty free ($\tau_w = 0$). Saving in TDAs is also preferable if the investment is held sufficiently long so that the tax-deferring benefit more than offsets the penalty, which occurs if

$$n \geqslant n^* \equiv \frac{\ln(1-\tau_w)}{\ln[\frac{1+r(1-\tau)}{1+r}]}. \tag{3}$$

where n^* is the break-even holding period of TDA assets. A little algebra reveals that

$$\frac{\partial n^*}{\partial \tau_w} > 0 \tag{4}$$

$$\frac{\partial n^*}{\partial \tau} < 0. \tag{5}$$

$$\frac{\partial n^*}{\partial r} < 0 \tag{6}$$

A longer saving horizon is required in order to lock in tax subsidies sufficient to offset a higher early withdrawal penalty. Conversely, the more significant the tax shelter, the sooner households can harvest higher yields by investing in TDAs. For instance, if $r = 6\%$, $\tau = 25\%$, and $\tau_w = 10\%$, the investment horizon required to make TDA investment preferable despite the withdrawal penalty will be almost 11 years, while $\tau_w = 15\%$ and $\tau = 30\%$ will require $n \geqslant 16$ and $n \geqslant 9$, respectively.

This exercise shows that the investment horizon matters for asset location choice. The early withdrawal penalty could make TDA investment *ex post* unattractive relative to CSAs, unless the probability of early withdrawal is sufficiently small. TDAs are preferable when savings are for retirement, a long term objective, while CSAs are the optimal location to establish a buffer against immediate shocks. This is reflected in the fact that (1) is greater than (2) when $n = 1$, a short horizon. The simple comparison of (1) and (2) suggests that the wealth-maximizing investment strategy might be to allocate all incremental savings into TDAs, if feasible, once a certain liquidity buffer has been established in CSAs.

1.3 A Life Cycle Model

In this section, I outline a rich life-cycle model to capture the labor supply and consumption behaviors of individuals who are equipped with both TDAs and CSAs and who save for liquidity reasons, retirement, and bequests.

1.3.1 Preferences

Households have a maximum life span of T years, at which age death is certain. At each age $t \leqslant T$, households derive utility from consumption, leisure and potential bequests. The preferences are described by the following expected lifetime utility function

$$E_0 \sum_{t=0}^{T} \beta^t \left[\Psi_t u(c_t, l_t) + (1 - \Psi_t) \Gamma(w_t) \right] \tag{7}$$

where E_0 is the expectation operator; β is the subjective discount factor; Ψ_t is the unconditional survival probability, specifically, $\Psi_t = (\prod_{j=1}^{t} \psi_j)$,with $\psi_t \in (0, 1)$ being the survival probability at age t conditional on being alive at age $t - 1$, given $\psi_0 = 1$; and c_t and l_t are consumption and leisure, respectively. The period utility function is constant relative risk aversion (CRRA) over consumption and logarithmic over leisure:

$$u(c_t, l_t) = \frac{{c_t}^{1-\gamma} - 1}{1 - \gamma} + \eta(t, h, e_t) \ln(l_t) \tag{8}$$

where $\gamma > 0$ indicates an individual's relative risk aversion. The propensity for individuals to increase savings as a reaction to uncertainty of income is embedded in the CRRA function, where the positive third derivative serves as a sufficient (and necessary) condition for this precautionary motive. The weight on disutility of work, $\eta(t, h, e_t)$, is dependent on age t, health h, and average wages e_t (defined in (10) to proxy earnings ability) to reflect that agents' attitude towards leisure is time-varying with age and that healthy and well-paid agents tend to view work as less burdensome (Autor and Duggan, 2003). Such modeling strategy of heterogeneity in *preferences* follows the spirit of Rust (2005). Households also derive utility from bequests in case of death, defined as a function of the terminal wealth w_t,

$$\Gamma(w_t) = \kappa \frac{w_t^{1-\gamma} - 1}{1 - \gamma} \tag{9}$$

where the parameter κ measures the attitude towards bequests.

1.3.2 Income and Social Security

I introduce a stochastic labor income process, which is required to generate precautionary savings in CSAs, as described in the literature on "buffer stock" savings (see Deaton (1991), and Carroll (1992), among others). This is also motivated by the observation that explicit insurance markets for labor income are not well developed. Specifically, the labor income process is expressed in (10).

$$\begin{aligned} \ln(y_t) &= \alpha_0 + \alpha_1 \ln(e_t) + \alpha_2 t + \alpha_3 t^2 + \varepsilon_t \\ \varepsilon_t &= \rho \varepsilon_{t-1} + \nu_t, \ \nu_t \sim N(0, \sigma_\nu^2) \\ y(l_t) &= (1 - l_t) y_t \end{aligned} \tag{10}$$

First, the earnings contains a deterministic component as a function of age t and average earnings e_t (defined below as a proxy for AIME), which captures the life-cycle trend in wages, an approach suggested by Rust and Phelan (1997). [5] Second, randomness of earnings is introduced through shocks ε's, with ρ controlling the degree of persistence. Accumulation of shocks makes life-cycle earnings profiles vary across individuals, which is an important source of *income* heterogeneity. Third, given the above "exogenous" factors, final income $y(l_t)$ is endogenously determined by the level of labor supply $(1 - l_t)$. The labor flexibility implies an endogenous decision on the timing of retirement, which is assumed to be reversible at no cost prior to a mandatory retirement age, t^m.

Social Security benefits, called Primary Insurance Amount (PIA), are determined by the Average Indexed Monthly Earnings (AIME). AIME is in practice calculated as the average of the 35 highest years of earnings. In order to keep the computation tractable while preserving the essence of Social Security rules, the annualized AIME in this model, denoted by e_t, is measured as the average of all earnings prior to retirement. Specifically,

$$e_{t+1} = \frac{te_t + \min[y(l_t), y^{\max}]}{t+1} \tag{11}$$

where $y^{\max}$ is the maximum of earnings subject to payroll tax and counted toward e.

The PIA, denoted by b, is a concave piece-wise function of the AIME (e^*) achieved

[5] This modeling strategy has at least three merits. First, the distribution of e_t effectively captures fixed effects across individuals since e_t, as a proxy of AIME, follows a rather gradual evolution and thus reflects a permanent component of wages. Second, this setup is computationally efficient: with e_t already being carried as a state variable, a single solution of the model is sufficient for simulations to generate income heterogeneity given various initial values for e_1. Third, the specification of e_t and t fits the real life-cycle trend of wages quite well, which is the ultimate objective of such modeling.

at the claim age (t^*). For $t = t^*, t^*+1, t^*+2, ..., T$,

$$b = \begin{cases} \max\{b^{\min}, \alpha_0 e^*\}, & if \quad e^* < B_1 \\ \alpha_1 + \alpha_2 (e^* - B_1), & if \quad B_1 \leqslant e^* < B_2 \\ \alpha_3 + \alpha_4 (e^* - B_2), & if \quad B_2 \leqslant e^* \end{cases} \tag{12}$$

where B_1 and B_2 are referred to as the bend points, and $b^{\min}$ is the minimum floor of Social Security benefits. Individuals are assumed to make separate decisions with regard to the timing of retirement and take-up of Social Security benefits. They can elect to claim Social Security provided that they have reached the early retirement age, t^e. However, benefits are higher if individuals wait until a normal retirement age, t^n, where $t^e < t^n < t^m$. Social Security claiming is irreversible; that is, once individuals begin receiving Social Security they are locked into their PIA annuity for their remaining lifetime. According to current regulations, early claims prior to age t^n are granted lower benefits, while delayed claims past t^n get credit. Both adjustments are approximately actuarially fair for the average person. In addition, Social Security benefits are subject to an earnings test if individuals are younger than t^m. Early claims face a higher earnings test tax rate and a lower exempt minimum compared with delayed claims. Specifically, Social Security benefits are reduced by $\tau^0 \max\{y(l_t) - \overline{y}^0, 0\}$ for claims between ages t^e and t^n, and by $\tau^1 \max\{y(l_t) - \overline{y}^1, 0\}$ for claims between ages t^n and t^m, with $\tau^0 > \tau^1$ and $\overline{y}^0 < \overline{y}^1$. Obviously, the reduction is no larger than b.

1.3.3 The Household Optimization Problem

Let a and q denote assets in CSAs and TDAs, respectively. I impose the following simple liquidity restrictions on CSAs and TDAs via (13)-(14). These conditions prevent households from capitalizing or borrowing against future labor income or retirement wealth.

$$a_t \geqslant 0, \forall t \tag{13}$$

$$q_t \geqslant 0, \forall t \tag{14}$$

Households can contribute to TDAs up to ξ percent of labor income or a specific ceiling, L, whichever is smaller. They may instead choose to draw down TDA assets. Formally, if the TDA transaction in dollars is denoted by x_t, then

$$-(1+r)q_t \leqslant x_t \leqslant \min\{\xi y(l_t), L\} \tag{15}$$

where positive values of x_t imply contributions, and negative values represent withdrawals. Condition (15) mandates that TDA contributions are not feasible when there is no labor income ($y(l_t) = 0$), which is consistent with tax regulations in practice. Contributions are tax deductible, while early withdrawals are subject to penalty at rate τ_w prior to the penalty-free age, t^f. Households need to pay federal and state income taxes on TDA withdrawals at then-prevailing rates regardless of age.

Households' dynamic budget constraints for CSAs and TDAs evolve as follows:

$$\begin{aligned} a_{t+1} &= (1+r)a_t + y(l_t) + b - (1-\lambda_t\tau_w)x_t - c_t \\ &\quad -\tau(y(l_t), x_t, ra_t, b) - \tau_s \min\{y^{\max}, y(l_t)\} \end{aligned} \tag{16}$$

$$q_{t+1} = (1+r)q_t + x_t \tag{17}$$

where λ_t is an indicator function that is equal to 1 if $x_t < 0$ *and* $t < t^e$, and 0 otherwise; τ_s denotes the payroll tax at rate, and $\tau(y(l_t), b, x_t, ra_t)$ encompasses all other taxes including a progressive tax on labor income, the Earned Income Tax Credit (EITC), income taxes (or refunds) on TDA withdrawals (contributions), taxes on CSA interest, taxes on income-adjusted Social Security benefits, and taxes due to the earnings test. It should be stressed that CSA assets accrue at an after-tax rate while TDAs accrue tax free. Early TDA withdrawals are costly due to the penalty $(\tau_w x_t)$ in addition to the income tax.

The consumer's problem is to maximize the discounted expected lifetime utility in (7), given initial endowment of wealth, subject to the short-selling constraints (13)-(14) and the dynamic budget constraints (15)-(17). The beginning-of-period state variables are $\Lambda_t = \{t, a_t, e_t, q_t, \varepsilon_t, z_t^s\}$, and the choice variables $\{c_t, l_t, x_t, z_t^d\}$, where z_t^s and z_t^d are the Social Security claim status and claim decision, respectively. Individuals must decide on consumption, c_t, labor supply, l_t, asset allocation between TDAs and CSAs, x_t, and whether to claim Social Security, z_t^d. It should be noted that labor earnings are unknown due to their stochastic nature when consumption decisions are made. Individuals in the model are thus restricted to consume no more than their current tangible wealth in CSAs and TDAs, net of taxes and early withdrawal penalty if applicable. [6] This implies that they cannot borrow against future earnings. Specifically,

$$c_t \leqslant (1+r)(a_t + q_t) + b - \tau(0, (1+r)q_t, ra_t, b) - \lambda_t \tau_w (1+r) q_t \tag{18}$$

[6] This restriction implies that part of CSA balances are assets-in-advance for transaction purposes.

However, realizations of earnings must be revealed when individuals are making TDA contributions since they need to know the limit imposed by $x_t \leqslant \min\{\xi y(l_t), L\}$. Otherwise, there would exist cases in which TDA contributions could exceed labor earnings, yielding negative CSA balances in violation of condition $a_t \geqslant 0$. Let $V(\Lambda_t)$ be the indirect value function for the dynamic programming problem. Then,

$$V(\Lambda_t) = \max_{c_t, l_t, x_t, z_t^d} \{u(c_t, l_t) + \beta[\psi_{t+1} E_t V(\Lambda_{t+1}) + (1 - \psi_{t+1}) E_t \Gamma(w_{t+1})]\} \tag{19}$$

subject to constraints (13)-(17), where E_t is the expectation over the distribution of Λ_{t+1} conditional on information at t. Terminal wealth w is the combined TDA and CSA assets.

1.4 Some Heuristic Findings

This complex dynamic programming problem calls for numerical solution and simulation of life-cycle behavior. Before presenting numerical results, it is worth highlighting some heuristic findings in a simplified version of the model in which I assume a flat and constant income tax rate τ, maintaining the assumptions that TDAs accrue tax free and are subject to early withdrawal penalty. These simplifications preserve the main characteristics of TDAs, while allowing for a progressive tax system would further strengthen the following analysis. Appendix 1.A outlines the derivation of the following findings.

1.4.1 Consumption

The first order necessary conditions of the utility maximization problem with respect to a_{t+1} and q_{t+1} at age t are (20) and (21), respectively.

$$\begin{aligned} u'_c(c_t, l_t) &= \beta\left[1 + (1-\tau)r\right] E_t[\psi_{t+1} u'_c(c_{t+1}, l_{t+1}) \\ &\quad + (1-\psi_{t+1})\Gamma'(w_{t+1})] + E_t \mu^a_{t+1} \qquad (20) \\ (1-\lambda_t \tau_w) u'_c(c_t, l_t) &= \beta(1+r) E_t[(1-\lambda_{t+1}\tau_w)\psi_{t+1} u'_c(c_{t+1}, l_{t+1}) \\ &\quad + (1-\psi_{t+1})\Gamma'(w_{t+1})] - \mu^L_t + (1+r)E_t \mu^L_{t+1} + E_t \mu^q_{t+1} \qquad (21) \end{aligned}$$

where μ^a_t and μ^q_t are the Lagrange multipliers on the non-negativity constraints for CSAs and TDAs; and μ^L_t is the Lagrange multiplier on the contribution limit.

Condition (20) is the Euler equation with respect to a_{t+1}. It implies that households will balance consumption and CSA saving so that the marginal utility of a unit of current consumption is equal to the marginal benefit of saving the same unit, which includes the discounted marginal utility of future consumption or bequests and the expected benefit from avoiding the liquidity constraint ($E_t \mu^a_{t+1}$).

Condition (21) is the Euler equation with respect to q_{t+1}, which embodies a similar intuition for the optimal allocation between consumption and saving in TDAs. The difference lies in the fact that the TDA savings have a higher rate of return and the fact that the intertemporal optimization regarding TDAs might be inhibited by the contribution limit. The marginal benefit of contributing in period t (thus $\lambda_t = 0$) is equal to the expected marginal utility of future consumption or bequests, plus the expected gain from avoiding the contribution limit and the liquidity constraint next period. Proposition 1 follows from further examination of (21).

Remark 1. *(i) The expected marginal benefit of TDA saving is lowered by the withdrawal penalty when it applies (i.e. when $\lambda_{t+1} = 1$); (ii) An individual may not be able to fully realize the benefit of contributing due to the contribution limit (i.e. when $\mu_t^L > 0$); and (iii) The marginal benefit of withdrawing (thus $\lambda_t = 1$) in period t is shrunk by the penalty and carries a higher opportunity cost in terms of lower wealth accumulation for future.*

Tax advantages induce wealth accumulation through TDAs, while the precautionary motive keeps savings in CSAs. The balance is struck by combining (20) and (21). The resulting equation (see Appendix 1.A) implies that an optimal interior asset allocation between CSAs and TDAs is reached when a dollar contribution to CSAs or TDAs brings the same level of marginal expected utility (otherwise a corner solution emerges, so that contributions will be made in only one type of account). Some simplification yields a straightforward interpretation for a special case in which the individual contributes to TDAs at age t (thus $\lambda_t = 0$) and the individual's future withdrawals are not subject to penalty (i.e. $\lambda_{t+1} = 0$ with probability one). The following condition holds in this special case:

$$\begin{aligned} & \beta\tau r E_t[\psi_{t+1} u'_c(c_{t+1}, l_{t+1}) + (1-\psi_{t+1})\Gamma'(w_{t+1})] \\ = \;& E_t\mu^a_{t+1} + \mu^L_t - (1+r)E_t\mu^L_{t+1} - E_t\mu^q_{t+1} \end{aligned} \tag{22}$$

The left hand side of equation (22) measures the advantage of contributing to TDAs rather than to CSAs, which is the discounted marginal expected utility due to the tax shelter on interest (via the term τr). Note that $E_t\mu^L_{t+1} \geqslant 0$ and $E_t\mu^q_{t+1} \geqslant 0$ and note also that the left hand side of equation (22) is strictly positive. The relative tax advantage for TDAs in this special case of no withdrawal penalties thus implies either a binding contribution limit ($\mu_t^L > 0$) or a binding constraint on borrowing against CSAs ($E_t\mu_{t+1}^a > 0$).

Remark 2. *Absent withdrawal penalty, all individuals would contribute to the limit.*

1.4.2 Saving Rules

Another way of seeing the impact of TDA rules on the allocation of savings heuristically is to examine the marginal value of CSA and TDA wealth. Applying the Envelope Theorem with respect to a_t and q_t, respectively, to the indirect value function and shifting one period forward produces the following conditions.

$$E_tV_a'(\Lambda_{t+1}) = [1+r(1-\tau)]E_t[\mu_{t+1}^B + \beta(1-\psi_{t+1})\Gamma'(w_{t+1})] + E_t\mu_{t+1}^a \quad (23)$$

$$\begin{aligned} E_tV_q'(\Lambda_{t+1}) &= (1+r)E_t[\mu_{t+1}^B(1-\lambda_{t+1}\tau_w) \\ &\quad +\beta(1-\psi_{t+1})\Gamma'(w_{t+1}) + \mu_{t+1}^L] + E_t\mu_{t+1}^q \end{aligned} \quad (24)$$

where μ_{t+1}^B is the Lagrange multiplier on the dynamic budget constraint in period $t+1$. Several interesting findings are exhibited in Proposition 3.

Remark 3. *(i) Absent a sufficient CSA buffer, it is not optimal to overinvest in TDAs. Shocks materialized next period may force early withdrawal (hence $\lambda_{t+1} = 1$ and $\mu_{t+1}^L = 0$),* which *makes after-penalty TDAs inferior to CSAs since $E_tV_a'(\Lambda_{t+1}) > E_tV_q'(\Lambda_{t+1})$. (ii) With a sufficient CSA buffer, savings for retirement should be allocated to TDAs since $E_tV_q'(\Lambda_{t+1}) > E_tV_a'(\Lambda_{t+1})$ when $\lambda_{t+1} = 0$ with probability*

1. *(iii) The presence of a bequest motive encourages both CSA and TDA savings, with the marginal benefit of TDA savings enhanced more substantially simply because* $1 + r > 1 + r(1 - \tau)$. *(iv) The stronger the bequest motive, the more valuable are TDAs compared with CSAs since*

$$\frac{dE_t V_q'(\Lambda_{t+1})}{dE_t \Gamma'(w_{t+1})} > \frac{dE_t V_a'(\Lambda_{t+1})}{dE_t \Gamma'(w_{t+1})}.$$

Another way of viewing (23) and (24) heuristically is that they imply an optimal sequencing of withdrawals from TDAs and CSAs, should the household need to dissave. For a given-sized transaction and absent withdrawal penalty, the opportunity cost of drawing down TDAs is larger than that of drawing down CSAs by a factor of $(1 + r)/[1 + r(1 - \tau)]$. In addition, when a withdrawal penalty exists, households have to increase TDA withdrawals by a factor of $1/(1 - \tau_w)$ to get the same level of financing.

Remark 4. *TDA withdrawals are more costly and individuals should first exhaust CSA funds before tapping TDAs.*

1.4.3 Retirement Effect of TDAs

Comparative statics help illustrate the impact of CSA and TDA wealth on leisure choice. A little algebra in Appendix 1.A shows that

$$\frac{\partial l_t}{\partial a_t} > 0 \quad (25)$$

$$\frac{\partial l_t}{\partial q_t} > 0 \quad (26)$$

These inequalities imply that higher wealth accumulated to date, either in CSAs or TDAs, tends to induce more leisure or even complete exit from labor force (retirement). Further analysis (in Appendix 1.A) reveals that

$$\frac{\partial l_t}{\partial q_t} > \frac{\partial l_t}{\partial a_t} \tag{27}$$

which is particularly true once the agent is old enough that TDA withdrawals are penalty free. The inequality in (27) implies that TDA wealth has a larger impact on labor supply and that early retirement becomes easier with TDA wealth accumulation.

Remark 5. *Leisure is a normal good and the higher pre-tax rate of return on TDAs provides a greater income effect, which encourages more retirement.*

1.5 Numerical Analysis

I now return to the fully-loaded version of the model and use numerical methods to analyze consumers' saving, labor supply, and Social Security claim decisions. The computation begins by discretizing the continuous state variables. The utility maximization problem is then solved backward from age T to age t_1 for all feasible combinations of state grid points and realizations of random variables. The optimal decision rules are recorded along this backward process. Large scale Monte Carlo simulations are finally carried out to generate average life-cycle profiles based on the decision rules derived above. See Appendix 1.B for details of the solution method.

1.5.1 State and Choice Variables

Some explanation of the discretization of variables is in order. Following Rust (2005) and Gustman and Steinmeier (2003), I introduce limited labor flexibility. Specifically, I assume discrete leisure choice, i.e. $l_t \in \{1, .817, .543\}$, where full leisure (no work) is normalized to 1, and leisure for part-time and full-time work is .817 and .543, respectively. [7] This assumption, in spite of its restriction on labor adjustment, may reflect the real world given the observation that legal and institutional impediments make phased retirement difficult to achieve (Penner, Perun and Steuerle (2002)). Ruhm (1990) finds that transition through bridge jobs or part-time employment is common for employees who desire partial retirement. It is assumed that individuals make discretionary decisions on labor supply before age 70 and that all employees must retire no later than 70.

The Social Security payment status z_t^s is either 0, which indicates non-eligibility or non-claiming, or one of $\{62, 63, ...70\}$, which indicates the age when an individual starts to claim and receive Social Security benefits. The Social Security claim decision z_t^d indicates individuals' choices conditional on not previously claiming benefits: to claim ($z_t^d = 1$) or not to claim ($z_t^d = 0$). Agents who claim receive the annuity value determined at the first claim age for their remaining life span. Agents cannot reverse their decision to claim. The actually disposable value of Social Security benefits may vary due to the earnings test.

[7] Assuming that 12 hours a day are available for discretionary work/leisure, and assuming 2000 hours a year (40hours*50weeks) are required for a full-time job, then $l_t = (12*365-2000)/(12*365) = .543$. Similarly, assuming 800 hours for a part-time job generate $l_t = (12*365-800)/(12*365) = .817$.

Households can elect to claim Social Security when $t \in \{62, 63, ...70\}$. The end points are the early and the mandatory retirement age, respectively. No Social Security benefit may be granted prior to 62. Early claims prior to the normal retirement/claim age 65 receive benefits reduced by an approximately actuarially fair factor of 6.67% per year prior to 65. For instance, a claim at age 62 will receive 80% of the normal benefit. [8] Delayed claims past 65 are awarded delayed credit, which is not applicable beyond age 70. The credit factor is assumed to be 5% for each year delayed. [9] Benefits between ages 62 and 70 may be partially or entirely taxed away depending on the level of labor income. The earnings test prior to age 65 is more stringent than after, which is reflected in the earnings test tax rates ($\tau^0 = 50\%$ and $\tau^1 = 33.3\%$) and the exempt minima ($\overline{y}^0 = \$10,800$ and $\overline{y}^1 = \$17,000$). [10] These assumptions are largely consistent with current Social Security rules.

Table 1. Summary of State Variables

Symbol	Description	Type
t	Age	discrete, $t \in \{21, 22, ...90\}$
a_t	CSA savings	continuous, $a_t \in [0, \infty)$
e_t	AIME	continuous, $e_t \in [0, 72.6]$
q_t	TDA savings	continuous, $q_t \in [0, \infty)$
ε_t	Persistent shock	Markov chain
z_t^s	S.S. claim status	discrete, $z_t^s \in \{0, 62, 63, ...70\}$

[8] The normal retirement age is now increasing gradually to 67 for individuals born in 1960 or later. The benefit reduction for retirement at 62 will rise to 30% for those born in 1960 or later.

[9] In practice, the annual delayed retirement credit varies from 3% to 8% by birth year. Individuals born in 1924 receive 3% more benefit per delayed year. The annual credit increases by 0.5% for each additional two years after birth year 1924 until it reaches 8% for those born in 1943 or later.

[10] The earnings test for ages 66 to 69 has been recently eliminated. Some researchers list this policy change as one of the reasons for the recently observed increase in labor supply among the old.

Table 2. Summary of Choice Variables

Symbol	Description	Type
c_t	Consumption	continuous
l_t	Leisure choice	discrete, $l_t \in \{1, .817, .543\}$
x_t	Asset allocation	continuous
z_t^d	S.S. claim decision	discrete, $z_t^d \in \{0, 1\}$

1.5.2 Parameter Calibrations

Individuals in the model make decisions starting at age 21 and can live up to age 90. The conditional survival probabilities, ψ_t, are the death rates for males in the Decennial Life Tables maintained by the U.S. Centers for Disease Control and Prevention. The value of the subjective discount factor, β, has been usually taken to be less than unity to reflect impatience (e.g. Auerbach and Kotlikoff, 1987 and Hubbard and Judd, 1987), although empirical evidence has also suggested values larger than unity (Hurd, 1989). The discount factor β is set to be 0.98 in this model. There is a wide range of empirical estimates for the elasticity of intertemporal substitution, $1/\gamma$ (the reciprocal of the coefficient of relative risk aversion). Hall (1988) believes $1/\gamma$ very close to zero. Kydland and Prescott (1982) calibrate $1/\gamma$ to 0.66. Carroll (2001) views γ between $[1, 5]$ as generally plausible. I set $1/\gamma = 0.73$ to reflect moderate risk aversion. I assume as a benchmark that there is a modest bequest motive, setting $\kappa = 0.2$.

The weight on disutility of work, $\eta(t, h, e_t)$, is assumed to increase with age t and to decrease with e_t, a proxy of earnings ability. The notion that the utility function changes over time because of changes in disutility of work is supported by Autor and Duggan (2003) who show that disability rates increase with age. The weight on leisure

$\eta(t, h, e_t)$ also increases with the deterioration of health h, a notion supported by the findings by Duggan, Singleton and Song (2005). This case is explored in Section 1.6. Graphically, Figure 1 shows the heterogeneity in preferences introduced by the weight on leisure.

The coefficients governing the life-cycle trend of earnings in (10) are estimated on the restricted Social Security earnings data from HRS and are reported in Table 3. The persistent shocks are approximated by a 2-state Markov chain with $\sigma_\nu^2 = .06$ and $\rho = .935$. These shock parameters are obtained from Storesletten, Telmer and Yaron (1998). Heathcote, Storesletten, and Violante (2004) report similar estimates. Their common emphasis is the importance of persistent and transitory shocks in forming individuals' earnings profiles. Figure 2 shows the heterogeneity in income and the corresponding AIME generated by this formulation.

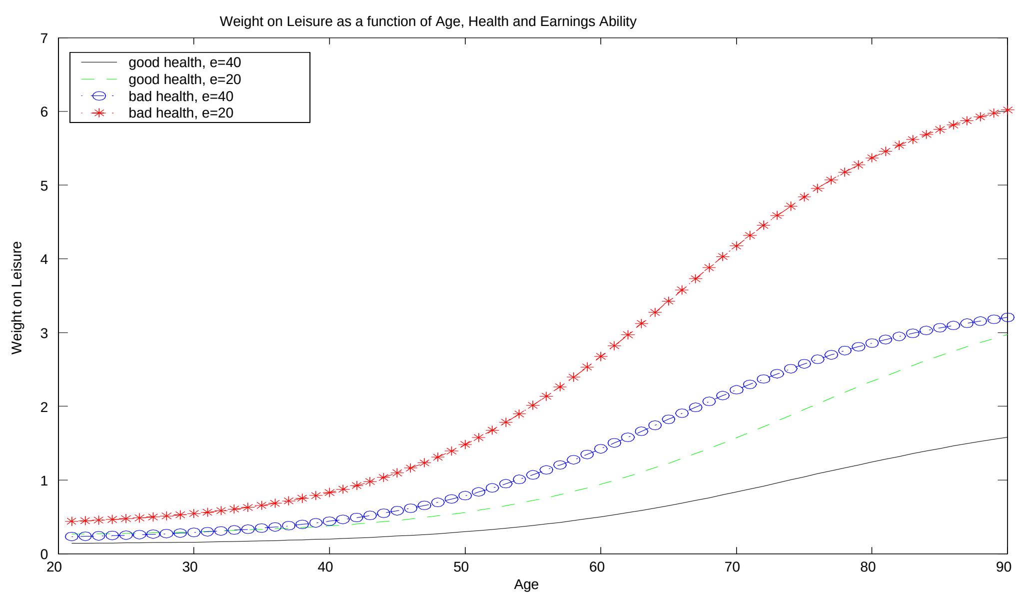

Figure 1: Heterogeneity in Preferences

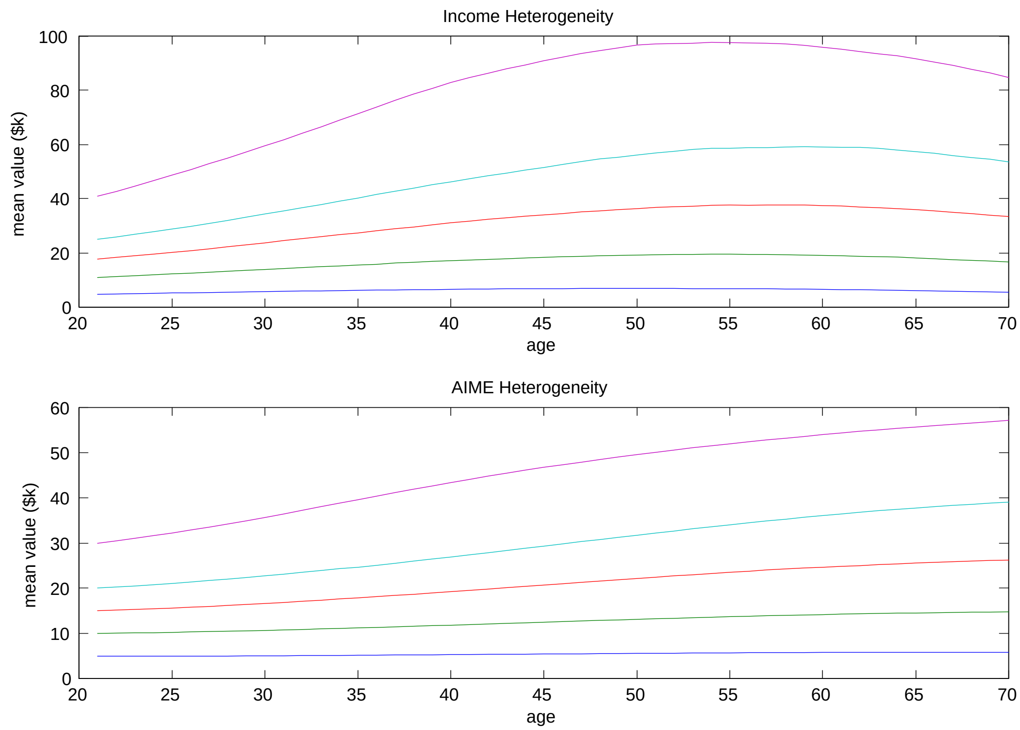

Figure 2: Heterogeneity in Income and AIME

The tax structure is constant over the life cycle. The income tax is intended to mimic the 2000 individual tax code, which includes a progressive Federal income tax schedule with tax brackets of 15, 28, 36 and 39.6 percent and a flat 5% state and local tax. [11] The model also incorporates a detailed Earned Income Tax Credit (EITC) applicable to low income individuals. The payroll tax rate, τ_s, is 6.2% for Old Age, Survivors, and Disability Insurance (OASDI) and is applied to earnings up to a maximum of \$76,200. [12] The parameter values and bend points determining PIA in (12) follow

[11] The marginal tax rate according to 2000 Federal tax code is 15 percent on income below \$26,250, 28 percent on income between \$26,251 and \$63,550, 31 percent on income between \$63,551 and \$132,600, 36 percent on income between \$132,601 and \$288,350, and 39.6 percent on income above \$288,350.

[12] I abstract from the Medicare tax since no medical costs are explicitly modeled. In practice the Medicare tax rate (HI) is 1.45%. The employer and employee combined rate for OASDI and HI is 15.3%.

the 2000 Social Security regulations. [13] The before tax return on savings is set to be 4%. [14]

According to the Economic Recovery Tax Act (ERTA) of 1981, individuals who are $59\frac{1}{2}$ or older are allowed to draw on their IRAs without penalty. Thus the penalty free age in the model is $t^f = 60$. The TDA contribution ceiling L is equal to $10,500, which was the value of the elective contribution limit on 401(k) plans in 2000. [15] In addition, the Employee Retirement Income Security Act (ERISA) regulates that employer and employee tax-deferred contributions combined can not exceed 25 percent of total earned income. These rules apply as well to other defined contribution plans, such as IRAs and Keogh plans. Many employers impose even tighter limits in the range of 10-15%. [16] Here I set $\xi = 25\%$. Early withdrawals are subject to a 10 percent penalty according to ERISA. Therefore, I set $\tau_w = 10\%$. The regulatory rules on special retirement accounts generally prohibit early withdrawals except in some special circumstances. [17]

[13] The values for PIA formula in Table 3 are monthly figures. PIA parameters are calculated as follows: $\alpha_1 = \alpha_0 B_1 = 477.9$, $\alpha_3 = \alpha_1 + \alpha_2(B_2 - B_1) = 1332.6$.

[14] This rate of return implicitly assumes a portfolio composed of both stocks and bonds. Scholz, Seshadri, and Khitatrakun (2004) report 7.6% as the average real stock market return between 1947 and 1996 and 0.8% as the average real return on 3-month Treasury bills (footnote 16).

[15] IRA contribution limits vary by year and age: they are $3,000 in 2002-2004, $4,000 in 2005-2007 and $5,000 in 2008; and individuals over 50 have a further $500 in 2002 and $1,000 in 2006. Limits will be indexed for inflation after 2008. Traditional IRA contributions are fully tax deductible if the owner does not participate in a 401(k) or other qualified retirement plan; otherwise the deductibility may decline to zero depending on the owner's modified adjusted gross income (AGI).

[16] See Engen, Gale, and Scholz (1994) (page 89).

[17] Some 401(k) plans allow the owners to borrow against their vested balances up to a limit for specific reasons. They must pay the loan back with interest over a short period; otherwise a 10% early withdrawal penalty will apply in addition to income tax. Borrowing implies the loss of the tax-deferring advantage and the loan is repaid with after-tax income. IRA owners are subject to a five-tax-year waiting period before any withdrawal. There are exceptions to early withdrawal penalties

Table 3. Parameter Calibrations

Preferences		Ages	
$\beta = 0.98$	discount factor	$t_1 = 21$	starting age
$\gamma = 1.37$	CRRA value	$t^f = 60$	penalty free
$\eta(t, h, e_t)$	see text	$t^e = 62$	early retirement
$\kappa = 0.2$	bequest factor	$t^n = 65$	normal ret.
Ψ, ψ	survival rate	$t^m = 70$	mandatory ret.
$r = .04$	interest rate	$T = 90$	max. life span
PIA Formula		**Earnings Process**	
$b^{\min} = \$300$	$\alpha_0 = .9$	$\delta_0 = -1.05$	$\delta_1 = 1.20$
$\alpha_1 = \$478$	$\alpha_2 = .32$	$\delta_2 = .04$	$\delta_3 = -.0005$
$\alpha_3 = \$1333$	$\alpha_4 = .15$	$\rho = .935$	$\sigma_\nu^2 = .06$
$B_1 = \$531$	$B_2 = \$3202$	$\sigma_\varepsilon^2 = .008$	
Income and Payroll Tax		**TDA Rules**	
$\{.15, .28, .36, .396\}$	tax brackets	$\tau_w = .10$	penalty rate
$\{.05\}$	state tax	$\xi = .25$	contribution
$\tau_s = .062$	OASDI tax	$L = \$10,500$	limit
$y^{\max} = \$76,200$	max. taxable		
Earnings test			
$\tau^0 = .50$	$\overline{y}^0 = \$10,080$		
$\tau^1 = .333$	$\overline{y}^1 = \$17,000$		

1.5.3 Benchmark Saving and Retirement

As a benchmark, I first examine individuals' behavior when TDAs are not available. Figure 3 shows life-cycle profiles for savings (CSAs only), consumption, employment, and labor income, which are averages over a large number of simulations. In the early phase of the life cycle, individuals need to rapidly build up a liquidity stock for precautionary and transaction reasons. Early consumption is depressed to some extent and closely tracks labor income, shifting upward as more resources become available. In the latter phase of the life cycle, effective impatience increases due to

but most do not apply to average tax payers. Such special events include permanent disability or death of the IRA owner, serious illness with expenses in excess of 7.5% of adjusted gross income, first-time home purchase with a lifetime limit of $10,000, and medical insurance payment conditional on unemployment for more than twelve weeks.

higher mortality risk. They are also assigning greater utility weight to leisure than they did earlier in life due to changing preferences. The consumption path hence slopes downward at this stage. A hump shape of life-cycle consumption emerges.

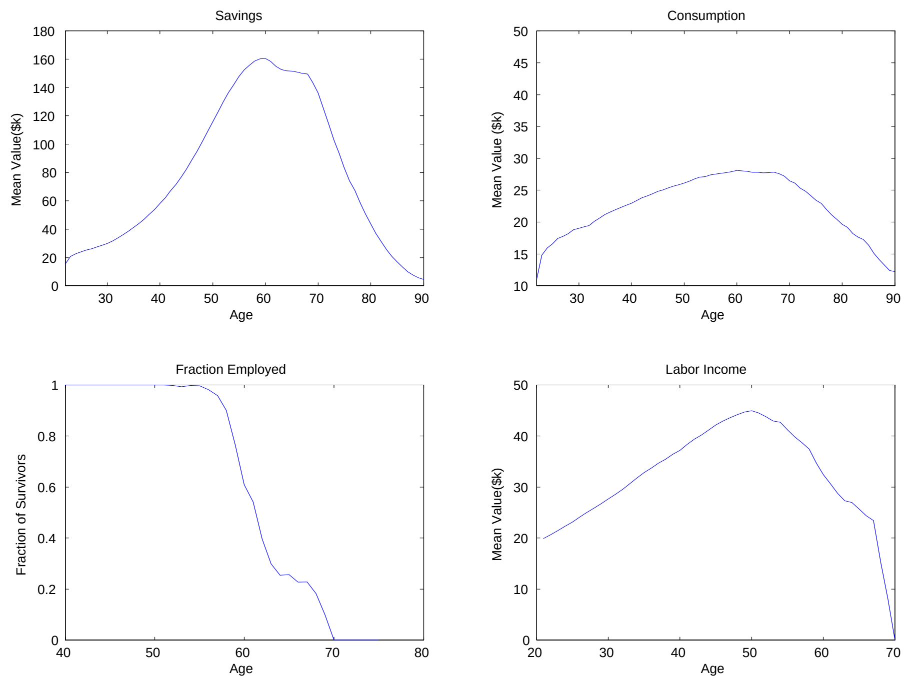

Figure 3: Benchmark Simulations - No TDAs

Once the buffer stock has reached a reasonable level, individuals start saving mainly for retirement. Individuals in the model start reducing labor supply on average in their late 50's. Wealth is decumulated to support consumption upon the transition from full-time to part-time work and the decumulation is more rapid after full retirement at age 70. Allowing for uncertain events during retirement in addition to the bequest motive would likely slow down the pace of wealth depletion. For instance, Rust (2005) shows that stochastic medical costs (and hence insurance coverage) have a large impact on faculty decisions regarding retirement, consumption, and wealth decumulation.

The timing of retirement is determined by several factors. First, changes in attitude towards work (i.e., η) make leisure significantly more appealing as agents age. Second, wealth accumulated is sufficient to support retirement consumption and bequests. Third, Social Security wealth facilitates the transition to lower labor supply. Although retirement and Social Security take-up are two discretionary decisions, they are not necessarily independent due to the existence of the earnings test. It is not optimal to claim Social Security while working full time if the earnings test will tax away all the benefits. The benchmark simulations show that quite a few individuals choose to switch to a part-time job in their 50's or 60's. The prevalence of part-time work echoes the findings by Ruhm (1990), who presents evidence from the Retirement History Longitudinal Survey "suggesting that partial retirement is both more prevalent and longer lasting than is generally believed" (p. 490). Fewer than two-fifth of the respondents retired directly from career jobs. Korczyk (2004) reports that 70 to 80 percent of older workers in surveys and public opinion polls expect to work at least part time in retirement. There apparently exists considerable discrepancy between the number of workers who desire to work part-time and the number who actually do so, due to various real world constraints. My model abstracts from these constraints and thus allows frictionless transitions from full-time to part-time jobs.

1.5.4 Wealth Allocation between TDAs and CSAs

This subsection describes life-cycle behaviors when both CSAs and TDAs are available. Figure 4 shows that individuals now allocate a substantial share of total wealth into TDAs. It demonstrates that there is to some degree a functional division between CSAs and TDAs, with the former serving mainly for liquidity and the latter for retirement. Savings are solely directed into CSAs in the beginning so as to rapidly establish a liquidity stock as a cushion against negative earnings shocks. [18] CSA balances increase with consumption because a bigger liquidity stock in CSAs is needed to accommodate a higher consumption. TDA contributions occur, up to the limit if desirable, when CSA savings have reached a reasonable level. Apparently, wealth accumulation through TDAs is not always feasible, particularly when individuals have no income available for TDA after giving priority to CSA buffer buildup. Alternatively, TDA contributions may hit the annual limit.

As illustrated in Section 1.2, sequencing savings between CSAs and TDAs is an optimal strategy in that forced early withdrawal from TDAs is costly. This does not necessarily imply that households require a liquidity buffer in CSAs that can absolutely cover all income shocks. TDAs may satisfy part of the need for precautionary savings since, after a period of time, the higher effective rate of return will more than offset the early withdrawal penalty. On the one hand, the bigger the liquidity buffer in CSAs, the less likely one is to suffer penalties or marginal disutility of reduced con-

[18] This model abstracts from the case where employers match TDA contributions. Employer matching could make contributing early optimal, even with the need to build up liquidity savings in CSAs.

sumption in case of shocks. On the other hand, the earlier the TDA contributions, the larger effective tax subsidies can be harvested for retirement. The trade-off encourages households to accumulate a reasonable level in CSAs and then use TDA assets as a backup. When adverse shocks strike and the CSA balance falls short, households will partially liquidate TDA assets to inject liquidity into their CSA buffer.

Heterogeneity in preferences and income serves to shape the savings profile. Individuals with low income and low AIME attach higher weight to leisure and will choose to retire early. They exhaust CSA balances first and start tapping TDA assets at age 60 since TDAs are now equally liquid without penalty. Others, those with high earnings ability, may choose to continue to work and contribute to TDAs until age 70. Restricted by contribution limits, their labor income cannot be fully sheltered in TDAs and thus they continue to accumulate in CSAs.

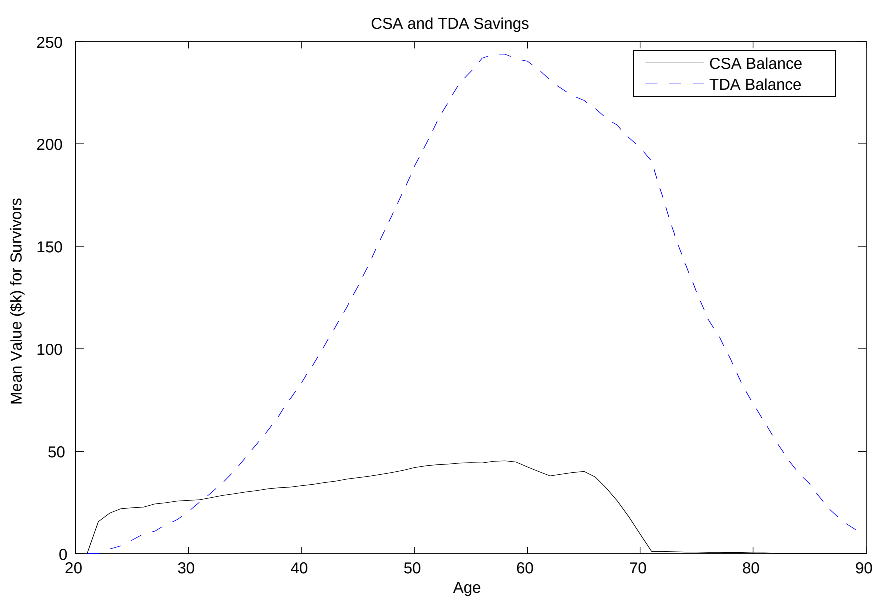

Figure 4: Asset Allocation between CSAs and TDAs

1.5.5 Effectiveness of Saving Incentives

One important and widely debated issue is whether special retirement programs have generated new private savings. That is, to what extent are CSA and TDA savings substitutes? Engen, Gale, and Scholz (1994) and Gale and Scholz (1994) find little evidence that retirement programs raise private savings. On the contrary, Poterba, Venti, and Wise (1995, 1997) and Venti and Wise (1986, 1990, 1995) argue that IRAs and 401(k)s do not crowd out other assets but instead constitute new savings.

This quantitative life-cycle model sheds new light on this issue. First, the simulations clearly show that at least part of TDA savings are reshuffled from CSA savings. That is, the portion of CSA savings earmarked for retirement in the benchmark case are now shifted to TDAs. The simulated peak value of CSA assets on average is approximately $160,000 in the benchmark case, while the average CSA balance never exceeds $50,000 in the case with TDAs. Second, the tax incentives have limited effect on households in their early 20's, who have limited resources for long-term investment. The introduction of TDAs leads to little new savings in the very early stage of building up the CSA buffer. Third, in the TDA accumulation stage, the effective tax subsidy generates a substitution effect that induces more saving. At the same time, since TDA assets are accruing at a higher pre-tax rate, the income effect will depress savings. Whether TDAs lead to new saving depends on which effect dominates. Figure 5 reveals that the substitution effect dominates between ages 20 and 45, as individuals sacrifice consumption to some extent in working years when TDAs are present. The difference between benchmark consumption and the path with TDAs constitutes new private savings in the early phase of the life cycle. In the later phase, TDAs facilitate a higher consumption path and encourage early retirement (see the next subsection for retirement behavior). The income effect thus dominates later since consumption and leisure are both normal goods.

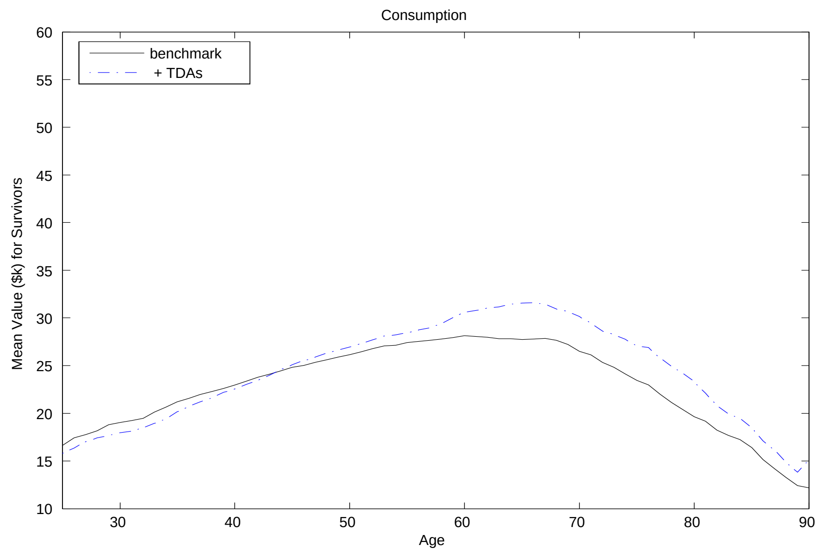

Figure 5: Comparison of Consumption

Some caution should be used when assessing the effectiveness of TDAs at stimulating new savings. This model is a partial equilibrium analysis, with the objective being to gain a deep understanding of the complex individual decisions. The model implicitly assumes that wages, rates of return, and tax rates are unchanged in spite of the introduction of TDAs. [19] Government revenue loss due to the tax deduction on TDA contributions is not made up by imposing other taxes. Although government can partially recover these taxes upon TDA withdrawals, individuals may still receive net

[19]The curse of dimensionality, due to the large number of state and choice variables, makes it difficult to extend the model to a general equilibrium framework while preserving the rich features.

tax subsidies. The effectiveness of TDAs can be assessed only after subtracting tax loss from private savings. This loss is defined as the difference between tax revenue with TDAs and that without TDAs. Tax revenue includes the payroll tax on labor earnings, the progressive income tax on earnings, interest, TDA withdrawals, and income-adjusted Social Security benefits, the penalty on early TDA withdrawals, and the tax from the earnings test. The introduction of TDAs leads to a different life-cycle tax profile. Tax revenue prior to retirement is lower with TDAs due to the tax deferral associated with TDA contributions. Early retirement encouraged by TDAs (see the next subsection) implies further tax loss compared with the benchmark case since lower labor participation undercuts the tax base substantially. Tax revenue recovers considerably in one's 60's and 70's by virtue of the income tax on TDA withdrawals.

Table 4 reports the effectiveness of TDAs by age groups. Column 1 contains average contributions to CSAs in the benchmark case. Column 2 contains mean overall contributions when TDAs are available. The fraction of TDA contributions is reported in column 3. Mean tax loss is defined as above. Net new savings are calculated by netting out asset reshuffle and tax loss, specifically, defined as column 2 minus columns 1 and 4, all divided by column 3. Clearly, tax-deferred programs produce private saving at the cost of government revenue. But they effectively induce substantial new national saving during the working years. A considerable fraction of these new savings are utilized to finance early retirement, which is reflected in the apparently lower net new savings for ages 51-65 (8%) and even negative net new savings (-11%) for ages 61-65. These simple calculations suggest that the possibility of early retirement enhances the incentive to save through TDAs and that early retirement, facilitated by tax advantages in TDAs, shrinks the overall addition to national savings.

Table 4. Effectiveness of Tax Incentives

	No TDAs	With TDAs			
Age	Overall($)	Overall($)	TDA($)	Tax Loss($)	New Savings(%)
21-30	2,844	4,167	1,623	695	39.1
31-40	2,062	4,997	4,430	1,372	35.5
41-50	3,497	6,787	6,089	1,430	30.5
51-60	2,298	3,602	3,977	991	8.1
61-65	-766	-1,563	-2,350	-1,052	-11.3
66-70	-1,166	-3,243	-1,890	195	–
71-80	-3,115	-4,977	-3,984	-1,622	–
81-90	-1,089	-2,034	-2,034	-596	–

Notes: 1. Negative values in column 4 represent tax gains. 2. Net new savings is defined as overall savings with TDAs (col. 2) minus savings without TDAs (col. 1) and minus tax loss (col. 4), all divided by TDA savings (col. 3).

1.5.6 Retirement Effect of TDAs

The substitution effect, coming from the higher rate of return on TDAs, increases wealth accumulation and reduces consumption compared to the case without TDAs in the early phase of life cycle. One reason for this is that TDAs are utilized by individuals who are planning on earlier retirement. Leisure choice is a function of wealth, increasing with savings levels in both CSAs and TDAs, with the latter yielding a stronger impact. Figure 6 plots the employment status for survivors in the cohort and their financial resources to support retirement. Apparently, the higher pre-tax rate of return on TDAs implies a stronger income effect in the later phase of life cycle, which encourages more retirement. The fraction of survivors employed are lower in the TDA case than in the benchmark. Consequently, the drop in labor supply means less income. A considerable share of individuals now choose to claim Social Security earlier than otherwise since the earnings test is less likely to tax away income given lower levels of labor earnings. In short, the tax advantage of TDAs enables individuals to retire early. Social Security benefits serve as a complementary financial resource.

The finding that early retirement is encouraged by the introduction of TDAs should be given consideration in the process of policy formulation. Such early retirement does not necessarily add an immediate threat to the solvency of Social Security since, as modeled in this chapter, the benefits are subject to approximately "actuarially fair" adjustment so that early claimers get lower benefits and delayed retirees receive higher benefits. However, as summarized by Gruber and Wise (2005), early retirement has substantial fiscal implications: it reduces tax revenue due to lower labor force participation and increases expenditure due to the increasing number of retirees.

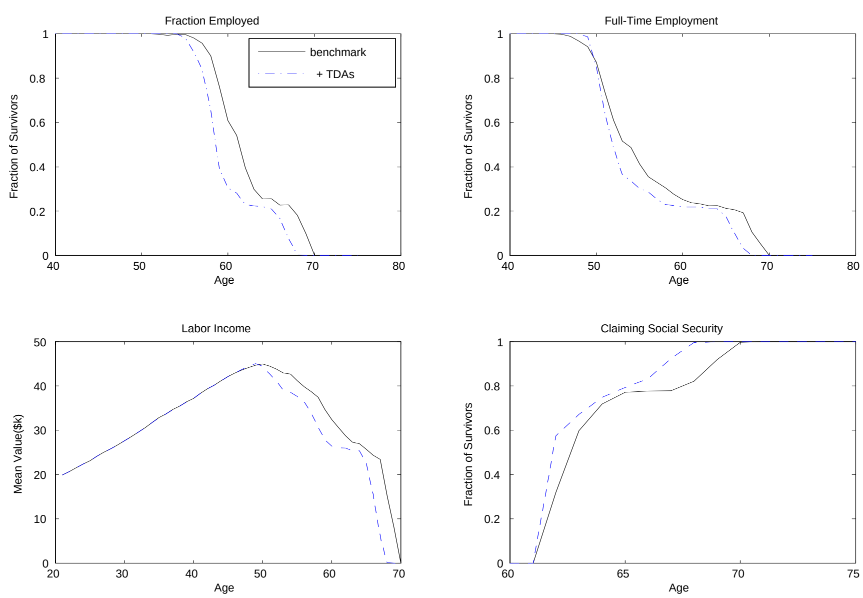

Figure 6: Retirement Effect of TDAs

1.5.7 Cost-Benefit Analysis of TDAs

Apparently, TDAs are welfare enhancing for households, since TDAs expand investment options and provide opportunities to accumulate wealth at pre-tax rate. As is shown in the top panel in Figure 7, the indirect value function for households with TDAs at all ages is above that without TDAs. TDAs at the same time carry cost in terms of tax loss from the fiscal perspective. For the purpose of cost-benefit analysis, I use the concept of equivalent variation (EV) to measure the welfare gain from TDAs for households. Specifically, the equivalent variation is numerically computed as the amount of extra CSA wealth required to make individuals without TDAs as well off as with TDAs in the expected utility terms. This benefit (EV) is compared with the fiscal cost, the present discounted value (PDV) of tax loss that is calculated as the difference between tax revenue with and without TDAs. The bottom panel of Figure 7 shows such cost-benefit analysis. In the early phase of the life-cycle, the fiscal cost outweighs the welfare gain. Put differently, there is room for Pareto improvement at this stage: both individuals and the government would be better off if the government gave individuals a lump sum transfer (in a magnitude smaller than the fiscal cost and bigger than EV) instead of the TDA options. This is because the transfer helps relax the budget constraint typically faced by workers in their 20's-30's. In the later phase of the life-cycle, the welfare benefit induced by TDAs exceeds the cost. This is because the tax deferral of TDAs offers effective means for retirement wealth accumulation. The fiscal cost in this phase is substantially lower, thanks to the tax recovery upon TDA withdrawals.

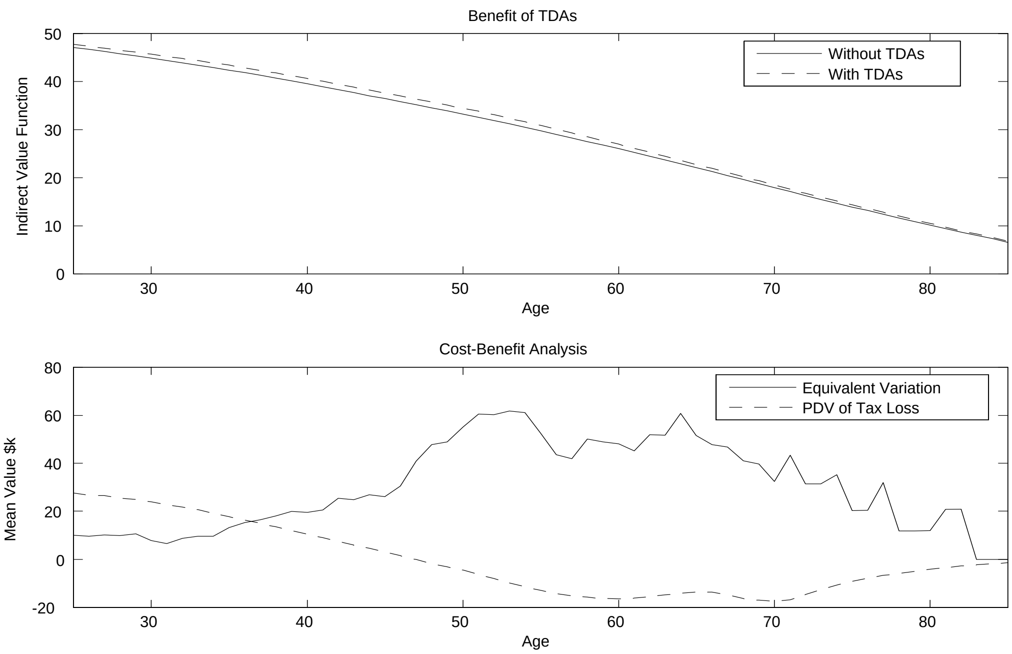

Figure 7: Welfare and Cost-Benefit Analysis

1.6 Alternative Policies and Heterogeneity

1.6.1 Alternative Policies and Impact of TDAs

This section presents the impact of TDAs on saving and retirement behavior for different policy scenarios. Table 5 reports the results from assuming alternative policies. First, assuming mandatory retirement and Social Security take-up at age 65 (experiment 2), individuals in the model would save less in terms of dollar value than in the case of flexible retirement choice. This implies higher consumption prior to retirement since mandatory retirement yields higher cumulative lifetime earnings before age 65. On the other hand, the fraction of TDA savings that represent new savings is now substantially higher than in experiment 1. [20] This is because individuals contemplat-

[20] The assessment of new saving in experiment 2 is compared with a benchmark with mandatory retirement at 65 but no TDAs.

ing early retirement in mind would shift more savings from CSAs to TDAs. This finding shows that the possibility of early retirement encourages tax-deferred savings and national savings compared with the case of mandatory retirement, but with a larger share of reshuffling of savings from CSAs to TDAs.

Second, an experiment is carried out to study how the bequest motive alters saving profiles. Kotlikoff and Summers (1981), Hurd and Smith (1999), Dynan, Skinner and Zeldes (1996), and De Nardi (2004) show that the bequest motive is an important factor in explaining the upper tail of the wealth distribution. This experiment assumes higher utility from bequest ($\kappa = .4$) as opposed to the modest bequest motive assumed in experiment 1 ($\kappa = .2$). Not surprisingly, individuals would contribute more to TDAs by reshuffling a larger part of CSA wealth compared with experiment 1, thus yielding a lower share of new savings in TDAs.

Third, one may be concerned that a certain degree of employer intervention is embedded in 401(k)s, which may significantly restrict individuals' voluntary choices. I thus narrow my definition of TDAs to include IRAs only, by decreasing the annual TDA contribution limit to $L = \$4,000$, which is the total allowable amount in 2005 for annual IRA contribution. A larger fraction of individuals in this case are restricted by the contribution limits. Nevertheless, IRAs are still an effective means to solicit new savings and to support early retirement.

Fourth, holding the contribution limit constant, a higher withdrawal penalty ($\tau_w = .30$) forces individuals to make TDA investments more conservatively. The role of TDAs as a backup for emergency liquidity is undercut by the high penalty. Put differently, a larger CSA buffer is necessary before saving in TDAs is optimal.

Table 5. Alternative Policies and the Impact of TDAs

	Ages 21-65 savings($k)			Ages 21-90 savings($k)		
	Overall	TDAs	% New	Overall	TDAs	% New
1. Bench. + TDAs	187.2	148.9	30.3	101.6	79.7	35.3
2. Mandatory at 65	184.3	137.3	43.1	86.4	64.2	65.2
3. Bequest ($\kappa = .4$)	189.8	150.9	29.5	104.3	82.1	34.7
4. $L = \$4,000$	170.4	127.0	27.5	93.1	67.6	34.4
5. $\tau_w = .30$	181.5	142.1	29.0	96.3	72.2	35.7

1.6.2 Heterogeneity and impact of TDAs

To this point I have considered only how TDAs affect the mean behavior of households. Undoubtedly, there is tremendous heterogeneity among individuals. Table 6 and Figure 8 present findings along this line. First, TDAs have differential impacts between high- and low-income groups. TDAs are more effective in stimulating new savings for the top quintile than for the bottom quintile, with the fraction of new savings being 51.7% and 1.8%, respectively. This is in line with the findings of Venti and Wise (1991 and 1992) and Gale and Scholz (1994), who observe that households with more wealth and higher income tend to make more contributions to IRAs. The existence of TDAs generates a strong retirement effect on the rich despite the assumption that high income earners (proxied by AIME) place a lower preference weight on leisure compared with the poor. Many of them switch to part-time work and elect to claim Social Security earlier than otherwise (Figure 8). The behavior of the poor, on the other hand, is less altered by the introduction of TDAs for several reasons. First, the poor have few resources available to take advantage of TDAs, and they derive less benefit from tax deferral because they face lower marginal tax rates. Second, agents with low earnings attach more weight to the disutility of work, so they tend to retire early even in the absence of TDAs. Third, poor agents tend to claim Social Security early even absent TDAs, so there is no impact of TDAs on the claiming decision for these workers.

Table 6. Heterogeneity and the Impact of TDAs

	Ages 21-65 Savings($k)			Ages 21-90 Savings($k)		
	Overall	TDAs	% New	Overall	TDAs	% New
1. Bot 20%	52.8	26.9	-5.0	35.3	14.3	1.8
2. Top 20%	390.2	278.3	45.0	187.9	140.9	51.7
3. Impatience	23.0	1.2	-86.5	22.9	1.2	-88.9
4. Mortality	18.3	2.9	-81.6	15.0	2.7	-88.9

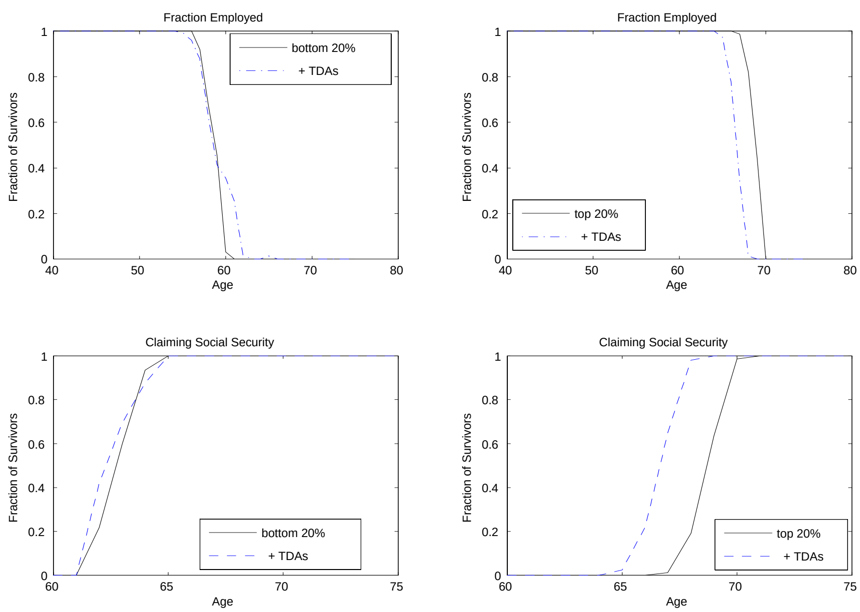

Figure 8: TDAs and Income Heterogeneity

These results shed new light on the relationship between Social Security and retirement. Rust and Phelan (1997) show that a drop in employment at age 62 is an optimal response for liquidity constrained individuals since 62 is the earliest age for Social Security eligibility. The retirement and claiming decisions of the bottom quintile in this model confirm their findings. As for the rich, they will also retire early if they have accumulated sufficient wealth, and they will optimally claim Social Security to complement retirement financing, even though they do not face a cash shortage. This model predicts that retirement can be encouraged by a public scheme - the creation of TDAs. [21]

Second, I explore how savings and retirement behavior would change in the case of myopia, which is motivated by Feldstein (1985), who argues that "some individuals lack the foresight to save for their retirement years (p.303)". Complete myopia would imply that individuals do not expect to retire and thus do no saving. This would imply that TDAs are totally irrelevant to them. I thus introduce the more relevant case of partial myopia, in which individuals give little weight to future utility, following Feldstein. But I assume they correctly estimate future social security benefits, in order to isolate the impact of TDAs. Here a higher subjective discount rate ($\beta = .9$) is used to reflect such impatience. Impatient individuals usually claim Social Security as their main financial source at 62. TDAs fail to solicit new savings from this group. Not surprisingly, the net addition to national savings is negative since the income effect dominates over the whole lifetime.

Third, the exercise is redone for the scenario in which mortality risk and average earnings are strongly negatively related. Duggan, Singleton and Song (2005) suggests that the mortality rate for those in top decile of AIME at age 62 is three times lower than for those in lowest decile. This will affect the optimal time to claim Social

[21] This loosely echoes Feldstein (1974) who shows that Social Security induces retirement.

Security. The simulations for the group of individuals with a high mortality rate and low AIME reveal that they tend to retire early and claim Social Security at the earliest eligible age, with or without TDAs. Similar to the case of impatience, TDAs mainly boost consumption for groups with high mortality risk, yielding negative new savings.

1.7 Concluding Remarks

This chapter combines the assessment of special savings plans with the study of retirement behavior. I develop a quantitative and realistically calibrated model to solve for optimal consumption/saving and leisure decisions of finitely lived individuals who face mortality risk and stochastic earnings. Individuals are assumed to save for liquidity reasons, for retirement and for bequests. They hold assets in conventional savings and tax-deferred accounts. They also make endogenous labor supply and retirement choices and a separate decision on the timing of Social Security take-up.

The simulations reveal that there is a functional division between CSAs and TDAs, with the former serving mainly for liquidity and the latter for retirement and bequests. The stronger the incentive to retire early, the more attractive is the TDA option. Individuals who are contemplating early retirement tend to hold more savings in terms of dollar value, shift a greater fraction of assets from CSAs to TDAs and have a lower share of new net savings in TDAs than otherwise. The effectiveness of savings incentives is also strengthened by the voluntary bequest motive.

There is tremendous heterogeneity with regard to the utilization of TDAs, retirement decisions, and Social Security claiming. The tax incentives are generally most effective at stimulating new savings for the middle and upper income groups. The introduction of TDAs appears to exert a bigger impact on their life-cycle behavior. The higher rate of return on TDAs facilitates wealth accumulation, which consequently and perhaps unintentionally encourages early retirement. Impatient and low-income individuals tend to retire and claim Social Security early with or without TDAs. They contribute much less to TDAs both because they face lower marginal tax rates and because they have limited resources with which to take advantage of TDAs. For them, the income effect dominates and TDAs fail to induce new savings. The finding that early retirement is associated with TDAs should be given consideration in the process of policy formulation. As summarized by Gruber and Wise (2005), early retirement has substantial fiscal implications, since it reduces tax revenue due to lower labor force participation and increases expenditure due to the increasing number of retirees, despite the approximately "actuarially fair" adjustment of Social Security benefits.

There is no doubt about the increasing importance of tax deferred programs with regard to national savings and individual retirement wealth security. They deserve further study in various aspects. First, the newly induced savings will likely alter the level of capital stock as well as factor prices. A general equilibrium model is a natural step to quantify this second-round effect. Second, along with their popularity, 401(k) plans increasingly offer loans. It is worth exploring the effects of the universal availability of pension loans on asset location choice and retirement wealth security. These are on the agenda for future research.

Appendix 1.A. The Derivation of Heuristic Findings

To derive some heuristic findings, I assume a flat and constant income tax at rate τ, maintaining the assumptions that TDAs accrue tax free and are subject to early withdrawal penalty. Allowing for a progressive tax system will strengthen the analysis in the text. The stripped down version of the utility maximization problem and the dynamic budget constraints and contribution limits can be written as follows. [22]

$$\max_{c,l,x,z^d} E_t \sum_{t=0}^{T} \beta^t \left[\Psi_t u(c_t, l_t) + (1-\Psi_t)\Gamma(w_t)\right] \tag{A.1}$$

$$s.t.$$

$$\mu_t^B \quad : \quad a_{t+1} = [1+(1-\tau)r]a_t + y(l_t) + b$$

$$-(1-\lambda_t\tau_w)\left[q_{t+1} - (1+r)q_t\right] - c_t \tag{A.2}$$

$$\mu_t^L \quad : \quad L \geqslant q_{t+1} - (1+r)q_t \tag{A.3}$$

$$\mu_t^a \quad : \quad a_t \geqslant 0 \tag{A.4}$$

$$\mu_t^q \quad : \quad q_t \geqslant 0 \tag{A.5}$$

where $w_t = [1+(1-\tau)r)]a_t + (1+r)q_t$ is the terminal wealth bequeathed; and $\mu' s$ in front of the constraints are the corresponding Lagrange multipliers.

1.A.1 Consumption

Plugging the expression for c_t defined in the dynamic budget constraint into the objective function and taking first order conditions w.r.t. a_{t+1} and q_{t+1}, respectively,

[22] With slight abuse of notation, $y(l_t)$ here indicates disposable income net of income and payroll taxes.

yields

$$
\begin{aligned}
a_{t+1} \quad &: \quad u_c'(c_t, l_t) = \beta\left[1 + (1-\tau)r\right] E_t[\psi_{t+1} u_c'(c_{t+1}, l_{t+1}) \\
&\qquad + (1-\psi_{t+1})\Gamma'(w_{t+1})] + E_t \mu_{t+1}^a \qquad \text{(A.6)} \\
q_{t+1} \quad &: \quad (1 - \lambda_t \tau_w) u_c'(c_t, l_t) = \beta(1+r) E_t[(1 - \lambda_{t+1}\tau_w)\psi_{t+1} u_c'(c_{t+1}, l_{t+1}) \\
&\qquad + (1-\psi_{t+1})\Gamma'(w_{t+1})] - \mu_t^L + (1+r)E_t \mu_{t+1}^L + E_t \mu_{t+1}^q \qquad \text{(A.7)}
\end{aligned}
$$

Combining the above two equations yields

$$
\begin{aligned}
& \beta\left[1 + (1-\tau)r\right] E_t[\psi_{t+1} u_c'(c_{t+1}, l_{t+1}) + (1-\psi_{t+1})\Gamma'(w_{t+1})] + E_t \mu_{t+1}^a \\
= \; & \frac{\beta(1+r)}{1 - \lambda_t \tau_w} E_t[(1 - \lambda_{t+1}\tau_w)\psi_{t+1} u_c'(c_{t+1}, l_{t+1}) + (1-\psi_{t+1})\Gamma'(w_{t+1})] \\
& \frac{1}{1 - \lambda_t \tau_w}[-\mu_t^L + (1+r)E_t \mu_{t+1}^L + E_t \mu_{t+1}^q] \qquad \text{(A.8)}
\end{aligned}
$$

This equation implies that an optimal interior asset allocation between CSAs and TDAs is reached when a dollar contribution to CSAs or TDAs brings the same level of marginal expected utility (otherwise a corner solution emerges, so that contributions will be made in only one type of account). An interesting special case arises when an individual contributes to TDAs at t (hence $\lambda_t = 0$) and future withdrawals are not subject to penalty (i.e. $\lambda_{t+1} = 0$ with probability one). Then the above equation is reduced to the following. See text for the interpretation.

$$
\begin{aligned}
& \beta \tau r E_t[\psi_{t+1} u_c'(c_{t+1}, l_{t+1}) + (1-\psi_{t+1})\Gamma'(w_{t+1})] \\
= \; & E_t \mu_{t+1}^a + \mu_t^L - (1+r)E_t \mu_{t+1}^L - E_t \mu_{t+1}^q \qquad \text{(A.9)}
\end{aligned}
$$

1.A.2 Saving Rules

Let $V(\Lambda_t)$ denote the indirect utility realized at t given the beginning-of-period states $\Lambda_t = (t, a_t, e_t, q_t, \varepsilon_t, z_t^s)$. Taking derivatives to $V(\Lambda_t)$ w.r.t. a_t and q_t, respectively, and applying the Envelope Theorem produces the following equations.

$$V_a'(\Lambda_t) = [1 + r(1-\tau)][\mu_t^B + \beta(1-\psi_t)\Gamma'(w_t)] + \mu_t^a \quad \text{(A.10)}$$

$$V_q'(\Lambda_t) = (1+r)[\mu_t^B(1-\lambda_t\tau_w) + \beta(1-\psi_t)\Gamma'(w_t) + \mu_t^L] + \mu_t^q \quad \text{(A.11)}$$

Shifting these equations forward by one year gives the expected marginal value of savings in the two accounts, respectively.

$$E_t V_a'(\Lambda_{t+1}) = [1 + r(1-\tau)]E_t[\mu_{t+1}^B + \beta(1-\psi_{t+1})\Gamma'(w_{t+1})] + E_t\mu_{t+1}^a \quad \text{(A.12)}$$

$$\begin{aligned} E_t V_q'(\Lambda_{t+1}) &= (1+r)E_t[\mu_{t+1}^B(1-\lambda_{t+1}\tau_w) \\ &\quad + \beta(1-\psi_{t+1})\Gamma'(w_{t+1}) + \mu_{t+1}^L] + E_t\mu_{t+1}^q \end{aligned} \quad \text{(A.13)}$$

1.A.3 Retirement Effect of TDAs

Taking first order condition to the utility maximization problem w.r.t. leisure l_t yields

$$u_l'(c_t, l_t) = -u_c'(c_t, l_t)y'(l_t) \quad \text{(A.14)}$$

where $y'(l_t) < 0$. This equation facilitates implementing comparative statics on optimal labor supply with respect to a_t and q_t. Applying Implicit Function Theorem yields

$$\frac{\partial l_t}{\partial a_t} = -\frac{[1 + (1-\tau)r]\,[u_{lc}''(c_t, l_t) + u_{cc}''(c_t, l_t)y'(l_t)]}{u_c'(c_t, l_t)y''(l_t)} \quad \text{(A.15)}$$

$$\frac{\partial l_t}{\partial q_t} = -\frac{(1+r)(1-\lambda_t\tau_w)\,[u_{lc}''(c_t, l_t) + u_{cc}''(c_t, l_t)y'(l_t)]}{u_c'(c_t, l_t)y''(l_t)} \quad \text{(A.16)}$$

It is straightforward to show that $u''_{lc} = 0$ and $u''_{cc} < 0$ given the period utility and bequest functions and $\gamma > 1$. Also, it is reasonable to assume that $y''(l_t) > 0$, which means that the opportunity cost of leisure in terms of foregone wages is declining with leisure. Thus,

$$\frac{\partial l_t}{\partial a_t} > 0 \tag{A.17}$$

$$\frac{\partial l_t}{\partial q_t} > 0 \tag{A.18}$$

and the comparison of them further reveals that

$$\frac{\partial l_t}{\partial q_t} > \frac{\partial l_t}{\partial a_t} \tag{A.19}$$

which is particularly true when withdrawals take place at age $t \geqslant t^f$ (i.e. $\lambda_t = 0$).

Appendix 1.B. The Solution Method

Given the large number of state and choice variables, numerical method is used to solve the model. The computation begins by discretizing the space of the continuous state variables, i.e., CSA assets, a, TDA assets, q, and AIME, e. The discretization yields denser grid points at lower values and coarser points towards the upper end, which is to accommodate the potential nonlinearity and sensitivities in decision rules.

I first solve the trivial maximization problem for age T, the last period, where individuals simply divide wealth between consumption and bequest. The value function is derived as $V(\Lambda_T)$. Then the computation moves backward to solve for the optimal decisions and the value function for age $T-1$. If the realized assets do not lie on the grids on which the expected value function is defined, linear interpolations are implemented. This backward induction continues until the starting age is reached. Along the process, the optimal decisions are recorded for all feasible realizations of random variables (earnings and mortality) given initial states. Policy functions are thus defined as $a_{t+1} = f(t, a_t, e_t, q_t, \varepsilon_t, z_t^s)$, and $q_{t+1} = f(t, a_t, e_t, q_t, \varepsilon_t, z_t^s)$, for $t = 20, ..., T$. The fully-loaded model requires tremendous computational resources, including those granted by the Pittsburgh Supercomputer Center. The computation is run in parallel on a large number of computers, using the Message Passing Interface (MPI) standard. In each decision-making age, the up-to-date value functions and a subset of state variables are passed on to each parallel processor for evaluation. The newly derived value functions and decision rules are gathered and to be collectively shared next period.

With optimal decision rules derived, large scale simulations are carried out to generate life-cycle profiles of earnings, savings, labor supply, and Social Security. Simulations start with age 21 when individuals are endowed with no assets. They make optimal choices based on policy and value functions derived above. Values of random variables are generated by Monte Carlo method. Simulations move forward until end of the life cycle.

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CHAPTER 2

EFFICIENCY OF PUBLIC SPENDING IN DEVELOPING COUNTRIES

-- AN EFFICIENCY FRONTIER APPROACH[23]

Abstract

This chapter attempts quantitatively to measure the efficiency of public spending in developing countries. The efficiency is defined as the distance between observed input-output combinations and an efficiency frontier. Both input- and output- efficiencies are estimated for several health and education output indicators by means of the Free Disposable Hull (FDH) and Data Envelopment Analysis (DEA) techniques. This chapter further seeks to verify empirical regularities associated with cross-country efficiency variation. The panel Tobit regressions reveal that countries are more likely to register lower efficiency if they are faced with higher government expenditure levels, larger wage shares in government budget composition, higher ratios of public to private financing in service provision (health), more prevalence of HIV/AIDS epidemic (health), stronger external aid dependency, and/or higher income inequality (education). Though no causality may be inferred from these exercises, they help point at different factors to understand why some countries spend more resources than others to achieve similar educational and health outcomes.

[23] This chapter is based on the joint work with Santiago Herrera, who is affiliated with the World Bank.

2.1 Introduction

Government spending in developing countries frequently account for a large share of GDP. Small changes in the efficiency of public spending can have a significant impact on the attainment of the government's objectives. The first challenge faced by stakeholders is to measure efficiency. This chapter attempts such quantification on a most comprehensive set of indicators on education and health, which are largely publicly financed in developing countries. Given the observation that relatively rich countries tend to face higher price levels, public spending as an input is orthogonalized against income level. This approach was not previously explored in the literature and is more accurate, in terms of goodness-of-fit, to capture the true efficiency variation across countries. The exercises reveal the efficiency positioning of countries. In a second stage, this chapter seeks to identify empirical regularities associated with the variation in the estimated efficiency scores. Several policy and environmental variables are found significantly relevant by means of a panel Tobit regression model, which allows for the fact that the efficiency scores are distributed over a limited interval between zero and one.

This chapter has four sections following this Introduction. Section 2.2 outlines the methodology that defines inefficiency as the distance from the observed input-output combinations to an efficiency frontier. This frontier, defined as the maximum attainable output for a given input level or the minimum input required for a certain output level, is estimated using the Free Disposable Hull (FDH) and Data Envelopment Analysis (DEA) techniques. The exercises focus on health and education expenditure because they frequently constitute large shares of government budgets and because a lack of data prevents international comparisons in other types of expenditures.

Section 2.3 estimates the efficiency frontiers for nine education output indicators and four health output indicators, based on a sample of 140 countries. Both input-efficiency (excess input consumption to achieve a level of output) and output-efficiency (output shortfall for a given level of input) are scored. The section presents both the single input-single-output and the multiple-input multiple-output frameworks. In addition, it explores how technical efficiency has changed over time.

Section 2.4 seeks to identify empirical regularities that explain variations in the efficiency scores over time and across countries. The panel Tobit regression analysis reveals that higher government expenditure is generally associated with lower efficiency scores. Similarly, countries in which the wage bill forms a larger share of the total budget tend to have lower efficiency scores. Three other variables that explain efficiency variations are the degree of urbanization (positively correlated with efficiency, the prevalence of the HIV/AIDS epidemic (negatively associated with efficiency scores), and inequality in income distribution (higher inequality associated with lower efficiency).

Section 2.5 gives concluding remarks.

2.2 Measuring Efficiency: Methodologies and Literature Review

This section briefly describes the methods that are applied in this chapter to measure efficiency and the literature that is directly related to the analysis of public expenditure efficiency. Empirical and theoretical measures of output efficiency are based on ratios of observed output levels to the maximum that could have been obtained given the inputs utilized, while the measure of input efficiency is based on the ratio of minimum input to the observed input given same level of output. This maximum (minimum) constitutes the efficiency frontier which will be the benchmark for measuring the relative efficiency of the observations. There are multiple techniques to estimate this frontier, as surveyed by Murillo-Zamorano (2004), and they have been recently applied to examine the efficiency of public spending.

2.2.1 Methods for Measuring Efficiency

The origin of the modern discussion of efficiency measurement dates back to Farell (1957), who identified two different ways in which productive agents could be inefficient: one, they could use more inputs than technically required to obtain a given level of output, or two, they could use a sub-optimal input combination given the input prices and their marginal productivities. The first type of inefficiency is termed technical inefficiency while the second one is known as allocative inefficiency.

These two types of inefficiency can be represented graphically by means of the unit isoquant curve in Figure 9. The set of minimum inputs required for a unit of output lies on the isoquant curve YY'. An agent's input-output combination defined by bundle P produces one unit of output using input X_1 and X_2. Since the same output can be achieved by consuming less of both inputs along the radial back to bundle M, the segment MP represents the inefficiency in resource utilization. The input-oriented technical efficiency measure (TE) is therefore defined as TE = OM/OP. Furthermore, the producer could achieve additional cost reduction by choosing a different input combination. The least cost combination of inputs that produces one unit of output is given by point T, where the marginal rate of technical substitution is equal to the input price ratio. To achieve this cost level implicit in the optimal combination of inputs, input use needs to be contracted to bundle N. The input allocative efficiency measure (AE) is defined as AE = ON/OM.

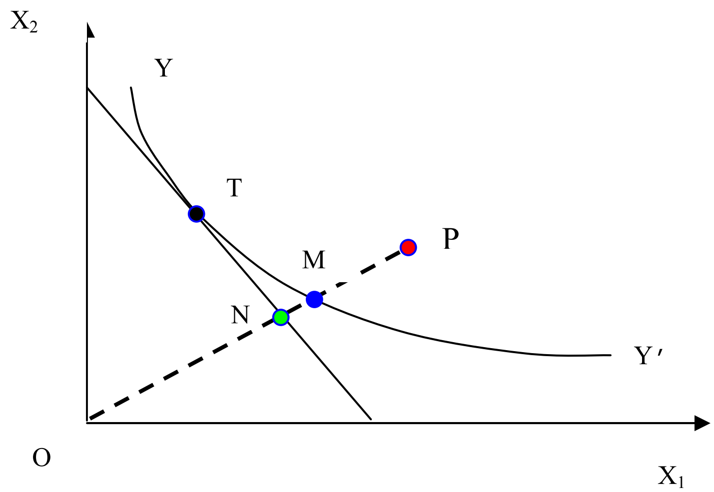

Figure 9 Technical and Allocative Inefficiency

The focus of this chapter is on technical efficiency, given the lack of comparable input prices across countries. This concept of efficiency is narrower than the one implicit in social welfare analysis. That is, we abstract from the consideration that countries may be producing the wrong output very efficiently at low cost (as discussed by Tanzi, 2004).

Various techniques have been developed over the past decades to tackle the challenge of estimating the unknown and unobservable efficiency frontier (i.e. the isoquant YY' in Figure 9). The widely used taxonomies classify the estimation methods into parametric or non-parametric, and stochastic or deterministic catalogs. The parametric approach assumes a specific functional form for the relationship between the inputs and the outputs as well as for the inefficiency term incorporated in the deviation of the observed values from the frontier. The non-parametric approach calculates the frontier directly from the data without imposing specific functional restrictions. The former approach is based on econometric methods, while the latter uses mathematical programming techniques. The deterministic approach assumes all deviations from the frontier explained by inefficiency, while the stochastic approach considers those deviations as a combination of inefficiency and random shocks out of the control of decision makers.

This chapter uses deterministic non-parametric methods to avoid assuming specific functional forms for the relationship between inputs and outputs or for the inefficiency terms. Specifically, two methods are utilized in measuring efficiency: Free Disposable Hull (FDH) and Data Envelopment Analysis (DEA). The FDH method imposes the least restrictions on the data as it only assumes free disposability of resources. Figure 10 illustrates the single-input single-output FDH production possibility frontier. Country A and country B use inputs X_A and X_B to produce outputs Y_A and Y_B, respectively. The *input efficiency* score for country B is defined as the quotient X_A/X_B. The *output efficiency* score is given by the quotient Y_B/Y_A. A score of one implies that the country is on the frontier, while a score less than one implies inefficiency. An input efficiency score of 0.75, for instance, indicates that this particular country uses inputs in excess of the most efficient producer by 25 percent to achieve the same output level. An output efficiency score of 0.75 indicates that the inefficient producer attains 75 percent of the output obtained by the most efficient producer with the same input intake. Efficiency for multiple inputs and outputs can be defined in an analogous way. Formally, the efficiency of multiple inputs and multiple outputs calculated as follows. Let X and Y be the vectors containing I inputs and J outputs, respectively. Let N be the set of countries that are more efficient than country 0, with $X_{in} \leq X_{i0}$ and $Y_{jn} \geq Y_{j0}$, where X_{in} is the i-th type of input used and Y_{jn} is the j-th type of output produced by country n. The input efficiency for country 0 is defined as $\underset{n \in N}{Min} \underset{\text{i=1,...I}}{Max} \frac{X_{in}}{X_{i0}}$ and the output efficiency defined as $\underset{n \in N}{Min} \underset{\text{j=1,...J}}{Max} \frac{Y_{j0}}{Y_{jn}}$.

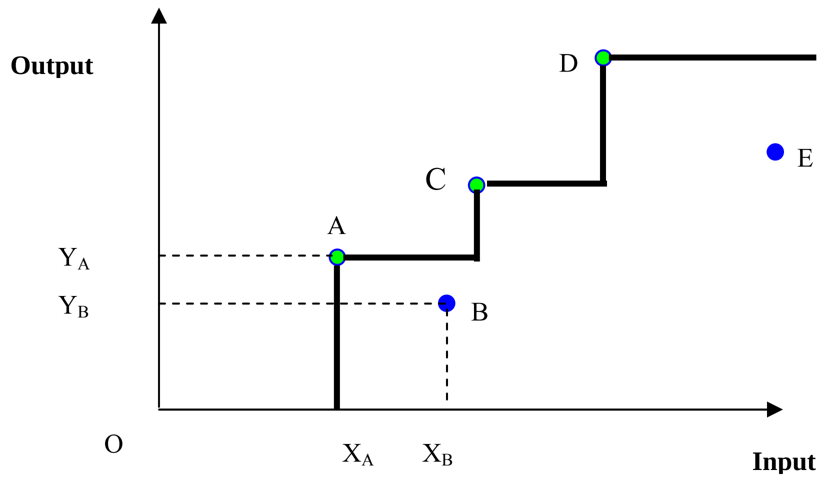

Figure 10 Free Disposal Hull (FDH) production possibility frontier

Data Envelopment Analysis (DEA) assumes that linear combinations of the observed input-output bundles are feasible. Hence it assumes convexity of the production set to construct an envelope around the observed combinations. Figure 11 illustrates the single input-single output DEA production possibility frontier. In contrast to the vertical step-ups of FDH frontier, DEA frontier is a piecewise linear locus connecting all the efficient decision-making units (DMUs). The feasibility assumption, assuming piecewise linearity, implies that the efficiency of C, for instance, is not only ranked against the real performers A and D, called the peers of C in the literature, but also evaluated relative to a virtual decision maker, V, which employs a weighted collection of A and D inputs to yield a virtual output. DMU C, which would have been considered to be efficient by

FDH, is now inefficient by DEA ranking, lying below the efficiency frontier XADF (which reflects variable returns to scale, explained below). This example shows that FDH tends to assign efficiency to more DMUs than DEA does. The input-oriented technical efficiency of C is now defined by TE = YV/YC.

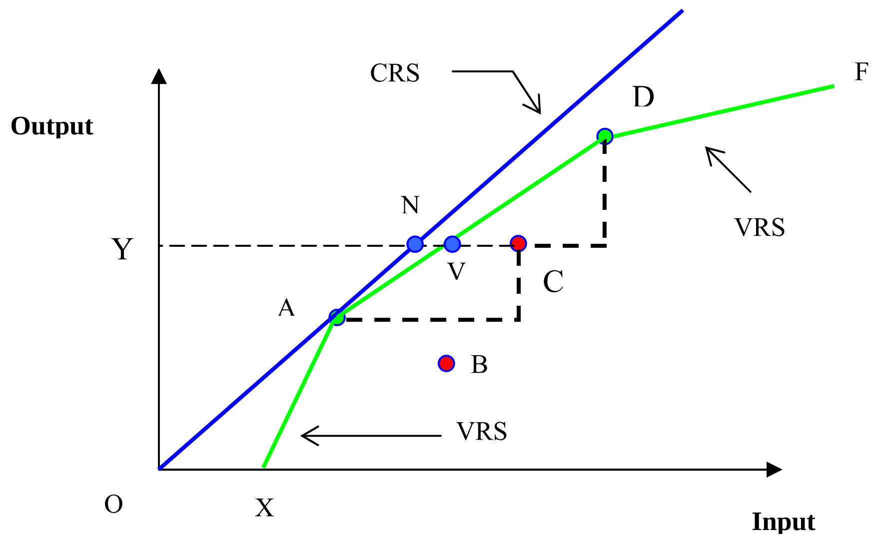

Figure 11 DEA production possibility frontier

When constant returns to scale (CRS) characterize the production set, the frontier may be represented by a ray extending from the origin through the efficient DMU (ray OA). By this standard, only A would be rated efficient. The important feature of the XADF frontier is that this frontier reflects variable returns to scale (VRS). The segment XA reflects locally increasing returns to scale (IRS), that is, an increase in the inputs results in a greater than proportionate increase in output. Segments AD and DF reflect decreasing returns to scale. It is worth noticing that the constant returns to scale technical efficiency (CRSTE) is equal to the product of variable returns to scale technical efficiency (VRSTE) and scale efficiency (SE). Accordingly, DMU D is technically efficient (VRSTE) but scale inefficient, while DMU C is neither technically efficient nor scale efficient. The scale efficiency of C is calculated as YN/YV. [24] The technical Appendix 2.A provides more detailed exploration of Data Envelopment Analysis, which shows how peers are identified, how the virtual DMUs are constructed, and how weights to the different efficient DMUs and efficiency scores are calculated.

The limitations of non-parametric methods derive mostly from the sensitivity of the results to sampling variability and to the presence of outliers. This has led some literature to apply tighter statistical analysis to the non-parametric methods (Simar and Wilson, 2000). For instance, confidence intervals for the efficiency scores can be estimated using asymptotic theory in the single input case (for input-efficiency) or single-output case (for output efficiency), given that these can be shown to be maximum likelihood estimators (Banker, 1993 and Grosskopf, 1996). For multiple input-output cases the distribution of the efficiency estimators is unknown or quite complicated and analysts recommend constructing the empirical distribution of the scores by the means of bootstrapping methods (Simar and Wilson, 2000). Other solutions to outliers or noisy data consist of constructing a frontier that does not envelop all the data points, building an expected minimum input function or expected maximum output function (Cazals, Florens and Simar, 2002, and Wheelock and Wilson, 2003).

2.2.2 Literature Review

There is a large literature measuring productive efficiency of diverse types of decision making units. For instance, there are studies on the efficiency of museums (Bishop and

[24] See Charnes, Cooper, and Rhodes (1978) and Banker, Charnes, and Cooper (1984), among others, for further exploration of returns to scale.

Brand, 2003), container terminals (Cullinane and Song, 2003), electric generation plants (Cherchye and Post 2001), banks (Wheelock and Wilson, 2003), schools (Worthington, 2001) and hospitals (Bergess and Wilson, 1998). Relatively fewer papers, however, analyze aggregate public sector spending efficiency using cross-country data. The following is a brief overview of them.

Gupta and Verhoeven (2001) employ the input-oriented FDH approach to assess the efficiency of government spending on education and health in 37 African countries in 1984-1995. They find that African countries are on average inefficient in providing education and health services relative to both Asian and Western Hemisphere countries. They report an increase in the productivity of spending over time, as reflected in outward shifts in the efficiency frontier. The authors report a negative relationship between the input efficiency scores and the level of public spending, which leads them to conclude that higher educational attainment and health output requires efficiency improvement more than increased budgetary allocations.

Evans and Tandon (2000) adopt a parametric approach to measuring output efficiency of national health systems for the World Health Organization, running a fixed effects panel regression on 191 countries for the period 1993-1997. Health output is measured by the disability adjusted life expectancy (DALE) index, while health expenditures (public and private aggregated) and the average years of schooling of the adult population are considered as inputs. The output-efficiency score is defined as the ratio of actual performance to the potential maximum. The authors introduce quadratic terms of the inputs, arguing that they are a second-order Taylor-series approximation to an unknown functional form. The significance of these terms may be an indication of the importance of non-linearity. It may also reflect neglected dynamics or heterogeneity in the sample, given that both developed and developing nations are included.[25] An interesting contribution of the paper is a construction of a confidence interval for the efficiency estimates through a Monte-Carlo procedure. The authors document a positive relationship between the efficiency scores and the level of spending. The more efficient health systems are those of Oman, Chile and Costa Rica, while the least efficient countries are all African: Zimabawe, Zambia, Namibia, Botswana, Malawi and Lesotho.

Jarasuriya and Woodon (2002) also adopt a parametric approach to estimating output efficiency of health and education provision in a sample of developing countries. The authors consider separately an educational attainment indicator (net primary enrollment) and a health output indicator (life expectancy) and estimate a functional linear relationship between these output indicators and three inputs: per capita GDP, spending per-capita, and the adult literacy rate. Their panel estimations reveal no relationship between expenditure and the educational or health outputs when per-capita GDP is included as an input. They conclude that spending more is not guaranteed to produce better education or health results. The authors do not point at the correlation between the two variables (i.e. per-capita GDP and per-capita spending) as a possible cause of this problem, which is discussed in the next section. The countries with the lowest efficiency are all African: Malawi, Zambia, Mozambique, and Ethiopia for the case of health and Ethiopia, Niger, and Burkina Faso for education. The authors go further to explain the cross-country variation in efficiency and find that the degree of urbanization and the quality of bureaucracy are the most relevant variables. To capture possible non-linearity, they introduce quadratic terms of these variables. This stage of their work poses several

[25] See Haque, Pesaran and Sharma (1999) for an econometric illustration.

problems. First, it is possible that the non-linear terms reflect heterogeneity across countries and dynamics across time. As shown by Haque, Pesaran, and Sharma (1999), this would produce inconsistent estimates. Second, the authors do not adjust for the fact that the dependent variable (efficiency scores) is censored, given that it can adopt only values between zero and one.

Greene (2003a) concentrates on health efficiency using the WHO panel data and makes an effort to explain inefficiency variations. He first estimates a health production function using expenditure (public plus private) and education as input. His stochastic frontier estimation allows for time variation of the coefficients and heterogeneity in the countries' sensitivity to explanatory variables. He then attempts to explain inefficiency with a set of explanatory variables of which the significant ones are the income inequality measure, GDP per capita and a dummy variable for tropical location.

Afonso, Schuknecht and Tanzi (2003) examine the efficiency of public spending in 23 OECD countries using a non-parametric approach. They construct a composite indicator of public sector performance capturing quality of administrative functions, educational and health attainment, and the quality of infrastructure. Taking the performance indicator as the output and total public spending as the input, they perform single-input, single-output FDH to rank the expenditure efficiency of the sample. Their results show that countries with smaller public sectors exhibit higher overall performance.

Afonso and St. Aubyn (2004) address the efficiency of expenditure in education and health by applying both DEA and FDH to a sample of OECD countries, which is different from our focus on developing countries. The small overlap of the samples limits the direct comparability of the results.

2.3 Empirical Estimation of Efficiency

2.3.1 Assumptions and Limitations

Cross-country efficiency comparisons assume some homogeneity across the world in the production technology of health and education. There are two particular aspects in which the homogeneity assumption is important. First, the comparison assumes that a small number of factors are commonly used for production across countries. Any omission of an important factor will yield as a result a high efficiency ranking of the country that uses more of the omitted input. Second, the comparison requires that the quality of the inputs is more or less the same, with the efficiency scores biased in favor of countries where the quality is of higher grade.

Factor heterogeneity will not be a problem as long as it is evenly distributed across countries. It will be problematic if there are differences between countries in the average quality of a factor (Farrell, 1957). Our study is not immune to this limitation, given that the main input in both production technologies is used more intensively in richer countries (with higher per-capita GDP). The main input is public spending per capita on education and health measured in constant 1995 US dollars in PPP terms. A clear positive association between this variable and per-capita GDP can be verified in Figure 12.

This positive association between expenditure and the level of economic development (as measured by per-capita-GDP) may be explained by several reasons. One of them could be the Balassa-Samuelson effect, according to which price levels in wealthier countries tend to be higher than in poorer countries.[26] This applies to both final goods and factor prices. Thus price of the same service (health or education, for instance) will be higher in the country with higher GDP. Similarly, wages in the relatively richer countries are higher, given the higher marginal productivity of labor, which will tend to increase costs, especially in labor-intensive activities such as health and education.

Figure 12 can also be interpreted as evidence of the validity of Wagner's hypothesis at the *cross-country* level. This hypothesis postulates that there is a tendency for governments to increase their activities as economic activity increases either because the rising complexity associated with economic development requires more governmental activity or because the income elasticity of demand for publicly provided services, in particular education is greater than one. This hypothesis has been tested econometrically (Chang, 2002) in time series and cross-country settings.

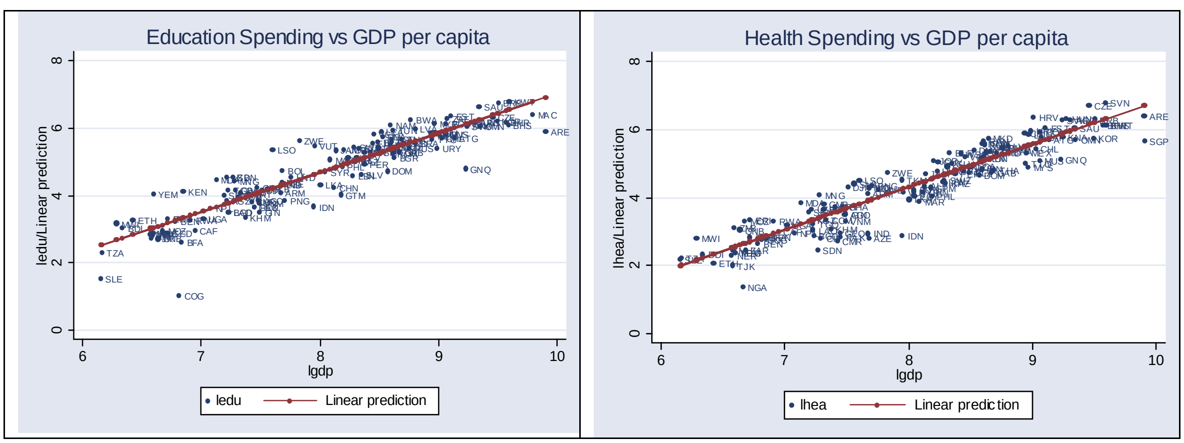

Figure 12 Public Expenditure and GDP (both per capita and in log)

[26] The Balassa-Samuelson effect refers to the fact that price levels are higher in richer countries than in poorer countries. It can be shown that relative wages and prices are a function of the marginal productivity of labor in the traded goods. Given higher capital abundance in the richer countries, the productivity of labor tends to be higher in these countries, and hence will be wages and prices.

Previous studies on the efficiency of public spending recognized the positive association reflected in Figure 12 and suggested alternative solutions. One possibility is to split the sample by groups of countries (Gupta and Verhoeven, 2001). This chapter in part follows this approach by excluding the industrialized nations from the sample and by presenting most of the results clustered regionally (Africa (AFR), East Asia and Pacific (EAP), Latin America and Caribbean (LAC), Middle-East and North Africa (MNA) and South Asia (SAS)).[27] A second alternative incorporates per-capita GDP directly as a factor of production, jointly with expenditure and other inputs (Jarasuriya and Woodon 2002). The problem with this approach lies in the difficulty in disentangling the effects of these two variables, besides the burden in justifying GDP per capita as an input for production.

Here we explore a third option, which consists in using as an input the component of public expenditure orthogonal to GDP.[28] The orthogonalized expenditure is the residual of a linear regression of pubic expenditure on GDP per capita. We calculate efficiency using as inputs both the original expenditure and the orthogonalized component. The goodness-of-fit is gauged based on the frequency distribution of the efficiency measures, as suggested by Farrell (1957) and Varian (1990). Comparing the efficiency distributions (Figure 13a-b) apparently reveals that the orthogonalized expenditure version produces distributions that are not skewed towards extreme inefficient outcomes. On this basis, the chapter hereafter uses the orthogonal component of expenditure on health and education as an input.

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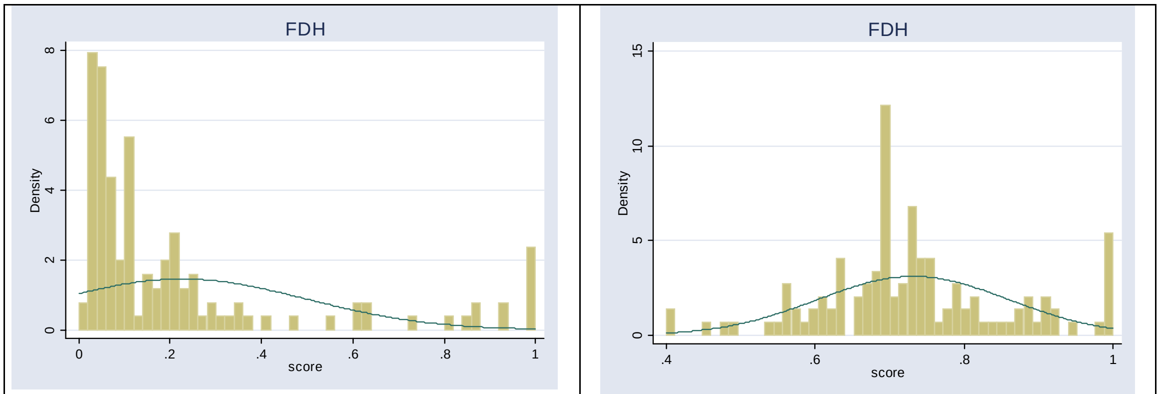
[27] Appendix 2.C provides the list of countries included in this study and their geographical regions.

[28] Since residuals may take positive and negative values, the variable is right-shifted to avoid negative values to facilitate the calculation of efficiency scores.



(a) Unorthogonalized Public Expenditure | (b) Orthogonalized Public Expenditure

Figure 13 Density of Efficiency Scores – Gross Primary School Enrollment

Besides public expenditure, input variables include literacy of adult and ratio of teachers to students for the study on education, and literacy of adult and private spending for the study on health. This chapter uses nine indicators of education output and four indicators of health output.[29] The education indicators are: primary school enrollment (gross and net), secondary school enrollment (gross and net), literacy of youth, average years of schooling, first level complete, second level complete, and learning scores. Learning scores, which are believed by many to reflect educational attainment accurately, are not generally available for a large number of developing countries, limiting their applicability to international comparison. Crouch and Fasih (2004) make a recent and useful reconciliation of several international assessments to construct a larger sample.[30] The correlation coefficients between the learning scores and other output variables are high,

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[29] A complete list of variables and data sources can be found in Table 2.C.2 of Appendix 2.C. The main data sources are: the World Bank World Development Indicators (WDI), Barro-Lee database, Crouch and Fasih (2004), and the World Health Organization (Mathers *et al,* 2000).

[30] Crouch and Fasih (2004) consider several international tests of learning achievement in math, science and literacy applied at different levels of the school system. The tests include: TIMSS (Third International Mathematics and Science Survey), PIRLS (Progress in International Literacy Study), PISA (Program for International Student Assessment), Reading Literacy Study, LLECE, SACMEQ (Southern Africa Consortium for Monitoring of Education Quality), and MLA (Monitoring Learning Achievement).

as shown in Figure 14 (.81 with net secondary school enrollment and .76 with average years of schooling).[31] The health output indicators are: life expectancy at birth, immunization (DPT[32] and measles), and the disability-adjusted life expectancy (DALE).

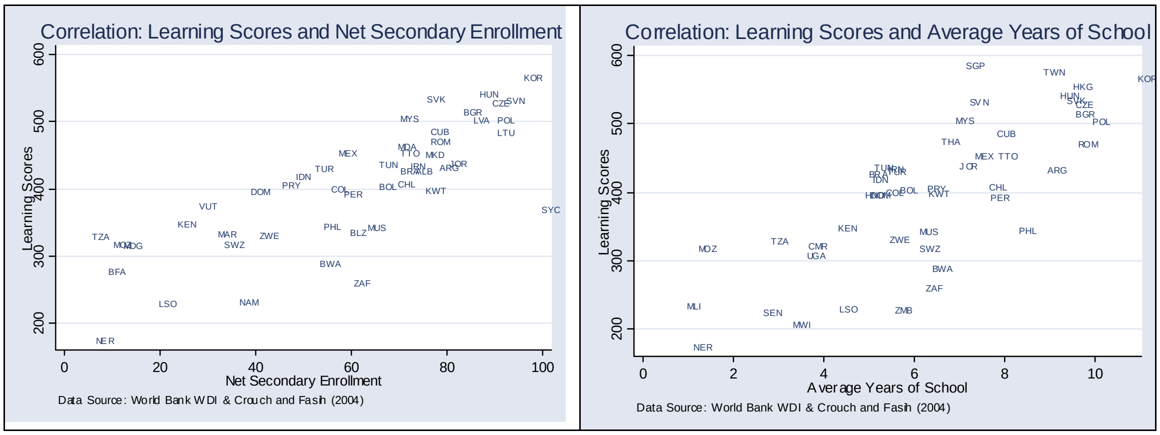


Figure 14 Correlation between Learning Scores and Other Education Indicators

Four limitations of the analysis arise from these particular data sources: First, there is a slight inconsistency in the level of aggregation. This chapter uses aggregate public spending on health and education, while using disaggregate measures of output such as primary enrollment or secondary enrollment. Ideally, the input should use separately public spending on primary and secondary education. Similarly, health care spending could be disaggregated into primary level and secondary level care. The data could be disaggregated even further to analyze efficiency at the school or hospital levels. Second, there are omitted factors of production. This is especially true in education, as this chapter does not consider private spending due to lack of data for developing nations. If this factor is used more intensively in a particular group of countries, the efficiency

[31] The correlations and Figure 14 exclude developed nations from the Crouch and Fasih (2004) sample.

[32] DPT stands for Diphtheria-Pertussis and Tetanus

scores would be biased favoring efficiency in that group. The third limitation is the combination of monetary and non-monetary factors of production. In addition to public expenditure, this chapter uses non-monetary factors of production such as the ratio of teachers to students in the case of education, and literacy of adults in the case of both health and education. Other factors of production that could have been used are the physical number of teaching hours (in education) or the number of doctors or in-patient beds (in health), as done by Afonso and St. Aubyn (2004) for the OECD countries. However, non-existent data for a large number of developing countries constrained the options. The fourth limitation is that the selected indicators do not allow for a good differentiation between outputs and outcomes. For instance, most of the indicators of education, such as completion and enrollment rates, do not measure how much learning is taking place in a particular country. In education, this chapter contributes by considering learning scores as one of the indicators. In health, other outcomes such as the number of sick-day leaves or the number of missed-school days due to health-related causes could be important reflections of outcomes. Two of the selected health output indicators, DPT and measles immunizations, are delivered in vertical programs, that is, in campaigns that are relatively independent of basic health systems and therefore may not be sufficient indicators of the actual quality of the health system. Finally, the fact that life expectancy is influenced by diet, lifestyle, sanitation, and a clean environment which are not included as factors of production, may bias the efficiency scores.

2.3.2 Single Input Single Output Results

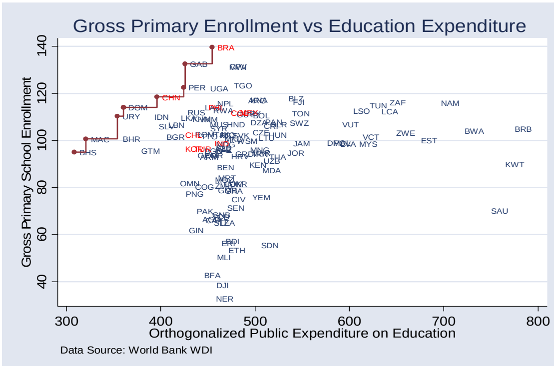
2.3.2.1 FDH and DEA analysis: Education

We start with estimating the efficiency scores and frontiers for education and health based on the average input and output values over 1996-2002. We turn to multiple periods later. Figure 15a-d show both FDH and DEA estimation of the efficiency frontier for three of the nine output indicators: gross primary school enrollment, first level complete and learning scores. Individual country efficiency scores for the three indicators are reported in Tables 2.D.1-3 of Appendix 2.D. The graphical efficiency frontiers for other output indicators can be found in Appendix 2.D (Figure 2.D. 1).

Figure 15d, in contrast to Figure 15c, illustrates the efficiency frontier for the learning scores if the developed countries are included in the sample, demonstrating the sensitivity of the results to the sample selection. This fact is acute in the case of learning scores which capture the quality dimension of education that no other indicator captures. While in the sample of developing countries Chile, Hungary and the Czech Republic are on the frontier in Figure 15c, once the developed nations are included they appear inefficient. The complete set of efficiency scores can be found in Tables 2.D.2-3 in Appendix 2.D (including and excluding the set of developed countries).[33]

[33] Figure 15d excludes Japan, Korea, Ireland and Belgium to facilitate comparisons.

Free Disposable Hull (FDH) | Data Envelopment Analysis (DEA)



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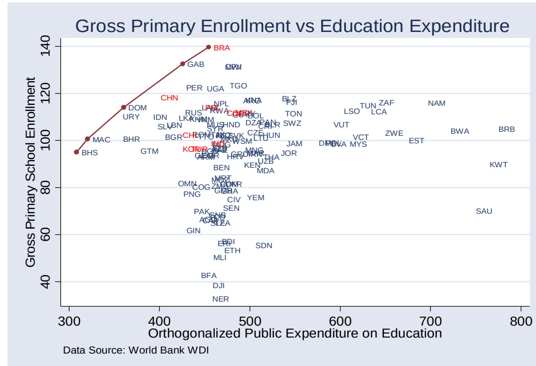

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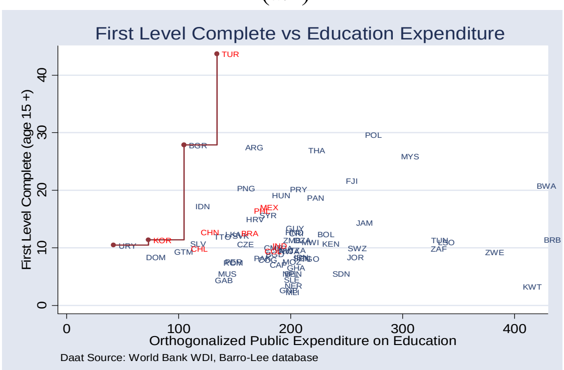

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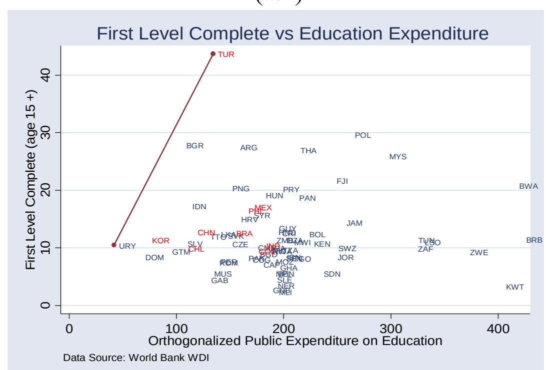

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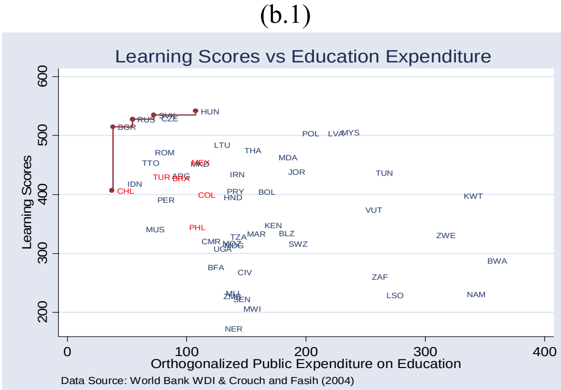

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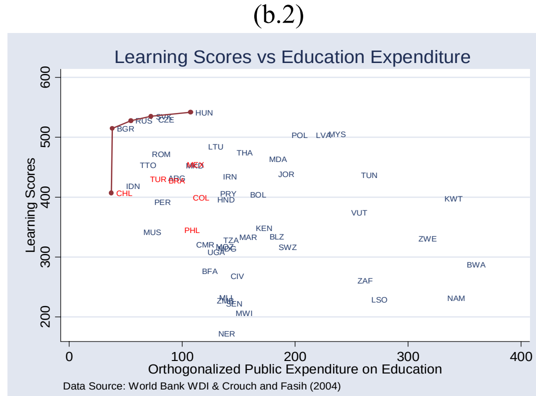

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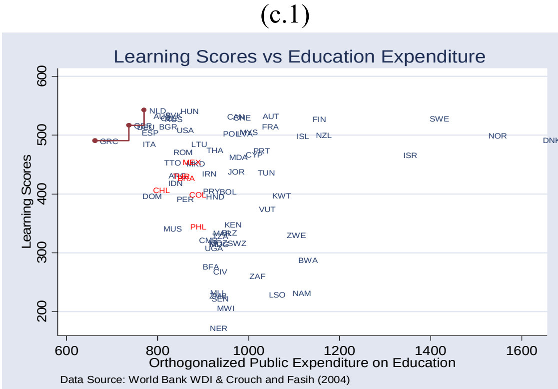

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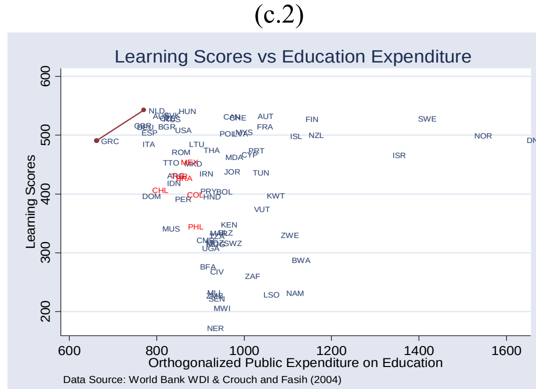


(d.2)

Figure 15 Education Efficiency Frontier: Single Input and Single Output

Several results from the FDH and DEA analyses on education are worth highlighting:

a. The rankings are generally robust to the output indicators selected. This can be verified by the Spearman rank-correlation coefficients (see Tables 2.E.1 and 2.E.2 in Appendix 2.E). They are all positive, significant and high. The range oscillates from a minimum of .53 to a maximum of .94, with a mean of .70. This result implies that countries appearing efficient (or inefficient) according to one indicator are ranked similarly when another output indicator is used.

b. Despite the orthogonalization by GDP, the relatively rich countries tend to be in the less efficient group, i.e. countries with higher per-capita GDP spend more than other countries in attaining similar education outcomes. Higher spending may reflect the higher cost of tertiary education. This is a factor that may help explain the positioning of Estonia, Latvia, and Poland. Oil-rich countries, such as Kuwait and Saudi Arabia, tend to be in the group of inefficient producers.

c. Another group of relatively inefficient producers are those with "average" expenditure levels but extremely low education attainment. Among those are mostly African countries (Angola, Niger, Burkina Faso, Sudan, and Ethiopia), some Middle Eastern countries (Djibouti, and Yemen) and South Asian countries (Bangladesh and Pakistan). Tables 2.D.1-3 in Appendix 2.D list the output-efficiency scores for three of the indicators.

d. Output-efficiency rankings also vary with the selected output indicators. The Spearman correlation coefficients of the output-efficiency scores (see Tables 2.E.3 and 2.E.4 in Appendix 2.E) show that these are robust to the selected indicators, though the mean of the correlation coefficients is lower (.52) and the range is somewhat wider (.30 to .95) than those registered in the input-efficiency rankings.

e. In an attempt to identify clusters of more efficient (inefficient) countries, the top (and bottom) 10 percent of the efficiency rankings are selected for each of the indicators. If a country appears in the efficient (inefficient) tail for three or more of the indicators, it is included in Table 7. This clustering exercise reveals a group of African countries as the most inefficient. Two oil-rich countries appear in this group as well. Among the more efficient group of countries we consistently find Uruguay, Korea, Bahamas, and Bahrain. Why these countries cluster in particular sets requires more in-depth analysis and explanation. The last section of this chapter attempts to associate efficiency results with some explanatory variables.

Table 7 Educational Attainment: Single Input, Single Output

	Input Efficiency	Output Efficiency
Most efficient	Uruguay, Korea, Dominican Republic, Indonesia, Guatemala, China, Bahamas, Bahrain, El Salvador	Uruguay, Korea, Bahrain, Bahamas
Least efficient	Botswana, South Africa, Kuwait, Tunisia, Lesotho, Barbados, Saudi Arabia, Zimbawe, Namibia, Malaysia, St. Lucia, Jamaica, St. Vincent, Latvia	Niger, Mali, Tanzania, Burkina Fasso, Gunea-Bissau, Ethiopia, Guinea, Burundi, Sudan, Sierra Leone, Chad

f. To grasp the magnitude of deviations from the efficiency frontier, we computed an average for all indicators for the inefficient countries. The input-efficiency estimations indicate that the most inefficient decile could reach the same educational attainment levels by spending approximately 50 percent less. The output efficiency estimators indicate that, on average, with their expenditure level this group could reach educational attainment levels four times as high.

g. It is critical to note that even if a country appears efficient, there might still be a significant discrepancy between the observed output level and the socially desired or target output level. For instance, Bahamas, Bahrain, Dominican Republic and Guatemala appear on the efficiency frontier or very close to it (Figure 15a.1). However, these countries are still far away from where Gabon and Brazil are, and it could be desirable to achieve those target enrollment rates. Guatemala spends about two percent of GDP on education but has a net secondary enrollment rate below 40 percent and a net primary enrollment around 80 percent (Figure 2.D. 1 in Appendix 2.D). It would be difficult to argue that these are desirable outcomes although they are very close to the input-oriented efficiency frontier. Similarly, though Chile appears efficient with learning scores of about 400, the country could still achieve higher learning scores of over 500 points at the cost of slightly higher public spending. What is critical is to make sure that the country moves along the efficiency frontier to the higher target output level. Countries can as well exploit scale economies if they are operating in the increasing returns to scale zone of production (output levels smaller than that of point A in Figure 11).

h. The regional aggregation of the efficiency scores by each individual output indicator shows that scores are lower when they are input oriented (Table 8) than output oriented (Table 9).[34] This is especially true for ECA. The exception is Africa. Higher efficiency scores are generally observed when primary enrollment

[34] The regional aggregation is computed as the simple average of individual country scores obtained for the whole sample. The scores are not computed by constructing separate efficiency frontiers for each region.

is considered as the output indicator than in the case of secondary enrollment, especially when output-oriented measures are considered. Africa and MNA have similar levels of input inefficiency: in most cases, both regions have public spending 35 percent in excess of the benchmark cases. EAP, ECA, LAC and SAS, on average, spend between 20-30 percent in excess of the benchmark level.

Table 8 Educational Attainment: Input-Efficiency scores by region - Single Input, Single Output

	AFR	EAP	ECA	LAC	MNA	SAS
Gross primary enrollment	.69	.74	.67	.74	.65	.75
Net primary enrollment	.68	.78	.72	.77	.68	.71
Gross Secondary enrollment	.65	.69	.67	.69	.63	.70
Net secondary enrollment	.64	.71	.71	.69	.64	.72
Average years of school	.21	.36	.37	.32	.18	.25
First level complete	.21	.43	.48	.36	.20	.26
Second level complete	.22	.37	.33	.32	.19	.27
Literacy of youth	.66	.73	.86	.72	.63	.72

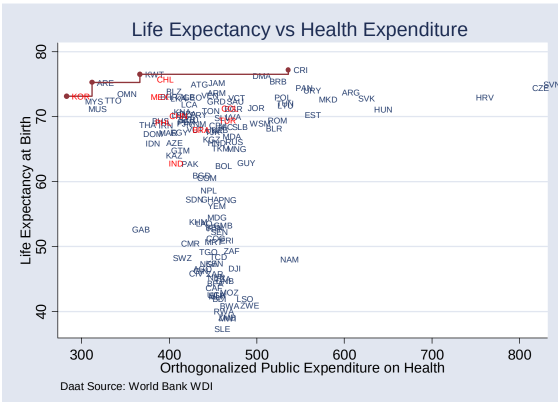
Table 9 Educational Attainment: Output-Efficiency scores by region - Single Input-Single Output

	AFR	EAP	ECA	LAC	MNA	SAS
Gross primary enrollment	.62	.79	.72	.82	.67	.72
Net primary enrollment	.64	.93	.90	.93	.79	.78
Gross Secondary enrollment	.23	.50	.70	.61	.54	.39
Net secondary enrollment	.26	.58	.84	.66	.60	.44
Average years of school	.32	.63	.79	.60	.53	.38
First level complete	.19	.49	.50	.36	.22	.20
Second level complete	.09	.37	.38	.24	.26	.22
Literacy of youth	.72	.95	.99	.94	.88	.66

2.3.2.2 FDH and DEA Analysis: Health

This subsection considers the efficiency of pubic spending on health, in the case of one input (public expenditure on health per capita in PPP terms) and four alternative output indicators: life expectancy at birth, DPT immunization, measles immunization, and the disability adjusted life expectancy (DALE) which takes into account both mortality and illness. The efficiency frontier for each indicator is computed using both the FDH and DEA methodologies. Figure 16a-d show the efficiency frontiers. The specific country rankings for two of the health indicators are listed in Table 2.D.4 of Appendix 2.D.

Free Disposable Hull (FDH) | Data Envelopment Analysis (DEA)



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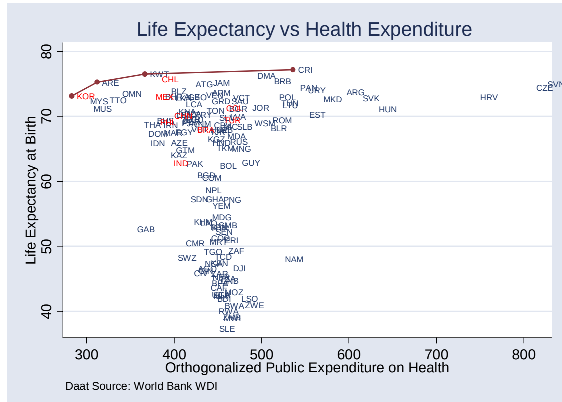

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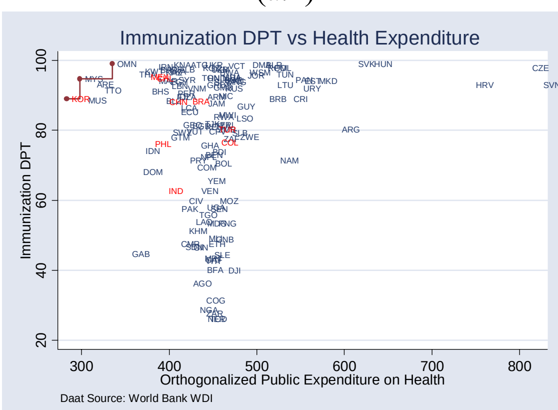

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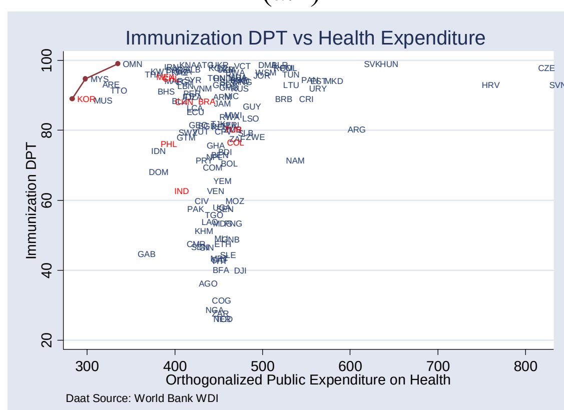

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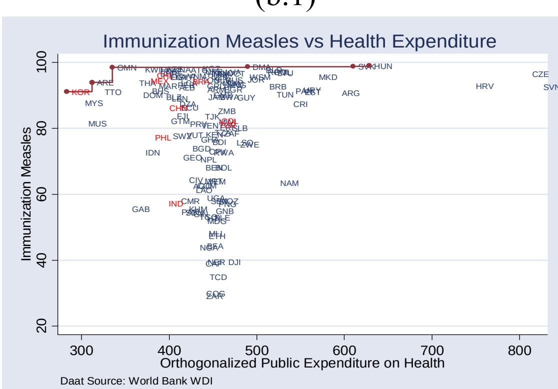

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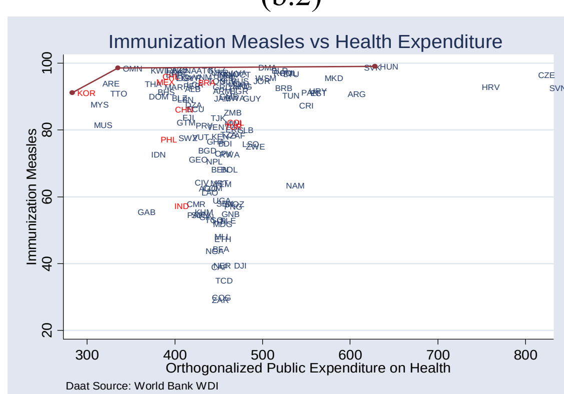

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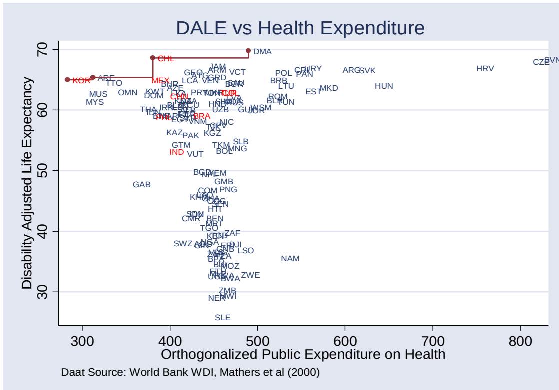

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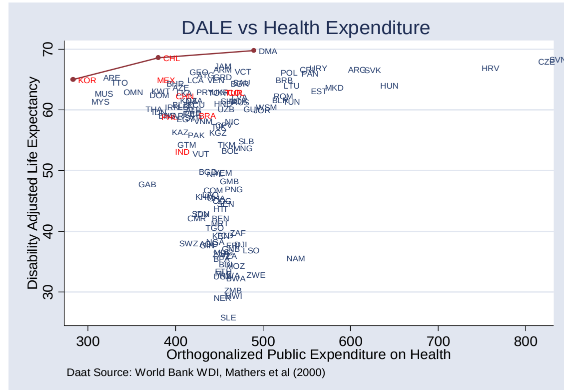


(d.1)

Figure 16 Health Efficiency Frontier: Single Input and Single Output

Several results from the efficiency analysis on health spending may be highlighted:

a. The input efficiency scores obtained for each of the output indicators are highly correlated. The Spearman rank-order correlation coefficient oscillates between .66 and .94, with a mean of 0.81 (see Tables 2.E.1 and 2.E.2 in Appendix 2.E). This indicates that the efficiency ranking is very similar regardless of the output indicator being used.

b. Despite the orthogonalization by GDP the relatively rich countries tend to be in the less efficient group. The group of inefficient producers cluster in two groups of countries: one group of relatively rich countries like the Czech Republic, Croatia, Slovenia and Hungary that have large expenditure but not substantially high output (input inefficiency) and another group of countries that spend relatively little but whose output could be substantially larger, like Sierra Leone, Namibia, Zimbawe and Lesotho (output efficiency). The rankings between input and output orientations are highly correlated (Tables 2.E.3-2.E.4 in Appendix 2.E).

c. The most efficient and least efficient countries are listed in Table 10. The selection criterion is the same as in Table 7. The group of least efficient countries could, on average, increase output significantly for a given expenditure level. For instance, the least efficient countries could almost double the disability-adjusted life expectancy (DALE) index to achieve the same efficiency as the benchmark. Similarly the DPT immunization would have to triple to achieve the same efficiency level as the benchmark developing countries.

d. The regional aggregation of the efficiency scores by each individual output indicator shows that input efficiency scores (Table 11) tend to be lower than output efficiency scores (Table 12). This is especially true in ECA, LAC and MNA, and to a lesser extent in EAP and SAS. In Africa, both scores are strikingly similar, indicating that, on average, the region spends about 35 percent in excess of the benchmark countries to achieve the same output level. Alternatively, the output level is 35 percent below that of efficient countries that use the same input (expenditure) level.

Table 10 Health Attainment: Single Input, Single Output

	Input Efficiency	Output Efficiency
Most efficient	Korea, Malaysia, Thailand, Trinidad & Tobago, Oman, United Arab Emirates, Mauritius, Kuwait, Chile	Korea, Dominica, Oman, United Arab Emirates, Anigua and Barbuda
Least efficient	Argentina, Estonia, Czech Republic, Slovenia, Macedonia, Croatia, Namibia, Tunisia, Latvia, Hungary, Barbados	Sierra Leone, Ethiopia, Burkina Fasso, Central African Republic, Mali

Table 11 Health Attainment: Input-Efficiency scores by region

- Single Input, Single Output

	AFR	EAP	ECA	LAC	MNA	SAS
Life Expectancy at birth	.65	.72	.58	.69	.73	.69
Immunization DPT	.66	.73	.63	.68	.76	.71
Immunization Measles	.65	.73	.67	.69	.76	.71
DALE	.65	.72	.60	.70	.71	.69

Table 12 Health Attainment: Output-Efficiency scores by region

- Single Input, Single Output

	AFR	EAP	ECA	LAC	MNA	SAS
Life Expectancy at birth	.63	.87	.91	.92	.90	.83
Immunization DPT	.62	.83	.95	.87	.90	.75
Immunization Measles	.63	.83	.95	.91	.90	.71
DALE	.56	.83	.90	.90	.86	.79

2.3.3 Multiple-Input and Multiple-Output Results

Attainment of education and health is not solely determined by public spending. Other inputs such as private spending also affect output. Unfortunately, a comprehensive database of private spending does not exist for education. For education we have multiple indicators of educational attainment and three inputs (public spending, teachers per pupil, and adult literacy rate). For health, besides public spending, two other inputs are available: private spending and the education level of adults. This study considers three outputs at most. Too many output indicators will complicate the analysis, biasing efficiency scores towards one, increasing the variance of the estimators, and reducing their speed of convergence to the true efficiency estimates (Simar and Wilson, 2000; Groskopff, 1996).

In education, the selected input-output combinations produce rankings that are somewhat similar: the average rank correlation coefficient is .53. The frequency distribution of the efficiency scores is similar in all models, and as the model shifts from a basic two-input two-output model to a more complex three-input three–output model, the frequency distribution shifts to the right, becoming more concentrated around more efficient results. The multi-input multi-output model results (Table 13) in general confirm the results of Table 7. Some new countries that appear efficient are Bangladesh, Congo and Argentina. In the case of Bangladesh and Congo, this is the result of considering literacy of adults as a factor of production. Because adult literacy in these countries is low, they appear very efficient. Congo has also extremely low ratio of teachers per student, the other factor of production, reinforcing the bias towards a higher efficiency score. The least efficient countries include Zimbabwe, Lesotho, Botswana, Malaysia and Saudi Arabia, as in the single input models. In addition, Costa Rica and Swaziland appear as input inefficient.

Table 13 Educational Attainment: Multiple Inputs, Multiple Outputs

	Input Efficiency	Output Efficiency
Most efficient	Bangladesh, Bahrain, Dominican Republic, Argentina, Estonia	Argentina, Bangladesh,, Chile, Brazil, Bahrain, Dominican Republic, Congo
Least efficient	Zimbabwe, Lesotho, Botswana, Costa Rica, Swaziland, Saudi Arabia, Malaysia	Sudan, Ghana, Tanzania, Ethiopia, Kenya, Niger

The regional aggregation of input and output efficiency scores using the multi-input, multi-output framework shows (Table 14 and Table 15) that as the model becomes more complex (with more inputs or outputs), more regions emerge as efficient. The input efficiency regional aggregation allows several interesting comparisons across the regions on the impact of an additional input on the efficiency scores. For instance, the first two rows of Table 14 allow examination of the impact of adding adult literacy as an additional input. The biggest impact is in the MNA region, followed by ECA and LAC.

Rows 4 and 5 of Table 14 show the impact of adding teachers per pupil as an additional input. In Africa the change is dramatic, while that in ECA and MNA is not significant. Further analysis is required to explain this differential response to the inclusion of this input.

Table 14 Educational Attainment: Input-Efficiency scores by region - Multiple Inputs, Multiple Outputs

	AFR	EAP	ECA	LAC	MNA	SAS
2 inputs (public expenditure, teachers per pupil) – 2 outputs (gross primary and secondary enroll.)	.88	.83	.72	.82	.73	.91
3 inputs (public expenditure, teachers per pupil, literacy of adult) – 2 outputs (gross primary and secondary enroll.)	.92	.89	.86	.89	.92	.96
3 inputs (public expenditure, teachers per pupil, literacy of adult) – 2 outputs (net primary and secondary enroll.)	.87	.94	.93	.93	.92	1.0
2 inputs (public expenditure, literacy of adult)- 3 outputs (first complete, second level complete, average years of school)	.78	.92	.95	.84	.80	.91
3 inputs (public expenditure, literacy of adult, teachers per pupil)- 3 outputs (first complete, second level complete, average years of school)	.91	.97	.94	.89	.81	.95
3 inputs (public expenditure, teachers per pupil, literacy of adult) – 3 outputs (literacy of youth, first level complete, second level complete)	.91	.97	.94	.89	.80	.95

Table 15 Educational Attainment: Output-Efficiency scores by region - Multiple Inputs, Multiple Outputs

	AFR	EAP	ECA	LAC	MNA	SAS
2 inputs (public expenditure, teachers per pupil) – 2 outputs (gross primary and secondary enroll.)	.68	.83	.80	.85	.71	.79
3 inputs (public expenditure, teachers per pupil, literacy of adult) – 2 outputs (gross primary and secondary enroll.)	.82	.88	.89	.89	.91	.90
3 inputs (public expenditure, teachers per pupil, literacy of adult) – 2 outputs (net primary and secondary enroll.)	.79	.97	.96	.96	.92	1.0
2 inputs (public expenditure, literacy of adult)- 3 outputs (first complete, second level complete, average years of school)	.64	.87	.94	.80	.79	.83
3 inputs (public expenditure, literacy of adult, teachers per pupil)- 3 outputs (first complete, second level complete, average years of school)	.86	.94	.93	.86	.80	.89
3 inputs (public expenditure, teachers per pupil, literacy of adult) – 3 outputs (literacy of youth, first level complete, second level complete)	.98	1.0	1.0	.98	.99	.99

In health there are multiple combinations of inputs (public expenditure, private expenditure, and literacy of adults) and outputs (life expectancy at birth, DPT immunization, measles immunization, and disability adjusted life expectancy (DALE)). The combinations do not yield drastic changes in the rankings (Table 16-Table 18). The correlations between efficiency rankings based on different indicators range between .65 and .98. Bangladesh appears efficient, so does Niger, mainly due to the inclusion of (low) levels of adult literacy as an input.

Table 16 Health Attainment: Multiple Inputs, Multiple Outputs

	Input Efficiency	Output Efficiency
Most efficient	Bangladesh, Malaysia, Costa Rica, Kuwait, Morocco, Oman, Mauritius, Niger	Bangladesh, Costa Rica, Kuwait, Malaysia, Morocco, Mauritius, Oman, Niger
Least efficient	Russia, Belarus, Namibia, Romania, Estonia, Croatia, Lituania,, Hungary, Jordan	Namibia, Togo, Ethiopia, Mozambique, Cote d"Ivoire, Cameroon, Congo, Central African Republic, Nigeria, Uganda

Table 17 Health Attainment: Input-Efficiency scores by region - Multiple Inputs, Multiple Outputs

	AFR	EAP	ECA	LA	MNA	SAS
2 inputs (public expenditure, literacy of adult) – 2 outputs (life expectancy, immunization DPT.)	.85	.82	.72	.82	.91	.93
3 inputs (public expenditure, private spending, literacy of adult) – 2 outputs (life expectancy, immunization DPT.)	.86	.82	.74	.83	.91	.94
3 inputs (public expenditure, private spending, literacy of adult) – 2 outputs (life expectancy, immunization measles.)	.86	.82	.77	.83	.91	.94
3 inputs (public expenditure, private spending, literacy of adult) – 3 outputs (life expectancy, immunization DPT., DALE)	.86	.82	.80	.87	.93	.94

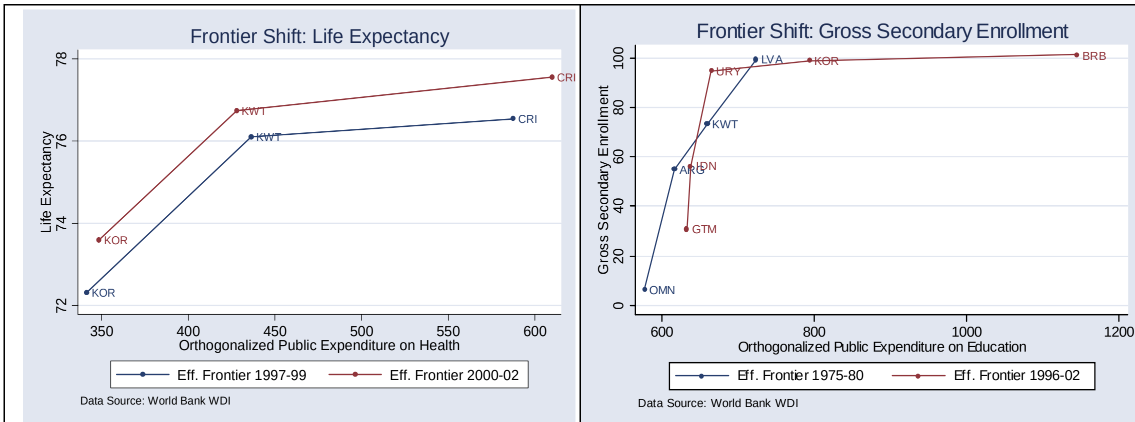
Table 18 Health Attainment: Output-Efficiency scores by region
- Multiple Inputs, Multiple Outputs

	AFR	EAP	ECA	LA	MNA	SAS
2 inputs (public expenditure, literacy of adult) – 2 outputs (life expectancy, immunization DPT.)	.81	.91	.97	.93	.97	.96
3 inputs (public expenditure, private spending, literacy of adult) – 2 outputs (life expectancy, immunization DPT.)	.81	.91	.97	.94	.97	.96
3 inputs (public expenditure, private spending, literacy of adult) – 2 outputs (life expectancy, immunization measles.)	.80	.91	.96	.94	.98	.96
3 inputs (public expenditure, private spending, literacy of adult) – 3 outputs (life expectancy, immunization DPT., DALE)	.82	.91	.97	.95	.98	.97

Table 15 and Table 18 show that, on average, developing nations score between .85 and .95 in output efficiency in the multiple input-output framework. These figures imply that developing countries could raise their output levels by an average of 10 percent with the same input consumption, if they were as efficient as the comparable benchmark countries. This figure is simply indicative, as the precise estimate varies with the country and with the selected indicator, and has a large variance across countries; for instance, the bottom decile of (output) efficiency scores is about .66, implying that the scope for increases in health and education attainment levels is 3 to 4 times higher than for the whole sample average.

2.3.4 Efficiency Change Over Time

To examine the evolution of input and output efficiency over time, we computed the efficiency scores in two different time periods: 1975-1980 and 1996-2002 for education, and 1997-99 and 2000-02 for health, the construction of which is driven by data availability. Comparison of different input-output bundles in different time periods has to be done carefully because the frontier can be shifting outward over time. In some cases the frontier displacement can be parallel (in the case of life expectancy in Figure 17a). In others, the frontier displacement can be very uneven (biased frontier shift in Figure 17b) reflecting biased technological change.



(a) Parallel Shift	(b) Biased Shift

Figure 17 Efficiency Frontier Shift over Time

The detailed comparison between observed input-output combinations in different time periods distinguishes whether variations in the levels of input utilization or output production are due to changes in efficiency or changes in technology. This testing is possible with observed levels of inputs and outputs, and is based on the concept of a Malmquist Index (Fare, Grosskpof, Norris and Zhang, 1994). This method has been used to study productivity change in the OECD economies, as well as in agriculture across the world (Coelli and Rao, 2003; Nin, Arndt, and Preckel, 2003). Appendix 2.B describes details of the methodology and the Malmquist index that will facilitate the analysis of productivity change through time. Appendix 2.F summarizes, on a regional basis, the change in productivity of public spending decomposed into efficiency change (EFFCH) and technological change (TECHCH).

Results show that over the two decades output-efficiency growth was faster in the most inefficient countries, showing that there was a "catching-up" phenomenon. However, when measuring input-efficiency, the previous results do not hold: most regions increased expenditure levels without increasing output.

2.4 Explaining Inefficiency Variation across Countries

This section seeks to identify factors correlated with efficiency variation across countries. This two-stage approach attempts to identify statistically significant regularities common to efficient or inefficient countries using econometric techniques. This exercise does not try to identify supply or demand factors that affect health and education outcomes, such as those described by Filmer (2003). The scope is limited to verifying statistical associations between the efficiency scores and environmental variables.

2.4.1 Method and Variables

Given that the dependent variable, the efficiency score, is continuous and distributed over a limited interval (between zero and one), it is appropriate to use a censored (Tobit) regression model to analyze its relationships with other variables. The panel consists of a large number of countries (varying from 70 to 140 depending on the output indicator) and two time periods. The literature on panel estimation has shown that in panels with this configuration, that is, a large number of cross-section units and a relatively short time dimension, the fixed-effects estimator of the coefficients will be inconsistent (Maddala,

1987) and the estimated variance will be biased downward (Greene, 2003b). Hence the random effects panel estimation method is utilized.

The dependent variable in the Tobit panel estimation is the input efficiency score calculated by the DEA method in the first stage. The input orientation reflects the consideration that input choices are more under the policymaker's control. The independent variables reflect environmental effects, suggested by various studies. Specifically, the following independent variables are included:[35]

a. The size of government expenditure. Most of the papers surveyed in the previous section explore the relationship between the size of the government (i.e., total government expenditure as a percentage of GDP) and efficiency levels. The objective is to verify if additional pubic spending is associated with better education and health outcomes. While some papers find a negative association between efficiency and expenditure levels (Gupta and Verhoeven 2001, Jarasuriya and Woodon 2003, and Afonso *et al.* 2003), some find a positive association (Evans *et al.* 2003) and others find no significant impact (Filmer and Pritchett, 1999).

b. **Government budget composition**. Given that both education and health are labor-intensive activities, the government's labor policies affect the efficiency with which outputs are delivered. We choose a budget composition indicator to reflect this, in particular, the share of the wage and salaries as a percent of total budget. A higher ratio is expected to be negatively correlated with efficiency.

c. **Per-capita GDP**. We include the per-capita GDP to control for the Balassa-Samuleson effect in comparing across countries. If richer countries tend to be more inefficient (given higher wages/prices in these countries), a negative sign is expected. However, recall that

[35] The definitions and sources can be found in Table 2.C.2 of Appendix 2.C.

to obtain the efficiency scores in the "first stage" we constructed an auxiliary variable (the orthogonalized public expenditure). Hence the inclusion of this variable in the second stage is an attempt to control for any *remaining* Balassa- Samuleson effects.

d. **Urbanization**. The clustering of agents makes it cheaper to provide services in urbanized areas than in rural areas. A higher degree of urbanization should result in higher efficiency, making the expected sign of the coefficient on this variable positive. Urbanization is indicated by the percentage of urban population in total population.

e. Prevalence of AIDS. Based on WHO mappings of the disease, we include a dummy variable in the most severely affected countries to control for the role of this epidemic in the poor health outcomes. Evans *et al.* (2000) report that AIDS lowers the Disability adjusted life expectancy (DALE) by 15 years or more. AIDS affects education outcomes both directly and indirectly (Drake, *et al.* 2002). The direct effect occurs because school age children are affected: UNAIDS estimates that almost 4 million children have been infected since the epidemic began, and two thirds have died. However, the indirect channel is even more important: AIDS leaves orphaned children more likely to drop out of school or to repeat. These factors reflect how AIDS affects the demand for education. The supply of education is also affected by the decreasing teacher labor force due to illness or death, or the need to care for family (Pigozzi, 2004). Prevalence of HIV/AIDS should be negatively associated with education and health outcomes. Consequently, efficiency scores should be negatively associated with the dummy variable.

f. Income inequality. Ravallion (2003) argues that the income distribution, besides its mean, affects social indicators because their overall attainment is mostly determined by the outcomes of the poor. Hence, we control for the distribution of income by including the Gini coefficient as an explanatory variable. Higher inequality is expected to be associated with lower educational and health attainments, making the expected sign of this variable negative.

g. **Share of public financing in the provision of services.** Services can be provided by the public or private sectors, and efficiency indicators differ across countries depending on the relative productivities of both sectors. Previous studies have included this variable to explain differences in outcomes (Le Grand, 1987; Berger and Messer, 2002) or efficiency scores (Greene, 2003a). The variable specifically included is the ratio of public financing over the total spending on health (private plus public spending). Due to data shortage, this variable is explored only in explaining the health efficiency variation.

h. External Aid. To the extent that countries do not have to incur the burden of taxation, they may not have the incentive to use resources in the most cost-effective way. Another channel through which aid financing may affect efficiency is through the volatility and unpredictability of its flows. Given that this financing source is more volatile than other types of fiscal revenue (Bulir and Hamann, 2000), it is difficult to undertake medium-term planning in activities funded with aid resources. If this is the case, a negative association is expected between aid dependence and efficiency in those activities funded with aid, mostly in health services. To our knowledge there are no previous attempts to tackle the relationship between efficiency and the degree to which activities are financed by external aid. There is, however, recent evidence of a negative association between donor financing and some health outcomes (Bokhari, Gottret, and Gai, 2005).

i. Institutional characteristics. Countries with better institutions, more transparency, and less corruption are expected to have higher efficiency scores. Similarly, countries that have suffered wars or state failures are expected to register lower efficiency scores. To capture these effects we explore three different indicators: the ICRG International Country Risk Indicators, the Worldwide Governance Research Indicators, in particular the Control of Corruption component (Kaufmann, *et al.* 2002), and a dummy variable for state failure, such as internal wars, defined in the State Failure Task Force database.

The data on educational and health indicators are not available on a continuous annual basis for many countries. Thus, averages of the variables are computed over sub-periods both in the first stage calculation of efficiency score and in the second stage regression analysis. Specifically, educational indicators are averaged over two periods (1975-80 and 1996-2002) and health indicators over two periods (1996-99 and 2000-02). This discrepancy in the sub-period construction is due exclusively to data availability. The averages are treated as separate observations. The advantages of this approach are threefold. First, the averages may serve as a more robust measure of educational and health attainment, which can hardly be substantially improved on a yearly basis; Second, the averaging maximizes the coverage of countries for each period, since one observation is sufficient to include a country in the cross sectional comparison; Third, the time series thus constructed for each country, although short, facilitates the implementation of econometric techniques on panel data to explore the efficiency variations across countries and through time.

2.4.2 Regression Results

The Tobit estimation on panel data is specified as follows.

$$VRSTE_{it} = f(WAGE_{it}, GOVEXP_{it}, PUBTOT_{it}, GDPPC_{it}, URBAN_{it}, AIDS_{it}, GINI_{it}, EXTAID_{it}, INST_{it}, CONS)$$

where $VRSTE_{it}$ = Variable returns to scale DEA input efficiency scores

$GOVEXP_{it}$ = Total government expenditure (% of GDP)

$WAGE_{it}$ = Wages and salaries (% of total public expenditure)

$PUBTOT_{it}$ = Share of public financing to total expenditure on health

$GDPPC_{it}$ = GDP per capita in constant 1995 US dollars

$URBAN_{it}$ = Urban population (% of total)

$AIDS_{it}$ = Dummy variable for HIV/AIDS

$GINI_{it}$ = Gini Coefficient

$EXTAID_{it}$ = External aid (% of fiscal revenue)

$INST_{it}$ = Institutional indicators

$CONS$ = Constant

Table 19 and Table 20 report the results for the single-input single-output case and the multiple-input multiple-output case, respectively. Some findings are worth highlighting:

a. Countries with larger expenditure levels tend to register lower efficiency scores. This result is robust to changes in output indicators selected, to considering health or education, and to adopting either single-output or multiple-output frameworks. The negative association between size of expenditure and efficiency is quite robust.

b. Countries in which the wage bill represents a higher fraction of total expenditure are more likely to be inefficient. This finding does not hold for health in the multiple-output framework. The difference could be related to the observation that much of the world, especially the poor countries, suffers from a lack of health care professionals and that higher wages may help attract human resources into this sector (Liese, et al.

2003). Further investigation is needed to examine why this is not the case in education.

c. For health, countries in which public financing is a larger share of total expenditure on health services register lower efficiency scores. This is probably due to differential productivity rates in the provision of services. For instance, recent case studies of water companies in Argentina show that private companies are more efficient than public ones and provide better service quality leading to lower child mortality rates (Galiani, Gertler and Schargrodsky, 2005). In education, there is some evidence that efficiency scores are lower in public schools (Alexander and Jaforullah, 2004), though the evidence regarding the impact of privatizing education on outcomes is mixed (World Bank, 2003).

d. Urbanization is positively associated with efficiency scores in both education and health. However, when life expectancy is included as an output, the relationship is not significant (single output) or negative (multiple outputs). A possible reason is that when urbanization intensifies, communicable diseases are more difficult and costly to control; hence a negative association follows between urbanization and efficiency. Another possibility is that the urbanization variable is to some extent capturing other effects such as crime. There is ample literature studying the relationship between urbanization and crime (Glaeser E. and B. Sacerdote, 1999).

e. The effect of HIV/AIDS clearly has a negative affect on health efficiency scores in the multiple-output models. However, its effect on education is less clear, as the expected negative sign is significant in few cases and has the opposite sign occasionally. This confirms the difficulty to empirically verify this relationship, as reported in Wobst and Arndt (2003).

f. Income distribution has the expected negative effect on the educational and health efficiency scores. The impact of inequality on health scores is less robust than on education, but confirms Greene's findings (2003a). Other papers (Berger and Messer, 2002) have found a positive association between income inequality and health outcomes.

g. Results showed a negative relationship between some of the efficiency scores and the external aid dependency ratio. Only in one of the multiple-output cases is external aid associated with higher efficiency, but with border-line statistical significance. Though no causal relationship can be inferred from the exercise, this is one of the results that merit more detailed research. This result might be explained by the volatility of aid as a funding source that limits medium term planning and effective budgeting. Recent research (Bokhari, Gottret, Gai, 2005) show a negative association between some health outcomes and the degree of donor funding, pointing in this same direction. This result also coincides with the research showing that the quality of policies is not only unrelated to donor financing, but that highly indebted countries with "bad" policies receive more net transfers as a share of GDP (Birdsall *et al.* 2003).

h. None of the institutional variables is found to be statistically significant. This finding may not be conclusive since the available data may not adequately capture the characteristics of institutions. For instance the corruption index (Kaufmann et al, 2002) is only available since 1996 and the panel exercise is thus reduced to a cross-section version. The state-failure dummy variable and the ICRG indicators do not prove to be significant either. These results are not reported in any of the tables.

To investigate the possibility of slope heterogeneity across countries, we follow the approach proposed in Haque, Pesaran, and Sharma (1999). Specifically, the slope coefficients in each country are assumed to be fixed over time, but varying across countries linearly with the individual sample mean of GDP per capita. The final results (Table 21 and Table 22) only include the statistically significant interaction terms, in order to avoid co-linearity arising from the correlation between original explanatory variables and the auxiliary variable capturing the interaction of them with the sample mean of GDP per capita. The estimated model is specified as follows.

$$VRSTE_{it} = f(WAGE_{it}, GOVEXP_{it}, GDPPC_{it}, URBAN_{it}, AIDS_{it}, GINI_{it}, WAGEG_{it}, GOVG_{it}, GINIG_{it}, CONS)$$

where $VRSTE_{it}$ = Variable returns to scale DEA input efficiency scores

$GOVEXP_{it}$ = Total government expenditure (% of GDP)

$WAGE_{it}$ = Wages and salaries (% of total public expenditure)

$PUBTOT_{it}$ = Share of public financing to total expenditure on health

$GDPPC_{it}$ = GDP per capita in constant 1995 US dollars

$URBAN_{it}$ = Urban population (% of total)

$AIDS_{it}$ = Dummy variable for HIV/AIDS

$GINI_{it}$ = Gini Coefficient

$CONS$ = Constant

$WAGEG_{it} = WAGE_{it} * \overline{GDPPC_i}$

$GOVG_{it} = GOVEXP_{it} * \overline{GDPPC_i}$

$GINIG_{it} = GINI_{it} * \overline{GDPPC_i}$

$\overline{GDPPC_i} = T^{-1} \sum_{t=1}^{T} GDPPC_{it}$

Results show that the interaction terms are significant, especially for the health regression, implying that there is a heterogeneous response of efficiency scores to the different explanatory variables. This confirms Greene's (2003a) results on the WHO data. One of the key results is that the negative association between the size of government expenditure and efficiency is stronger in countries with higher per-capita GDP. Similarly, this happens with the wage variable. Results are somewhat similar to those of the homogeneous slopes, though statistical significance of many of the coefficients is lower. This is in part a result of the co-linearity between the auxiliary variables and the original set of explanatory variables.

Interpretation of the estimation results in this section requires caution due to several limitations. First, education and health outcomes are explained by multiple supply and demand factors (Filmer, 2003) that are not included here. This is not the object of this study. The omission of such factors in the health or education production functions in the previous stage could be related to some of the cross-country co-variation of the efficiency results (Ravallion, 2003). Of course, there can always be additional factors that could be included when available, but the curse of dimensionality is particularly pressing in non-parametric statistical methods, making it desirable to use a small number of variables.[36]

The second limitation derives from the intuitive question of why the set of explanatory variables used in the second stage are not included in the first stage. The answer lies in that most of these variables are environmental and outside the control of the decision-making units in the education and health sector. The inclusion of these environmental variables would have had little justification from the production function perspective. Additionally, the curse of dimensionality is avoided by maintaining the production function as simple as possible.

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[36] As the number of outputs increase, the number of observations must increase exponentially to maintain a given mean-square error of the estimator. See Simar and Wilson (2000).

Finally, a limitation arises from the fact that if the variables used in the first stage to obtain the efficiency estimator are correlated with the second stage explanatory variables, the coefficients will be inconsistent and biased (Simar and Wilson, 2004; Grosskopf, 1996; Ravallion, 2003). To examine the extent of this potential problem we calculate correlation coefficients between the "first-stage" inputs and the second stage explanatory variables. The largest correlation coefficients are between GDP per capita and the teachers per pupil ratio and adult literacy. To examine the sensitivity of the results to the inclusion of GDP per capita, all the estimations are performed without this variable and none of the results changed significantly.

2.5 Concluding Remarks

This chapter presents an application of non-parametric methods to analyze the efficiency of public spending. Based on a sample of up to 140 countries, this study estimates efficiency scores for nine education output indicators and four health output indicators. Our results indicate that countries could achieve substantially higher education and health output levels: developing countries on average obtain output efficiency of about .9 (in the multiple input, multiple output model) or around .7 (in the single input, single output model), implying that they could increase health and education attainment by 10 to 30 percent while consuming the same input level, if they were as efficient as the comparable benchmark countries. This is just indicative, as the figures vary across countries and with the selected output indicator. It is crucial to identify the social or economic factors that cause some countries to be more inefficient than others in service delivery.

In terms of policy implications, it is vital to differentiate between the technically efficient level and the optimal or desired spending level. Even if a country is identified as an "efficient" benchmark country, it may very well still need to expand its public spending levels to achieve a higher target level of educational or health attainment. Such is the case for countries with low spending levels and low output attainment, close to the origin of the efficiency frontier. The key is to make sure that countries expand their scale of operation along the efficiency frontier.

In a second stage this chapter verifies the statistical associations between the efficiency scores and environmental variables that are not under the control of the decision-making units in education and health. The panel Tobit regressions show that variables that are negatively associated with efficiency scores include the size of public expenditure, the share of the wage bill in the total public budget, the proportion of the service that is publicly financed, the prevalence of HIV/AIDS on health efficiency scores, income inequality on education efficiency scores, and external aid-financing on some of the efficiency scores. The last impact is likely due to the volatility of aid that impedes effective medium term planning and budgeting. It points in the same direction of previous research showing that donor financing is unrelated to the quality of domestic policies and that highly indebted countries with worse policies receive more transfers. A positive association between urbanization and efficiency outcomes is also identified in education but some of the health efficiency scores are negatively associated. This result is probably related to the ease of communicable diseases spreading with agglomeration.

The FDH and DEA methods are useful tools to identify efficient and inefficient units. Once they are identified, more in-depth analysis is required to explain departures from the efficiency benchmark, as proposed by Sen (1981). However, every non-parametric estimation technique has its limitations, and the approaches used here are no exception. First, caution should be used to the across-country comparison, given that considerable heterogeneity exists in the production function (even among a more homogeneous group of countries, such as the OECD, as illustrated by Jounard *et al*. 2003). Any omission of an important factor will yield an efficiency score biased in favor of the country that uses more of the omitted input. Lack of data, however, often makes it difficult to overcome this limitation. Dividing the sample into different groups is a partial remedy, which nevertheless may still face tremendous heterogeneity at the regional level. Second, the study in this chapter is unable to adequately tackle the flow-stock problem, given the lag between input consumption (public expenditure) and output production (health and education outcomes). Third, given that the methods are based on estimating the frontier directly from input-output observations, they are subject to sampling variability and are sensitive to the presence of outliers. Recent advances in the literature include proposals for constructing confidence intervals for efficiency scores (Simar and Wilson, 2000 and Wilson, 2004) and for bootstrapping methods (Simar and Wilson, 2000). These useful extensions will enhance the application of FDH and DEA approaches to various issues.

Table 19 Explaining cross-country variation in efficiency, Single Input-Single Output

Independent Variable	Gross Primary Enrollment	Net Primary Enrollment	Gross Secondary Enrollment	Net Secondary Enrollment	Youth Literacy	Average Years of Schooling	First Level Complete	Secondary Level Complete	Life Expectancy	Immuni-zation DPT	Immuni-zation Measles
WAGE	-.00117***	-.00357*	-.00172**	-.00680*	-.00189**	-.00570*	-.00470**	-.00546*	.00065	-.00052	-.00049
GOVEXP	-.00387*	-.00546*	-.00340*	-.00455**	-.00387*	-.00696*	-.00566*	-.00765*	-.00269**	-.00078	-.00227***
PUBTOT	--	--	--	--	--	--	--	--	-.00213*	-.00150*	-.00135***
GDPPC	-.00002*	-.00002*	-.00001*	.00002**	-.00002*	-1.5e-6	-.00001	-7.7e-6	7.6e-7	-.00001*	-.00001*
URBAN	.00167*	.00143***	.00168*	.00037	.00187*	.00532*	.00551*	.00555*	-.00018	.00099**	.00088
AIDS	-.04471**	-.08731**	-.02204	.01243	-.02974	.12717***	.1211***	.11041	-.05473	-.01108	-.02730
GINI	-.06688	.01507	-.19326**	-.42311	-.18484***	-.44658**	-.34402	-.45870**	.22118	.09510	.08692
EXTAID	-.00094	-.00196**	-.00021	-.00106	-.00054	.00089	-.00025	-.00006	-.00224***	-.00155	-.00324**
CONS	1.02996*	1.1282*	1.0472*	.84138*	1.0697*	.76791*	.70009*	.81705*	.79193*	.78734*	.84384*
# of Obs (# of Countrs)	79 (51)	44 (30)	79 (51)	34 (20)	72 (46)	71 (45)	71 (45)	71 (45)	118 (69)	118 (69)	118 (69)
Wald Chi2(6) (Prob > Chi2)	83.91 (.00)	66.09 (.00)	46.72 (.00)	55.31 (.00)	44.27 (.00)	64.13 (.00)	45.53 (.00)	61.94 (.00)	50.83 (.00)	123.97 (.00)	35.01 (.00)

Note: * indicates significance at 0.01 level, ** at 0.05, *** at 0.10, and insignificant otherwise.

Table 20 Explaining cross-country variation in efficiency, Multiple Inputs-Multiple Outputs

Independent Variable	EDU2-2	EDU2-2n	EDU3-2	EDU3-2n	EDU3-3	EDU3-3bl	HEA2-2	HEA3-2	HEA3-2m	HEA3-3
WAGE	-.00212**	-.00767*	-.00219**	-.00425	-.001000	-.00340***	.00126*	.00205*	.00203***	.00203***
GOVEXP	-.00321*	-.00365	-.00203***	.00099	-.00123***	-.00316***	-.0012***	-.00273*	-.0009	-.00090
PUBTOT	--	--	--	--	--	--	-.00151*	-.00142*	-.00159***	-.00151***
GDPPC	-.00001**	-6.6e-7	-.00001***	-.00003	-4.2e-6	1.98e-6	-2.7e-6	4.2e-6*	-7.1e-7	-9.3e-7
URBAN	.00138***	-.00045	.00191**	.001997	.00127*	.00091	-.00095*	-.00148*	-.00106	-.00105
AIDS	-.03295	-.05843	-.00956	-.14763	.01797	.06022	-.04815*	-.033147**	-.07162	-.06999
GINI	-.06485	.43602	-.14717	.27058	-.17237**	-.15697	-.03997	-.07958***	-.01015	-.01387
EXTAID	.00010	-.00622	.00152	-.00274	-.00066	.00123	.00087	.00128***	-.00095	-.00106
CONS	1.0655*	1.0223	1.0642*	1.0124*	1.06570*	1.1218*	1.0098	1.0117*	.98891*	.98787*
# of Obs (# of Countrs)	76 (49)	34 (20)	69 (44)	32 (19)	69 (44)	63 (40)	97 (55)	98 (56)	98 (56)	98 (56)
Wald Chi2(6) (Prob > Chi2)	24.48 (.00)	11.69 (.11)	20.84 (.00)	7.44 (.38)	18.72 (.01)	9.18 (.24)	185.21 (.00)	229.98 (.00)	19.25 (.01)	18.62 (.02)

Note: * indicates significance at 0.01 level, ** at 0.05, *** at 0.10, and insignificant otherwise.
EDU2-2: Inputs: orthogonalized public spending on education per capita, teachers per pupil
Outputs: gross primary and secondary enrollments
EDU2-2n: same inputs as EDU2-2, outputs: net primary and secondary enrollment
EDU3-2: literacy of adult is added to EDU2-2 as input
EDU3-2n: literacy of adult is added to EDU2-2n as input
EDU3-3: literacy of youth is added to EDU3-2 as output
EDU3-3bl: same inputs as in EDU3-2,
Outputs: average years of school, first level complete, and second level complete (Barro-Lee education indicators)
HEA2-2: Inputs: orthogonalized public spending on health per capita, literacy of adult
Outputs: life expectancy at birth, and immunization DPT
HEA3-2: orthogonalized private spending on health per capita is added to HEA2-2 as input
HEA3-2m: Immunization Measles is in place of DPT in HEA3-2 as output
HEA3-3: Immunization Measles is added to HEA3-2 as output

Table 21 Explaining cross-country variation in efficiency, Single Input and Single output - Heterogeneous Slopes

Independent Variable	Gross Primary Enrollment	Net Primary Enrollment	Gross Secondary Enrollment	Net Secondary Enrollment	Youth Literacy	Average Years of School	First Level Complete	Secondary Level Complete	Life Expectancy	Immuni-zation DPT	Immuni-zation Measles
WAGE	-.00006	.00076	-.00035	-.00228	-.00056	-.00200	-.00120	-.00419	-.00306***	-.00079	-.00241
GOVEXP	-.00363*	-.00255***	-.00377*	-.00727***	-.00552*	-.00595***	-.00453	-.00611***	.00337**	.00168***	.00221
PUBTOT	--	--	--	--	--	--	--	--	-.00162*	-.00162*	-.00097
GDPPC	-.00002*	-.00002*	-5.4e-6	.00003*	-.00002***	.00004*	.00003***	.00003***	.00002**	-.00002*	-.00001
URBAN	.00179*	.00132**	.00193*	.00139	.00212*	.00566*	.00601*	.00593*	-.00080	-.00117*	.00021
AIDS	-.03866***	-.06603**	-.03153	.01010	-.02177	.05491	.06656	.06464	-.02321	-.04147**	-.00826
GINI	-.14230	-.42098*	-.14976	-.29395	-.13107	-.09995	-.15463	-.24762	-.12865	-.38851*	-.42162**
WAGEG	-4.4e-6***	-1.2e-6*	-4.6e-7***	-9.4e-7	-4.5e-7	-8.1e-7	-8.8e-7	-2.4e-7	8.9e-7**	6.95e-8	5.1e-7
GOVG	-8.6e-8	-5.2e-7***	4.3e-8	3.6e-7	4.0e-7	-4.3e-7	-4.4e-7	-5.3e-7	-1.4e-6*	-5.4e-7*	-9.4e-7*
GINIG	.00003	.00011*	-2.4e-6	-.00003	2.0e-6	-.00006	-.00005	-.00006	.00001	.00009*	.00006***
CONS	1.0156*	1.1036*	1.0098*	.74603*	1.0365*	.60371*	.53977*	.68648*	.82665*	1.0119*	.93820*
# of Obs (# of Countrs)	82 (52)	47 (31)	82 (52)	36 (21)	75 (47)	74 (46)	74 (46)	74 (46)	120 (70)	121 (71)	121 (71)
Wald Chi2(6) (Prob > Chi2)	87.32 (.00)	93.98 (.00)	62.74 (.00)	105.34 (.00)	58.40 (.00)	94.00 (.00)	69.32 (.00)	82.38 (.00)	74.33 (.00)	450.54 (.00)	52.71 (.00)

Note: * indicates significance at 0.01 level, ** at 0.05, *** at 0.10, and insignificant otherwise.

Table 22 Explaining cross-country variation in efficiency, Multiple Inputs and Multiple Outputs - Heterogeneous Slopes

Independent Variable	EDU 2-2	EDU 2-2n	EDU 3-2	EDU 3-2n	EDU 3-3	EDU 3-3bl	HEA 2-2	HEA 3-2	HEA 3-2m	HEA 3-3
WAGE	.00051	-.00140	.00005	.00494	-.00018	-.00045	-.00063	-.00065	-.00093	-.00092
GOVEXP	-.00323**	.00501	-.00385**	.00520	-.00256**	-.00459	.00122***	.00063	-.00070	-.00064
PUBTOT	--	--	--	--	--	--	-.00180*	-.00145**	-.00149***	-.00141***
GDPPC	-8.6e-6	.00002	1.7e-6	.00003	-1.8e-6	-2.1e-6	-.00001**	-.00001	-.00003**	-.00003**
URBAN	.00137**	.00079	.00166**	.00096	.00134*	.00064	-.00246*	-.00167***	-.00160	-.00159
AIDS	-.04139	-.06211	-.04744	-.20362*	.00646	.04633	-.06289*	-.04001	-.07217	-.07025
GINI	-.14418	-.18676	.07096	-.02601	-.07474	-.20029	-.32844*	-.45695**	-.29885	-.30857
WAGEG	-8.3e-7**	-1.2e-6	-6.4e-7***	-1.9e-6	-2.0e-7	-7.9e-7	7.8e-7*	7.2e-7	6.0e-7	6.0e-7
GOVG	-6.3e-8	-2.6e-6***	3.5e-7	-1.2e-6	3.0e-7	3.5e-7	-5.98e-7*	-4.9e-7	2.7e-8	1.4e-8
GINIG	.00003	.00012	-.00003	.00005	-.00002	.00003	.00005*	.00005***	.00006	.00006***
CONS	1.0515*	.89986*	1.0021*	.84756*	1.0464	1.1257*	1.1494*	1.1457*	1.1512*	1.1495*
# of Obs (# of Countrs)	79 (50)	36 (21)	72 (45)	34 (20)	72 (45)	66 (41)	101 (58)	101 (58)	101 (58)	101 (58)
Wald Chi2(6) (Prob > Chi2)	41.93 (.00)	18.57 (.03)	31.15 (.00)	18.71 (.22)	23.89 (.00)	13.22 (.15)	600.70 (.00)	37.22 (.00)	25.33 (.00)	24.74 (.01)

Note:

1. Note: * indicates significance at 0.01 level, ** at 0.05, *** at 0.10, and insignificant otherwise.
2. EDU2-2: Inputs: orthogonalized public spending on education per capita, teachers per pupil
   Outputs: gross primary and secondary enrollments
   EDU2-2n: same inputs as EDU2-2, outputs: net primary and secondary enrollment
   EDU3-2: literacy of adult is added to EDU2-2 as input
   EDU3-2n: literacy of adult is added to EDU2-2n as input
   EDU3-3: literacy of youth is added to EDU3-2 as output
   EDU3-3bl: same inputs as in EDU3-2,
   Outputs: average years of school, first level complete, and second level complete (Barro-Lee education indicators)
   HEA2-2: Inputs: orthogonalized public spending on health per capita, literacy of adult
   Outputs: life expectancy at birth, and immunization DPT
   HEA3-2: orthogonalized private spending on health per capita is added to HEA2-2 as input
   HEA3-2m: Immunization Measles is in place of DPT in HEA3-2 as output
   HEA3-3: Immunization Measles is added to HEA3-2 as output

Appendix 2.A. Data Envelopment Analysis (DEA)[37]

A measure of production efficiency, perhaps the simplest one, is defined as the ratio of output to input. It is, however, inadequate to deal with the existence of multiple inputs and outputs. The relative efficiency for all decision-making units (DMUs), $j=1,\ldots,n$, is then modified as the ratio of weighted outputs to weighted inputs, as proposed by Farrell (1957), more precisely,

$$\textit{Relative efficiency} = \frac{\sum_{r=1}^{s} u_r y_{rj}}{\sum_{i=1}^{m} v_i x_{ij}} \qquad \text{(A.1)}$$

where x and y are inputs and outputs, respectively, and u and v are the common weights assigned to outputs and inputs, respectively. A challenge to this measure immediately follows: it is difficult to justify the common weights given that DMUs may value inputs and outputs differently.

The seminal paper by Charnes, Cooper and Rhodes (1978) proposes the following ratio form to allow for difference in weights across DMUs, which establishes the foundation of data envelopment analysis (DEA).

$$\begin{aligned}
&\mathit{M}\text{ax} \quad h_0 = \frac{\sum_{r=1}^{s} \mu_r y_{r0}}{\sum_{i=1}^{m} v_i x_{i0}} \\
&\textit{subject to}: \\
&\qquad \frac{\sum_{r=1}^{s} \mu_r y_{rj}}{\sum_{i=1}^{m} v_i x_{ij}} \le 1, \quad j = 1,\cdots,n \\
&\qquad \mu_r \ge \varepsilon, \quad r = 1,\cdots,s \\
&\qquad v_i \ge \varepsilon, \quad i = 1,\cdots,m \\
&\qquad \varepsilon > 0
\end{aligned} \qquad \text{(A.2)}$$

[37] For more technical expositions, see Farrell (1957), Charnes, Cooper and Rhodes (1978), Coelli (1996), Bowlin (1998), and Murillo-Zamorano (2004).

In the model, there are $j=1,\ldots, n$ observed DMUs which employ $i=1,\ldots, m$ inputs to produce $r=1,\ldots, s$ outputs. One DMU is singled out each time, designated as DMU_0, to be evaluated against the observed performance of all DMUs. The objective of model (A.2) is to find the most favorable weights, μ_r and v_i, for DMU_0 to maximize the relative efficiency. The constraints are that the weights will make ratio for every DMU be less than or equal to unity. The solution value of the ratio must be $0 \le h_0^* \le 1$. DMU_0 is efficient if and only if $h_0^* = 1$, otherwise it is considered as relatively inefficient. One problem with the ratio formulation is that there are an infinite number of solutions: if μ_r and v_i are solutions to (A.2), so are $\alpha\mu_r$ and αv_i, $\forall \alpha > 0$.

It is worth observing one important feature of model (A.2): in maximizing the objective function, it is the relative magnitude of the numerator and the denominator that really matters and not their particular values. It is thus equivalent to setting the denominator to a constant, say 1, and maximizing the numerator. This transformation will not only lead to the uniqueness of solution but also convert the fractional formulation of model (A.2) into a linear programming problem in model (A.3).

$$
\begin{aligned}
&Max \quad \sum_{r=1}^{s} \mu_r y_{r0} \\
&\textit{subject to}: \\
&\qquad \sum_{i=1}^{m} v_i x_{i0} = 1 \\
&\qquad \sum_{r=1}^{s} \mu_r y_{rj} - \sum_{i=1}^{m} v_i x_{ij} \le 0, \quad j = 1,\cdots,n \\
&\qquad -\mu_r \le -\varepsilon, \quad r = 1,\cdots,s \\
&\qquad -v_i \le -\varepsilon, \quad i = 1,\cdots,m
\end{aligned}
\qquad (A.3)
$$

Model (A.3) facilitates straightforward interpretation in terms of economics. The objective is now to maximize the weighted output per unit weighted input under various conditions, the most critical one of which is that the virtual output does not exceed the virtual input for any DMU. The optimal value of $\sum_{r=1}^{s} \mu_r^* y_{r0}$ indicates the efficiency of DMU_0. Since model (A.3) is a linear programming, one may convert the maximization problem into a minimization problem, e.g. a *dual* problem, by assigning a dual variable to each constraint in the *primal* (A.3). Specifically, dual variables $\theta, \lambda_j, \eta_r, \gamma_i$ are assigned as follows.

		Dual Variable	
Max	$\sum_{r=1}^{s} \mu_r y_{r0}$		
$subject\ to:$			
	$\sum_{i=1}^{m} v_i x_{i0} = 1$	θ	(A.3')
	$\sum_{r=1}^{s} \mu_r y_{rj} - \sum_{i=1}^{m} v_i x_{ij} \le 0, \quad j = 1, \cdots, n$	λ_j	
	$-\mu_r \le -\varepsilon, \quad r = 1, \cdots, s$	η_r	
	$-v_i \le -\varepsilon, \quad i = 1, \cdots, m$	γ_i	

A *dual* minimization problem is thus derived as model (A.4). It is clear that model (A.4) has $m+s$ constraints while model (A.3) has $n+m+s+1$ constraints. Since n (the number of DMUs) is usually considerably larger than $m+s$ (number of inputs and outputs), the dual DEA significantly reduces the computational burden and is easier to solve than the primal.

$$
\begin{aligned}
&Min && \theta - \varepsilon\left[\sum_{i=1}^{m}\gamma_i + \sum_{r=1}^{s}\eta_r\right] \\
&subject\ \ to: && \\
& && \theta x_{i0} - \sum_{j=1}^{n} x_{ij}\lambda_{\mathrm{j}} - \gamma_i = 0 \\
& && y_{r0} = \sum_{j=1}^{n} y_{rj}\lambda_j - \eta_r \\
& && \lambda_j \geq 0,\ \ \eta_r \geq 0,\ \ \gamma_i \geq 0 \\
& && i = 1,\cdots,m,\ \ r = 1,\cdots,s,\ \ \ j = 1,\cdots,n
\end{aligned} \tag{A.4}
$$

More importantly, the duality theorem of linear programming states that the solution value to the objective function in (A.4) is exactly equal to that in (A.3). And, the dual variables, $(\lambda_1, \lambda_2, \cdots, \lambda_n)$, have the interpretation of Lagrange multipliers. That is, the value of a dual variable is equal to the shadow price of Lagrange Multiplier. It is also known that, from standard constrained optimization problem, generally $\lambda_j > 0$ when the constraint in (A.3') is binding and $\lambda_j = 0$ if not. Note that the binding constraint in (A.3) implies that the corresponding DMU is efficient. In another word, efficient units are identified by positive $\lambda's$ while inefficient units are given $\lambda's$ of zero. The DMU in question in model (A.4) is thus compared with the efficient DMUs only, named as comparison *peers* in the literature. The solution values of $\lambda's$ reflect the exact weights assigned to each peer in the evaluation of DMU_0.

Since only efficient DMUs exert effective constraints in model (A.4), as argued above, the input-output bundle, $(\sum_{j=1}^{n} x_{ij}\lambda_j, \sum_{j=}^{n} y_{rj}\lambda_j)$, $i = 1,\cdots,m$ and $r = 1,\cdots,s$, is the most efficient combination for. To achieve an output level y_{r0}, which is as close as possible to $\sum_{j=}^{n} y_{rj}\lambda_j$, DMU_0 has to use an input bundle to meet the minimum requirement,

$\sum_{j=1}^{n} x_{ij}\lambda_j$. This further implies that the solution θ^* is the lowest proportion of the current input bundle, x_{i0} used by DMU$_0$, which is actually required to meet the minimum input requirement and produce target output y_{r0} . The solution θ^* is defined as the efficiency score for DMU$_0$. For instance, $\theta^* = 0.60$ implies that 40 percent of current input is a waste of resources.

Model (A.4) also offers the explanation why the data envelopment analysis is so named. The first constraint in (A.4) defines a lower limit of inputs and the second constraint an upper limit of outputs for DMU$_0$, and within the limits θ is minimized. The set of solutions to all DMUs forms an upper bound that envelops all observations.

Appendix 2.B Productivity Change Over Time[38]

Variations of input-output bundles between time periods may be due to efficiency change and/or technological change. The decomposition can be made by means of Malmquist indexes, which are defined using distance functions. These functions describe multi-input multi-output production technologies based on input and output quantity without price information or behavioral assumptions (i.e., cost minimization or profit maximization). The distance functions can be either output based or input based. As an illustration, the output distance function can be defined for any production technology S^t as the reciprocal of the maximum proportional expansion of the output vector y, given inputs x.

$$D_o^t(x^t, y^t) = \inf\left(\lambda : (x^t, y^t/\lambda) \in S^t\right) = \left[\sup(\lambda : (x^t, \lambda y^t) \in S^t)\right]^{-1} \qquad \text{(B.1)}$$

If $(x^t, y^t) \in S^t$, then $D_o \leq 1$ and $D_o = 1$ if and only if (x^t, y^t) is on the boundary or frontier of technology. The distance function is the reciprocal of the output efficiency measure defined by Farrell (1957).

In Figure 2.B. 1, the frontier of the transformation set is defined by (B_t, C_t) in period t and by (B_{t+1}, C_{t+1}) in period $t+1$. The distance of country A from the country B in period t, which is a measure of how far the production point A is from the frontier, can be expressed as $D^t(x^t, y^t) = OA_t / OB_t$. Similarly, the distance between the production point A_{t+1} and the frontier in period t+1 is defined as $D^{t+1}(x^{t+1}, y^{t+1}) = OA_{t+1} / OB_{t+1}$.

[38] For more expositions of productivity change, see Farrell (1957), Fare *et al* (1994), Nin, Arndt and Preckel (2003), and Coelli and Rao (2003).

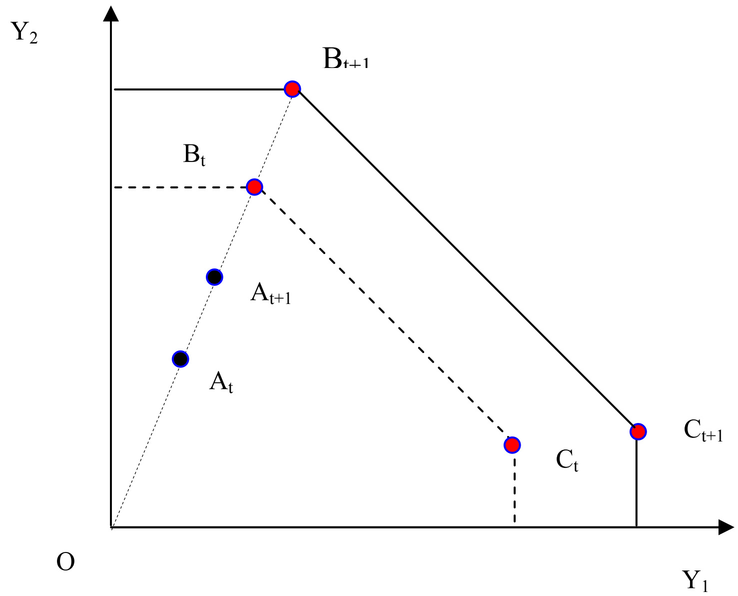


Figure 2.B. 1 Output Possibility Set, periods t and t+1

The Malmquist index requires the definition of a distance function with respect to two different time periods (t and t+1). The distance measures the maximum change in outputs required to make (x^{t+1}, y^{t+1}) feasible in relation to technology at t, and is defined as $D^t(x^{t+1}, y^{t+1}) = OA_{t+1} / OB_t$. Alternatively, the distance function could be defined as the change in output required to make (x^t, y^t) feasible in relation to technology at t+1. This would be defined as $D^{t+1}(x^t, y^t) = OA_t / OB_{t+1}$. Hence the Malmquist productivity index is defined as the ratio of two distances, which can be computed in relation with technology at t or at t+1. The period t-based and period (t+1)-based Malmquist indices are defined, respectively, as

$$M_0^t = \frac{D^t(x^{t+1}, y^{t+1})}{D^t(x^t, y^t)} \qquad \text{(B.2)}$$

$$M_0^{t+1} = \frac{D^{t+1}(x^{t+1}, y^{t+1})}{D^{t+1}(x^t, y^t)} \qquad \text{(B.3)}$$

One possible case in reality is that the frontier shift is not parallel in all dimensions, as indicated in Figure 2.B. 2. Country B in period t+1 is producing more y_1 and less y_2 compared to the production point in period t. In another word, country B is not expanding along the same ray through the origin, but rather biased in some direction, as pointed by Nin, Arndt, and Preckel (2003). In this case, the output-oriented, period t-based Malmquist index will yield an estimate of productivity decrease due to technical regress from B_t to M, while the period (t+1)-based Malmquist will show the opposite due to technical progress from N to B_{t+1}.

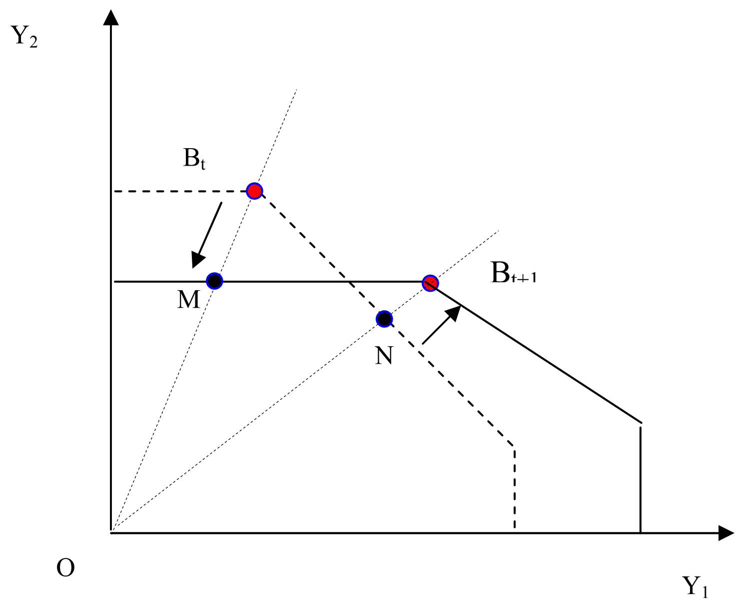


Figure 2.B. 2 Contemporaneous Production Set (Biased Technical Change)

To avoid arbitrary selection of base period mentioned above, the geometric average of both is suggested (Fare, *et al*, 1994):

$$M_0(x^{t+1}, y^{t+1}, x^t, y^t) = \left[\frac{D^t(x^{t+1}, y^{t+1})}{D^t(x^t, y^t)} \frac{D^{t+1}(x^{t+1}, y^{t+1})}{D^{t+1}(x^t, y^t)}\right]^{1/2} \qquad \text{(B.4)}$$

This expression can be rewritten as:

$$M_0(x^{t+1}, y^{t+1}, x^t, y^t) = \frac{D^{t+1}(x^{t+1}, y^{t+1})}{D^t(x^t, y^t)} \left[\frac{D^t(x^{t+1}, y^{t+1})}{D^{t+1}(x^{t+1}, y^{t+1})} \frac{D^t(x^t, y^t)}{D^{t+1}(x^t, y^t)} \right]^{1/2} \qquad \text{(B.5)}$$

The ratio outside the brackets captures the change in relative efficiency between the two time periods. The term in the brackets captures the technological shift between the two periods. This expression is the basis of the empirical application in this chapter, following Coelli and Rao (2003).

An alternative approach to dealing with the biased technical change is to define a sequential production set, as proposed by Nin, Arndt, and Preckel (2003). Specifically, it is assumed that the input-output mix, or technology, in period t is always available in period t+1. The production possibility set, the sequential one, in period t+1 is then defined by the frontier (B_t, B_{t+1}) in Figure 2.B. 3. This setup will clearly rule out the possibility of technical regress and give lower efficiency change than otherwise.

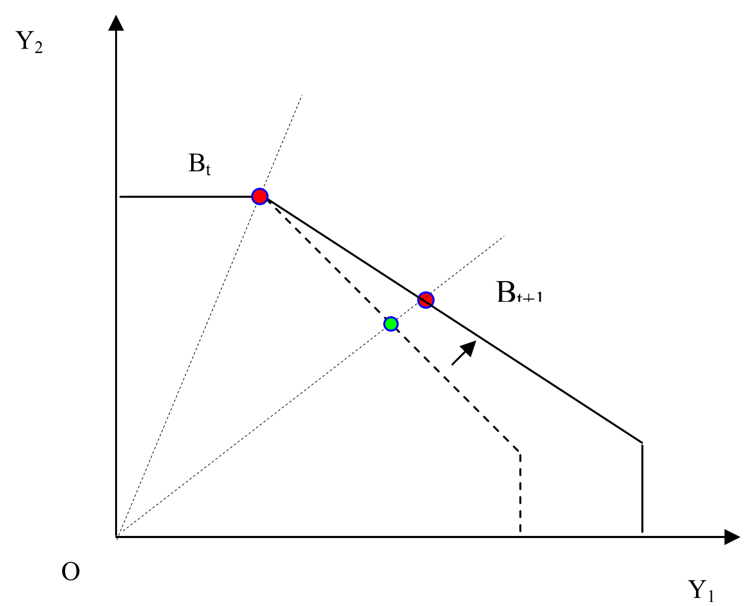


Figure 2.B. 3 Sequential Production Set (Biased Technical Change)

Appendix 2.C List of Countries and Variables Table 2.C.1 List of Countries

Code	Region	Country	Code	Region	Country	Code	Region	Country
AGO	AFR	Angola	GMB	AFR	Gambia, The	OMN	MNA	Oman
ALB	ECA	Albania	GNB	AFR	Guinea-Bissau	PAK	SAS	Pakistan
ARE	MNA	United Arab Emirates	GRD	LAC	Grenada	PAN	LAC	Panama
ARG	LAC	Argentina	GTM	LAC	Guatemala	PER	LAC	Peru
ARM	ECA	Armenia	GUY	LAC	Guyana	PHL	EAP	Philippines
ATG	LAC	Antigua & Barbuda	HND	LAC	Honduras	PNG	EAP	Papua New Guinea
AZE	ECA	Azerbaijan	HRV	ECA	Croatia	POL	ECA	Poland
BDI	AFR	Burundi	HTI	LAC	Haiti	PRY	LAC	Paraguay
BEN	AFR	Benin	HUN	ECA	Hungary	ROM	ECA	Romania
BFA	AFR	Burkina Faso	IDN	EAP	Indonesia	RUS	ECA	Russian Fed.
BGD	SAS	Bangladesh	IND	SAS	India	RWA	AFR	Rwanda
BGR	ECA	Bulgaria	IRN	MNA	Iran	SAU	MNA	Saudi Arabia
BHR	MNA	Bahrain	JAM	LAC	Jamaica	SDN	AFR	Sudan
BHS	LAC	Bahamas, The	JOR	MNA	Jordan	SEN	AFR	Senegal
BLR	ECA	Belarus	KAZ	ECA	Kazakhstan	SLB	EAP	Solomon Islands
BLZ	LAC	Belize	KEN	AFR	Kenya	SLE	AFR	Sierra Leone
BOL	LAC	Bolivia	KGZ	ECA	Kyrgyz Republic	SLV	LAC	El Salvador
BRA	LAC	Brazil	KHM	EAP	Cambodia	SVK	ECA	Slovak Republic
BRB	LAC	Barbados	KNA	LAC	St. Kitts & Nevis	SVN	ECA	Slovenia
BWA	AFR	Botswana	KOR	EAP	Korea, Rep.	SWZ	AFR	Swaziland
CAF	AFR	Central African Rep.	KWT	MNA	Kuwait	SYR	MNA	Syrian Arab Rep.
CHL	LAC	Chile	LAO	EAP	Lao PDR	TCD	AFR	Chad
CHN	EAP	China	LBN	MNA	Lebanon	TGO	AFR	Togo
CIV	AFR	Cote d'Ivoire	LCA	LAC	St. Lucia	THA	EAP	Thailand
CMR	AFR	Cameroon	LKA	SAS	Sri Lanka	TJK	ECA	Tajikistan
COG	AFR	Congo, Rep.	LSO	AFR	Lesotho	TKM	ECA	Turkmenistan
COL	LAC	Colombia	LTU	ECA	Lithuania	TON	EAP	Tonga
COM	AFR	Comoros	LVA	ECA	Latvia	TTO	LAC	Trinidad &Tobago
CPV	AFR	Cape Verde	MAR	MNA	Morocco	TUN	MNA	Tunisia
CRI	LAC	Costa Rica	MDA	ECA	Moldova	TUR	ECA	Turkey
CZE	ECA	Czech Republic	MDG	AFR	Madagascar	TZA	AFR	Tanzania
DJI	MNA	Djibouti	MEX	LAC	Mexico	UGA	AFR	Uganda
DMA	LAC	Dominica	MKD	ECA	Macedonia	UKR	ECA	Ukraine
DOM	LAC	Dominican Republic	MLI	AFR	Mali	URY	LAC	Uruguay
DZA	MNA	Algeria	MNG	EAP	Mongolia	UZB	ECA	Uzbekistan
ECU	LAC	Ecuador	MOZ	AFR	Mozambique	VCT	LAC	St. Vincent
EGY	MNA	Egypt, Arab Rep.	MRT	AFR	Mauritania	VEN	LAC	Venezuela, RB
ERI	AFR	Eritrea	MUS	AFR	Mauritius	VNM	EAP	Vietnam
EST	ECA	Estonia	MWI	AFR	Malawi	VUT	EAP	Vanuatu
ETH	AFR	Ethiopia	MYS	EAP	Malaysia	WSM	EAP	Samoa
FJI	EAP	Fiji	NAM	AFR	Namibia	YEM	MNA	Yemen, Rep.
GAB	AFR	Gabon	NER	AFR	Niger	ZAF	AFR	South Africa
GEO	ECA	Georgia	NGA	AFR	Nigeria	ZAR	AFR	Congo, Dem. Rep.
GHA	AFR	Ghana	NIC	LAC	Nicaragua	ZMB	AFR	Zambia
GIN	AFR	Guinea	NPL	SAS	Nepal	ZWE	AFR	Zimbabwe

Table 2.C.2 Definition and Source of Variables

Definition of Variable	Source
Output variables for education	
School enrollment, primary (% gross)	World Bank WDI
School enrollment, primary (% net)	World Bank WDI
School enrollment, secondary (% gross)	World Bank WDI
School enrollment, secondary (% net)	World Bank WDI
Literacy rate, youth total (% of people ages 15-24)	World Bank WDI
Average years of school, ages 15+	Barro-Lee Database
First level complete, ages 15+	Barro-Lee Database
Second level complete, ages 15+	Barro-Lee Database
Learning scores	Crouch and Fasih (2004)
Input variables for education	
Public education spending per capita in PPP terms, calculated	World Bank WDI
Literacy rate, adult total (% of people ages 15 and above)	World Bank WDI
Teachers per pupil, equal the reciprocal of pupils per teacher	World Bank WDI
Output variables for health	
Life expectancy at birth, total (years)	World Bank WDI
Immunization, DPT (% of children ages 12-23 months)	World Bank WDI
Immunization, measles (% of children ages 12-23 months)	World Bank WDI
Disability Adjusted Life Expectancy	Mathers et al (2000)
Input variables for health	
Literacy rate, adult total (% of people ages 15 and above)	World Bank WDI
Public spending on health per capita in PPP terms, calculated	World Bank WDI
Public spending on health per capita in PPP terms, calculated	World Bank WDI
Variables used in the calculation	World Bank WDI
Pupil-teacher ratio, primary	World Bank WDI
Public spending on education, total (% of GDP)	World Bank WDI
GDP per capita, PPP (constant 1995 international $)	World Bank WDI
Health expenditure, private (% of GDP)	World Bank WDI
Health expenditure, public (% of GDP)	World Bank WDI
Variables used in the Panel Tobit regression	
Wages and salaries (% of total public expenditure)	World Bank WDI
Total government expenditure (% of GDP)	World Bank WDI
Share of expenditures publicly financed (public/total)	World Bank WDI
GDP per capita in constant 1995 US dollars	World Bank WDI
Urban population (% of total)	World Bank WDI
Dummy variable for HIV/AIDS	WHO mappings of diseases
Gini Coefficient	World Bank WDI
Aid (% of fiscal revenue) calculated as Official development assistance and official aid (current US$) *official exchange rate * PPP conversion factor / Revenue, excluding grants (current LCU)	World Bank WDI
Institutional Indicators including a. State Failure data b. ICRG International Country Risk Indicators c. Worldwide Governance Research Indicators	a. The State Failure Task Force b. ICRG Online Website c. Kaufmann, *et al*. 1999a,b and 2002

Appendix 2.D. Efficiency Scores and Frontiers

Table 2.D.1 Efficiency Score for Selected Education Indicators

	Primary School Enrollment				Secondary School Enrollment			
	Input Efficiency		*Output Efficiency*		*Input Efficiency*		*Output Efficiency*	
Country	FDH	DEA	FDH	DEA	FDH	DEA	FDH	DEA
AGO	0.702	0.702	0.502	0.490	0.702	0.702	0.157	0.132
ARG	0.813	0.761	0.838	0.838	0.726	0.651	0.922	0.711
ARM	0.707	0.707	0.703	0.690	0.707	0.707	0.883	0.746
AZE	0.709	0.690	0.729	0.695	0.682	0.682	0.793	0.650
BDI	0.665	0.665	0.410	0.410	0.665	0.665	0.087	0.070
BEN	0.678	0.678	0.668	0.635	0.678	0.678	0.217	0.177
BFA	0.700	0.700	0.324	0.315	0.700	0.700	0.098	0.082
BGD	0.727	0.702	0.722	0.702	0.699	0.699	0.404	0.338
BGR	0.883	0.807	0.857	0.809	0.769	0.769	0.932	0.809
BHR	0.999	0.907	0.915	0.901	0.999	0.941	0.998	0.954
BHS	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
BLR	0.692	0.663	0.766	0.766	0.603	0.603	0.667	0.667
BLZ	0.747	0.707	0.846	0.846	0.581	0.581	0.496	0.496
BOL	0.732	0.712	0.794	0.794	0.626	0.626	0.549	0.549
BRA	1.000	1.000	1.000	1.000	0.779	0.709	0.932	0.761
BRB	0.460	0.433	0.752	0.752	0.636	0.472	0.786	0.786
BWA	0.494	0.463	0.747	0.747	0.430	0.430	0.551	0.551
CAF	0.697	0.697	0.500	0.485	0.697	0.697	0.097	0.081
CHL	0.842	0.776	0.866	0.782	0.733	0.733	0.813	0.707
CHN	1.000	0.949	1.000	0.953	0.778	0.778	0.693	0.607
CIV	0.656	0.656	0.538	0.538	0.656	0.656	0.234	0.186
CMR	0.699	0.699	0.708	0.689	0.699	0.699	0.284	0.238
COG	0.715	0.715	0.607	0.601	0.715	0.715	0.423	0.361
COL	0.768	0.754	0.801	0.801	0.657	0.657	0.692	0.550
COM	0.668	0.668	0.585	0.585	0.668	0.668	0.251	0.202
CPV	0.910	0.902	0.942	0.942	0.659	0.659	0.620	0.495
CRI	0.703	0.670	0.761	0.761	0.612	0.612	0.426	0.426
CZE	0.719	0.670	0.743	0.743	0.626	0.626	0.680	0.680
DJI	0.680	0.680	0.292	0.278	0.680	0.680	0.170	0.139
DMA	0.561	0.556	0.710	0.710	0.620	0.550	0.702	0.702
DOM	1.000	1.000	1.000	1.000	0.856	0.856	0.609	0.574
DZA	0.723	0.698	0.772	0.772	0.629	0.629	0.519	0.519
ERI	0.671	0.671	0.404	0.404	0.671	0.671	0.251	0.203
EST	0.478	0.476	0.717	0.717	0.731	0.586	0.835	0.835
ETH	0.661	0.661	0.383	0.383	0.661	0.661	0.156	0.125
FJI	0.741	0.690	0.835	0.835	0.577	0.577	0.596	0.596
GAB	1.000	1.000	1.000	1.000	0.724	0.724	0.487	0.419
GEO	0.711	0.711	0.708	0.697	0.711	0.711	0.763	0.647
GHA	0.666	0.666	0.564	0.564	0.666	0.666	0.363	0.292
GIN	0.726	0.726	0.507	0.469	0.726	0.726	0.136	0.118
GMB	0.677	0.677	0.566	0.566	0.677	0.677	0.320	0.261
GNB	0.686	0.686	0.516	0.495	0.686	0.686	0.145	0.120

Table 2.D.1 (continued)

	Primary School Enrollment				Secondary School Enrollment			
	Input Efficiency		Output Efficiency		Input Efficiency		Output Efficiency	
Country	FDH	DEA	FDH	DEA	FDH	DEA	FDH	DEA
GRD	0.651	0.651	0.678	0.678	0.651	0.651	0.633	0.500
GTM	0.857	0.829	0.840	0.812	0.824	0.824	0.324	0.297
GUY	0.758	0.740	0.796	0.796	0.649	0.649	0.826	0.650
HND	0.762	0.731	0.767	0.767	0.663	0.663	0.323	0.259
HRV	0.657	0.657	0.669	0.669	0.657	0.657	0.878	0.699
HUN	0.696	0.642	0.735	0.735	0.826	0.681	0.757	0.757
IDN	0.913	0.900	0.966	0.904	0.795	0.795	0.593	0.528
IND	0.709	0.702	0.747	0.713	0.682	0.682	0.478	0.392
IRN	0.625	0.625	0.677	0.677	0.625	0.625	0.634	0.634
JAM	0.599	0.591	0.708	0.708	0.576	0.576	0.622	0.622
JOR	0.583	0.583	0.679	0.679	0.583	0.583	0.613	0.613
KAZ	0.708	0.687	0.726	0.692	0.681	0.681	0.894	0.733
KEN	0.631	0.631	0.643	0.643	0.631	0.631	0.296	0.228
KGZ	0.775	0.713	0.733	0.733	0.675	0.675	0.843	0.686
KHM	0.827	0.809	0.824	0.821	0.720	0.720	0.212	0.182
KNA	0.809	0.759	0.840	0.840	1.000	1.000	1.000	1.000
KOR	0.762	0.741	0.815	0.736	1.000	0.839	1.000	0.870
KWT	0.406	0.406	0.645	0.645	0.406	0.406	0.666	0.666
LAO	0.897	0.817	0.861	0.837	0.698	0.698	0.347	0.291
LBN	0.880	0.840	0.900	0.846	0.766	0.766	0.840	0.726
LCA	0.573	0.565	0.805	0.805	0.490	0.490	0.642	0.642
LKA	0.852	0.835	0.926	0.845	0.742	0.742	0.808	0.681
LSO	0.602	0.594	0.807	0.807	0.515	0.515	0.248	0.248
LTU	0.710	0.647	0.725	0.725	0.710	0.654	0.722	0.722
LVA	0.548	0.541	0.707	0.707	0.527	0.527	0.684	0.684
MAC	1.000	1.000	1.000	1.000	0.962	0.962	0.889	0.863
MAR	0.628	0.628	0.679	0.679	0.628	0.628	0.304	0.304
MDA	0.613	0.613	0.626	0.626	0.613	0.613	0.572	0.572
MDG	0.708	0.697	0.742	0.707	0.680	0.680	0.152	0.124
MEX	0.752	0.740	0.802	0.802	0.644	0.644	0.700	0.548
MKD	0.766	0.694	0.722	0.722	0.667	0.667	0.798	0.643
MLI	0.679	0.679	0.382	0.363	0.679	0.679	0.128	0.104
MNG	0.655	0.634	0.688	0.688	0.630	0.630	0.647	0.497
MOZ	0.682	0.682	0.629	0.601	0.682	0.682	0.108	0.088
MRT	0.677	0.677	0.603	0.603	0.677	0.677	0.197	0.161
MUS	0.792	0.759	0.806	0.776	0.690	0.690	0.738	0.611
MWI	0.911	0.901	0.941	0.941	0.660	0.660	0.175	0.140
MYS	0.530	0.523	0.707	0.707	0.509	0.509	0.526	0.526
NAM	0.572	0.531	0.832	0.832	0.446	0.446	0.469	0.469
NER	0.680	0.680	0.249	0.237	0.680	0.680	0.067	0.055
NIC	0.773	0.712	0.734	0.734	0.673	0.673	0.526	0.427
NPL	0.871	0.807	0.830	0.830	0.678	0.678	0.401	0.328
OMN	0.742	0.742	0.692	0.632	0.742	0.742	0.763	0.643

Table 2.D.1 (continued)

	Primary School Enrollment				Secondary School Enrollment			
	Input Efficiency		Output Efficiency		Input Efficiency		Output Efficiency	
Country	FDH	DEA	FDH	DEA	FDH	DEA	FDH	DEA
PAK	0.712	0.712	0.528	0.522	0.712	0.712	0.261	0.222
PAN	0.701	0.678	0.774	0.774	0.610	0.610	0.527	0.527
PER	1.000	0.919	1.000	0.926	0.727	0.727	0.775	0.670
PHL	0.890	0.810	0.860	0.831	0.692	0.692	0.789	0.655
PNG	0.732	0.732	0.654	0.590	0.732	0.732	0.205	0.178
POL	0.554	0.549	0.710	0.710	0.727	0.608	0.766	0.766
PRY	0.747	0.732	0.800	0.800	0.639	0.639	0.555	0.432
ROM	0.821	0.758	0.774	0.767	0.715	0.715	0.806	0.687
RUS	0.852	0.837	0.945	0.849	0.729	0.729	0.875	0.758
RWA	0.800	0.792	0.851	0.815	0.685	0.685	0.130	0.107
SAU	0.414	0.414	0.504	0.504	0.414	0.414	0.519	0.519
SDN	0.616	0.616	0.398	0.398	0.616	0.616	0.220	0.220
SEN	0.663	0.663	0.513	0.513	0.663	0.663	0.171	0.137
SLB	0.708	0.690	0.731	0.696	0.680	0.680	0.181	0.148
SLE	0.684	0.684	0.492	0.470	0.684	0.684	0.167	0.137
SLV	0.902	0.858	0.930	0.861	0.785	0.785	0.518	0.457
SVK	0.752	0.692	0.733	0.733	0.655	0.655	0.881	0.699
SWZ	0.666	0.642	0.771	0.771	0.580	0.580	0.387	0.387
SYR	0.792	0.748	0.794	0.764	0.690	0.690	0.428	0.354
TCD	0.686	0.686	0.510	0.489	0.686	0.686	0.107	0.088
TGO	0.901	0.834	0.885	0.885	0.653	0.653	0.328	0.259
THA	0.605	0.605	0.667	0.667	0.605	0.605	0.513	0.513
TJK	0.784	0.724	0.775	0.740	0.683	0.683	0.790	0.649
TON	0.675	0.662	0.801	0.801	0.788	0.659	0.766	0.766
TTO	0.810	0.743	0.769	0.753	0.705	0.705	0.785	0.662
TUN	0.643	0.590	0.824	0.824	0.500	0.500	0.565	0.565
TUR	0.746	0.725	0.728	0.723	0.717	0.717	0.677	0.579
TZA	0.676	0.676	0.467	0.467	0.676	0.676	0.059	0.048
UGA	0.949	0.869	0.921	0.886	0.690	0.690	0.129	0.107
UKR	0.659	0.659	0.585	0.585	0.899	0.724	0.968	0.772
URY	1.000	0.986	1.000	0.985	1.000	0.945	1.000	0.957
UZB	0.612	0.612	0.655	0.655	0.835	0.678	0.748	0.748
VCT	0.581	0.532	0.728	0.728	0.506	0.506	0.548	0.548
VNM	0.813	0.794	0.823	0.808	0.708	0.708	0.638	0.540
VUT	0.603	0.578	0.766	0.766	0.525	0.525	0.203	0.203
WSM	0.675	0.671	0.716	0.716	0.649	0.649	0.729	0.574
YEM	0.627	0.627	0.544	0.544	0.627	0.627	0.324	0.324
ZAF	0.621	0.577	0.833	0.833	0.555	0.484	0.693	0.693
ZMB	0.682	0.682	0.610	0.582	0.682	0.682	0.259	0.212
ZWE	0.549	0.510	0.741	0.741	0.478	0.478	0.344	0.344

Table 2.D.2 Efficiency Score for Selected Education Indicator - Learning scores – Excluding Developed Countries

Code	Learning Score	Input Efficiency FDH	Input Efficiency DEA	Output Efficiency FDH	Output Efficiency DEA	Code	Learning Score	Input Efficiency FDH	Input Efficiency DEA	Output Efficiency FDH	Output Efficiency DEA
HUN	542	1.000	1.000	1.000	1.000	HND	396	0.294	0.294	0.731	0.731
SVK	535	1.000	1.000	1.000	1.000	PER	392	0.525	0.525	0.742	0.733
CZE	530	0.972	0.800	0.991	0.990	VUT	375	0.152	0.152	0.692	0.692
RUS	528	1.000	1.000	1.000	1.000	KEN	349	0.232	0.232	0.644	0.644
BGR	515	1.000	1.000	1.000	1.000	PHL	345	0.382	0.382	0.645	0.639
MYS	506	0.169	0.169	0.934	0.934	MUS	342	0.606	0.606	0.648	0.644
LVA	504	0.178	0.177	0.930	0.930	BLZ	335	0.216	0.216	0.618	0.618
POL	504	0.198	0.198	0.930	0.930	MAR	334	0.255	0.255	0.616	0.616
LTU	485	0.321	0.319	0.895	0.895	ZWE	331	0.122	0.122	0.611	0.611
THA	475	0.265	0.262	0.876	0.876	TZA	329	0.282	0.282	0.607	0.607
ROM	472	0.552	0.547	0.894	0.884	CMR	322	0.345	0.345	0.594	0.594
MDA	464	0.220	0.218	0.856	0.856	MOZ	318	0.297	0.297	0.587	0.587
MEX	455	0.382	0.377	0.850	0.842	SWZ	317	0.206	0.206	0.585	0.585
TTO	454	0.652	0.644	0.860	0.857	MDG	315	0.293	0.293	0.581	0.581
MKD	453	0.386	0.381	0.847	0.838	UGA	309	0.315	0.315	0.570	0.570
JOR	439	0.211	0.208	0.810	0.810	BWA	288	0.107	0.107	0.531	0.531
TUN	437	0.150	0.148	0.806	0.806	BFA	277	0.329	0.329	0.511	0.511
IRN	435	0.289	0.284	0.803	0.803	CIV	269	0.269	0.269	0.496	0.496
ARG	432	0.456	0.449	0.807	0.804	ZAF	261	0.149	0.149	0.482	0.482
TUR	431	0.565	0.556	0.816	0.809	MLI	233	0.291	0.291	0.430	0.430
BRA	428	0.456	0.448	0.800	0.797	NAM	232	0.113	0.113	0.428	0.428
IDN	419	0.826	0.811	0.814	0.804	LSO	230	0.142	0.142	0.424	0.424
CHL	407	1.000	1.000	1.000	1.000	ZMB	228	0.295	0.295	0.421	0.421
PRY	406	0.288	0.288	0.749	0.749	SEN	223	0.277	0.277	0.411	0.411
BOL	405	0.239	0.239	0.747	0.747	MWI	207	0.261	0.261	0.382	0.382
COL	400	0.354	0.354	0.748	0.739	NER	173	0.292	0.292	0.319	0.319
KWT	398	0.114	0.114	0.734	0.734						

Note: Learning scores are from Table 1.2. in Crouch and Fasih (2004). Sorted by learning scores.

Table 2.D.3. Efficiency Score for Selected Education Indicator - Learning scores – Including Developed Countries

Code	Learning Scores	Input efficiency FDH	Input efficiency DEA	Output efficiency FDH	Output efficiency DEA	Code	Learning Scores	Input efficiency FDH	Input efficiency DEA	Output efficiency FDH	Output efficiency DEA
NLD	543	1.000	1.000	1.000	1.000	IRN	435	0.747	0.747	0.801	0.801
HUN	542	0.918	0.916	0.998	0.998	ARG	432	0.814	0.814	0.796	0.796
SVK	535	0.956	0.936	0.985	0.985	TUR	431	0.806	0.806	0.794	0.794
AUS	533	0.987	0.961	0.982	0.982	BRA	428	0.795	0.795	0.788	0.788
AUT	533	0.755	0.735	0.982	0.982	IDN	419	0.815	0.815	0.772	0.772
CAN	532	0.818	0.794	0.980	0.980	CHL	407	0.850	0.850	0.750	0.750
CHE	531	0.807	0.781	0.978	0.978	PRY	406	0.745	0.745	0.748	0.748
CZE	530	0.967	0.933	0.976	0.976	BOL	405	0.716	0.716	0.746	0.746

SWE	529	0.555	0.534	0.974	0.974	COL	400	0.771	0.771	0.737	0.737
FIN	528	0.682	0.654	0.972	0.972	KWT	398	0.636	0.636	0.733	0.733
RUS	528	0.957	0.918	0.972	0.972	DOM	397	0.877	0.877	0.768	0.741
GBR	517	1.000	0.972	1.000	0.981	HND	396	0.740	0.740	0.729	0.729
BGR	515	0.931	0.899	0.948	0.948	PER	392	0.797	0.797	0.722	0.722
FRA	515	0.724	0.699	0.948	0.948	VUT	375	0.655	0.655	0.691	0.691
DEU	514	0.991	0.955	0.994	0.969	KEN	349	0.708	0.708	0.643	0.643
USA	509	0.888	0.842	0.937	0.937	PHL	345	0.769	0.769	0.635	0.635
MYS	506	0.760	0.715	0.932	0.932	MUS	342	0.826	0.826	0.630	0.630
ESP	505	0.977	0.917	0.977	0.943	BLZ	335	0.712	0.712	0.617	0.617
LVA	504	0.765	0.715	0.928	0.928	MAR	334	0.727	0.727	0.615	0.615
POL	504	0.790	0.739	0.928	0.928	ZWE	331	0.617	0.617	0.610	0.610
NZL	501	0.648	0.601	0.923	0.923	TZA	329	0.728	0.728	0.606	0.606
NOR	500	0.486	0.449	0.921	0.921	CMR	322	0.753	0.753	0.593	0.593
ISL	499	0.674	0.620	0.919	0.919	MOZ	318	0.735	0.735	0.586	0.586
DNK	493	0.451	0.407	0.908	0.908	SWZ	317	0.703	0.703	0.584	0.584
GRC	491	1.000	1.000	1.000	1.000	MDG	315	0.733	0.733	0.580	0.580
ITA	486	0.876	0.876	0.940	0.906	UGA	309	0.742	0.742	0.569	0.569
LTU	485	0.768	0.768	0.893	0.893	BWA	288	0.603	0.603	0.530	0.530
THA	475	0.739	0.739	0.875	0.875	BFA	277	0.746	0.746	0.510	0.510
PRT	474	0.663	0.663	0.873	0.873	CIV	269	0.727	0.727	0.495	0.495
ROM	472	0.804	0.804	0.869	0.869	ZAF	261	0.668	0.668	0.481	0.481
CYP	468	0.674	0.674	0.862	0.862	MLI	233	0.732	0.732	0.429	0.429
ISR	467	0.498	0.498	0.860	0.860	NAM	232	0.610	0.610	0.427	0.427
MDA	464	0.700	0.700	0.855	0.855	LSO	230	0.641	0.641	0.424	0.424
MEX	455	0.785	0.785	0.838	0.838	ZMB	228	0.734	0.734	0.420	0.420
TTO	454	0.825	0.825	0.836	0.836	SEN	223	0.730	0.730	0.411	0.411
MKD	453	0.777	0.777	0.834	0.834	MWI	207	0.720	0.720	0.381	0.381
JOR	439	0.702	0.702	0.808	0.808	NER	173	0.733	0.733	0.319	0.319
TUN	437	0.657	0.657	0.805	0.805						

Note: Learning scores are from Table 1.2. in Crouch and Fasih (2004). Sorted by learning scores.

Developed countries included in the efficiency estimation for learning scores

Code	Country	Code	Country	Code	Country
AUS	Australia	ESP	Spain	LUX	Luxembourg
AUT	Austria	FIN	Finland	NLD	Netherlands
CAN	Canada	FRA	France	NOR	Norway
CHE	Switzerland	GBR	United Kingdom	NZL	New Zealand
CYP	Cyprus	GRC	Greece	SWE	Sweden
DEU	Germany	ISL	Iceland	USA	United States
DNK	Denmark	ITA	Italy		

Table 2.D.4 Efficiency Score for Selected Health Indicators

	Life Expectancy at Birth				Immunization DPT			
	Input Efficiency		*Output Efficiency*		*Input Efficiency*		*Output Efficiency*	
Country	FDH	DEA	FDH	DEA	FDH	DEA	FDH	DEA
AGO	0.671	0.671	0.609	0.607	0.671	0.671	0.368	0.368
ALB	0.697	0.697	0.955	0.953	0.826	0.792	0.984	0.984
ARE	1.000	1.000	1.000	1.000	0.956	0.942	0.983	0.967
ARG	0.527	0.492	0.955	0.955	0.478	0.478	0.811	0.811
ARM	0.712	0.663	0.963	0.959	0.681	0.651	0.906	0.906
ATG	0.744	0.736	0.980	0.978	0.800	0.794	0.997	0.997
AZE	0.724	0.724	0.862	0.861	0.857	0.822	0.984	0.984
BDI	0.638	0.638	0.549	0.547	0.638	0.638	0.746	0.746
BEN	0.649	0.649	0.693	0.690	0.649	0.649	0.737	0.737
BFA	0.647	0.647	0.580	0.577	0.647	0.647	0.405	0.405
BGD	0.672	0.672	0.798	0.795	0.672	0.672	0.821	0.821
BGR	0.619	0.619	0.931	0.926	0.652	0.650	0.954	0.954
BHR	0.736	0.736	0.955	0.954	0.872	0.834	0.983	0.983
BHS	0.755	0.755	0.907	0.906	0.795	0.770	0.921	0.921
BLR	0.560	0.560	0.892	0.886	0.664	0.659	0.997	0.997
BLZ	0.797	0.749	0.966	0.964	0.723	0.723	0.893	0.893
BOL	0.633	0.633	0.816	0.812	0.633	0.633	0.714	0.714
BRA	0.672	0.672	0.888	0.886	0.672	0.672	0.892	0.892
BRB	0.721	0.632	0.987	0.979	0.556	0.556	0.899	0.899
BWA	0.626	0.626	0.535	0.533	0.741	0.695	0.975	0.975
CAF	0.649	0.649	0.571	0.569	0.649	0.649	0.436	0.436
CHL	0.964	0.879	0.990	0.990	0.881	0.787	0.958	0.958
CHN	0.717	0.717	0.917	0.916	0.717	0.717	0.890	0.890
CIV	0.679	0.679	0.600	0.598	0.679	0.679	0.605	0.605
CMR	0.694	0.694	0.661	0.659	0.694	0.694	0.482	0.482
COG	0.648	0.648	0.670	0.667	0.648	0.648	0.317	0.317
COL	0.623	0.623	0.931	0.927	0.623	0.623	0.773	0.773
COM	0.664	0.664	0.792	0.790	0.664	0.664	0.701	0.701
CPV	0.643	0.643	0.898	0.895	0.643	0.643	0.805	0.805
CRI	1.000	1.000	1.000	1.000	0.528	0.528	0.899	0.899
CZE	0.386	0.372	0.964	0.964	0.414	0.402	0.988	0.988
DJI	0.612	0.612	0.610	0.607	0.612	0.612	0.404	0.404
DMA	0.749	0.728	0.997	0.990	0.684	0.682	0.999	0.999
DOM	0.776	0.776	0.895	0.881	0.776	0.776	0.688	0.688
DZA	0.696	0.696	0.920	0.918	0.734	0.700	0.905	0.905
ECU	0.694	0.694	0.909	0.907	0.694	0.694	0.861	0.861
EGY	0.715	0.715	0.884	0.883	0.753	0.747	0.948	0.948
ERI	0.626	0.626	0.666	0.662	0.626	0.626	0.825	0.825
EST	0.515	0.515	0.910	0.910	0.543	0.541	0.952	0.952
ETH	0.644	0.644	0.556	0.554	0.644	0.644	0.482	0.482
FJI	0.702	0.702	0.902	0.900	0.740	0.706	0.905	0.905
GAB	0.804	0.804	0.700	0.691	0.804	0.804	0.452	0.452
GEO	0.689	0.689	0.954	0.951	0.689	0.689	0.824	0.824

Table 2.D.4 (continued)

	Life Expectancy at Birth				Immunization DPT			
	Input Efficiency		*Output Efficiency*		*Input Efficiency*		*Output Efficiency*	
Country	FDH	DEA	FDH	DEA	FDH	DEA	FDH	DEA
GHA	0.657	0.657	0.749	0.746	0.657	0.657	0.765	0.765
GIN	0.671	0.671	0.605	0.604	0.671	0.671	0.470	0.470
GMB	0.636	0.636	0.696	0.693	0.670	0.655	0.932	0.932
GNB	0.632	0.632	0.585	0.583	0.632	0.632	0.495	0.495
GRD	0.647	0.647	0.946	0.943	0.681	0.671	0.939	0.939
GTM	0.714	0.714	0.848	0.847	0.714	0.714	0.788	0.788
GUY	0.600	0.600	0.823	0.818	0.600	0.600	0.877	0.877
HND	0.645	0.645	0.862	0.859	0.764	0.683	0.958	0.958
HRV	0.380	0.380	0.945	0.945	0.400	0.394	0.939	0.939
HTI	0.647	0.647	0.690	0.688	0.647	0.647	0.431	0.431
HUN	0.450	0.450	0.921	0.921	0.533	0.533	1.000	1.000
IDN	0.770	0.770	0.862	0.861	0.770	0.770	0.749	0.749
IND	0.718	0.718	0.821	0.820	0.718	0.718	0.633	0.633
IRN	0.740	0.740	0.898	0.897	0.877	0.857	0.991	0.991
JAM	0.835	0.711	0.984	0.980	0.644	0.644	0.886	0.886
JOR	0.585	0.585	0.934	0.928	0.693	0.634	0.967	0.967
KAZ	0.725	0.725	0.838	0.836	0.858	0.807	0.977	0.977
KEN	0.648	0.648	0.621	0.618	0.648	0.648	0.820	0.820
KGZ	0.654	0.654	0.869	0.866	0.774	0.754	0.990	0.990
KHM	0.678	0.678	0.704	0.702	0.678	0.678	0.518	0.518
KNA	0.708	0.708	0.924	0.923	0.838	0.832	0.997	0.997
KOR	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
KWT	1.000	1.000	1.000	1.000	0.914	0.863	0.978	0.978
LAO	0.666	0.666	0.700	0.698	0.666	0.666	0.544	0.544
LBN	0.712	0.712	0.919	0.918	0.750	0.737	0.937	0.937
LCA	0.694	0.694	0.940	0.938	0.694	0.694	0.874	0.874
LKA	0.715	0.715	0.952	0.951	0.847	0.800	0.978	0.978
LSO	0.600	0.600	0.548	0.545	0.600	0.600	0.843	0.843
LTU	0.546	0.546	0.938	0.930	0.575	0.566	0.939	0.939
LVA	0.617	0.617	0.915	0.911	0.731	0.655	0.960	0.960
MAR	0.739	0.739	0.883	0.882	0.779	0.775	0.951	0.951
MDA	0.621	0.621	0.875	0.871	0.736	0.662	0.961	0.961
MDG	0.646	0.646	0.713	0.710	0.646	0.646	0.540	0.540
MEX	0.758	0.758	0.955	0.954	0.898	0.812	0.962	0.962
MKD	0.501	0.501	0.941	0.941	0.527	0.525	0.952	0.952
MLI	0.644	0.644	0.554	0.552	0.644	0.644	0.496	0.496
MNG	0.615	0.615	0.850	0.846	0.647	0.643	0.949	0.949
MOZ	0.625	0.625	0.562	0.559	0.625	0.625	0.606	0.606
MRT	0.651	0.651	0.663	0.660	0.651	0.651	0.439	0.439
MUS	0.936	0.936	0.973	0.955	0.936	0.936	0.937	0.932
MWI	0.627	0.627	0.510	0.508	0.627	0.627	0.853	0.853
MYS	0.949	0.949	0.989	0.975	1.000	1.000	1.000	1.000
NAM	0.543	0.543	0.628	0.623	0.543	0.543	0.723	0.723

Table 2.D.4 (continued)

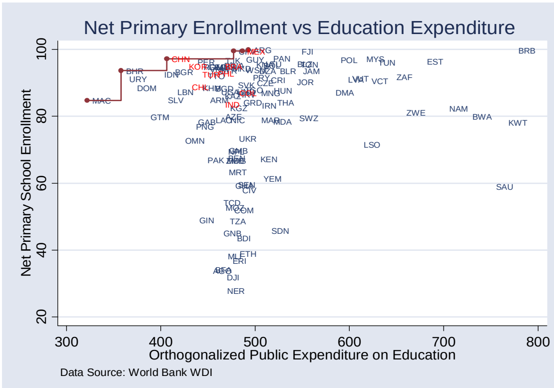
	Life Expectancy at Birth				Immunization DPT			
	Input Efficiency		Output Efficiency		Input Efficiency		Output Efficiency	
Country	FDH	DEA	FDH	DEA	FDH	DEA	FDH	DEA
NER	0.646	0.646	0.591	0.589	0.646	0.646	0.264	0.264
NGA	0.659	0.659	0.620	0.617	0.659	0.659	0.290	0.290
NIC	0.628	0.628	0.895	0.891	0.661	0.634	0.909	0.909
NPL	0.658	0.658	0.767	0.764	0.658	0.658	0.733	0.733
OMN	0.931	0.858	0.976	0.970	1.000	1.000	1.000	1.000
PAK	0.693	0.693	0.821	0.819	0.693	0.693	0.582	0.582
PAN	0.579	0.559	0.965	0.965	0.553	0.553	0.955	0.955
PER	0.700	0.700	0.905	0.903	0.737	0.710	0.915	0.915
PHL	0.748	0.748	0.904	0.904	0.748	0.748	0.769	0.769
PNG	0.628	0.628	0.748	0.744	0.628	0.628	0.541	0.541
POL	0.550	0.550	0.954	0.946	0.651	0.634	0.990	0.990
PRY	0.676	0.676	0.918	0.916	0.676	0.676	0.723	0.723
ROM	0.558	0.558	0.908	0.902	0.661	0.644	0.990	0.990
RUS	0.617	0.617	0.864	0.860	0.650	0.635	0.931	0.931
RWA	0.636	0.636	0.523	0.521	0.636	0.636	0.847	0.847
SAU	0.615	0.615	0.946	0.941	0.648	0.645	0.951	0.951
SDN	0.685	0.685	0.749	0.747	0.685	0.685	0.473	0.473
SEN	0.640	0.640	0.684	0.681	0.640	0.640	0.582	0.582
SLB	0.607	0.607	0.894	0.890	0.607	0.607	0.801	0.801
SLE	0.635	0.635	0.488	0.486	0.635	0.635	0.449	0.449
SLV	0.634	0.634	0.912	0.908	0.668	0.664	0.949	0.949
SVK	0.464	0.464	0.944	0.944	0.549	0.549	1.000	1.000
SVN	0.380	0.375	0.971	0.971	0.363	0.357	0.939	0.939
SWZ	0.710	0.710	0.631	0.630	0.710	0.710	0.804	0.804
SYR	0.699	0.699	0.910	0.908	0.736	0.735	0.955	0.955
TCD	0.642	0.642	0.633	0.631	0.642	0.642	0.264	0.264
TGO	0.660	0.660	0.644	0.641	0.660	0.660	0.564	0.564
THA	0.786	0.786	0.913	0.900	0.931	0.859	0.970	0.970
TJK	0.650	0.650	0.884	0.881	0.650	0.650	0.827	0.827
TKM	0.639	0.639	0.851	0.848	0.757	0.726	0.984	0.984
TON	0.655	0.655	0.927	0.924	0.776	0.696	0.960	0.960
TTO	0.883	0.883	0.964	0.962	0.930	0.903	0.965	0.939
TUN	0.547	0.547	0.942	0.934	0.648	0.598	0.970	0.970
TUR	0.627	0.627	0.908	0.904	0.627	0.627	0.811	0.811
TZA	0.634	0.634	0.589	0.587	0.634	0.634	0.821	0.821
UGA	0.647	0.647	0.556	0.554	0.647	0.647	0.586	0.586
UKR	0.650	0.650	0.887	0.884	0.770	0.767	0.999	0.999
URY	0.570	0.540	0.959	0.959	0.544	0.531	0.929	0.929
UZB	0.639	0.639	0.889	0.885	0.757	0.726	0.984	0.984
VCT	0.613	0.613	0.953	0.948	0.725	0.715	0.994	0.994
VEN	0.724	0.661	0.958	0.954	0.657	0.657	0.633	0.633
VNM	0.681	0.681	0.901	0.899	0.717	0.701	0.931	0.931
VUT	0.683	0.683	0.889	0.887	0.683	0.683	0.807	0.807

Table 2.D.4 (continued)

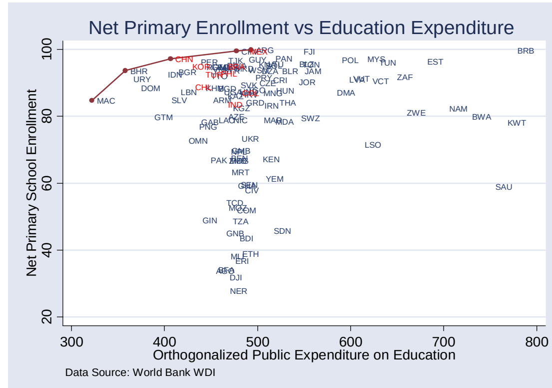
	Life Expectancy at Birth				Immunization DPT			
	Input Efficiency		*Output Efficiency*		*Input Efficiency*		*Output Efficiency*	
Country	FDH	DEA	FDH	DEA	FDH	DEA	FDH	DEA
WSM	0.582	0.582	0.902	0.896	0.689	0.646	0.975	0.975
YEM	0.646	0.646	0.736	0.733	0.646	0.646	0.662	0.662
ZAF	0.620	0.620	0.645	0.642	0.620	0.620	0.784	0.784
ZAR	0.648	0.648	0.599	0.597	0.648	0.648	0.280	0.280
ZMB	0.629	0.629	0.511	0.509	0.629	0.629	0.811	0.811
ZWE	0.595	0.595	0.535	0.532	0.595	0.595	0.791	0.791

Figure 2.D. 1 Efficiency Frontiers for Education

Free Disposable Hull (FDH)	Data Envelopment Analysis (DEA)



(a.1)



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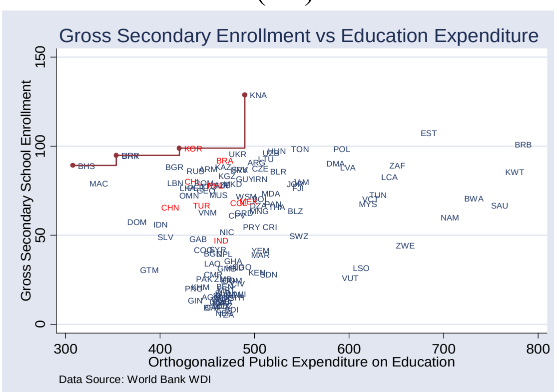

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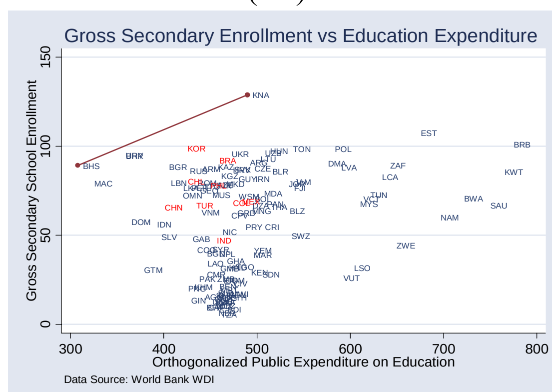

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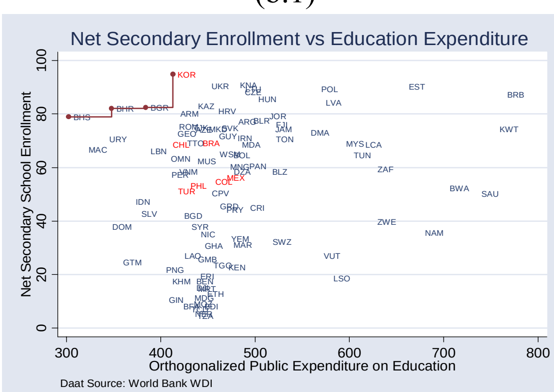
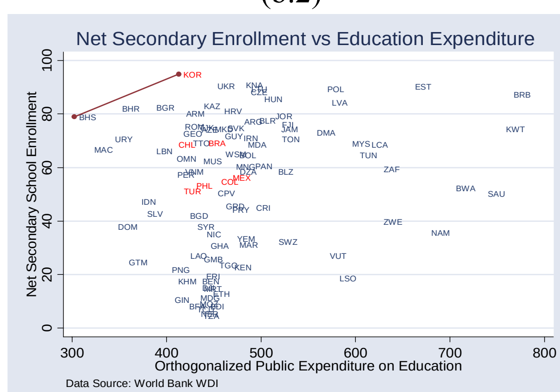


(c.1)



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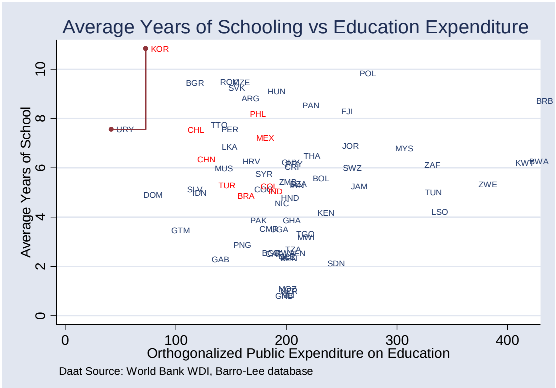
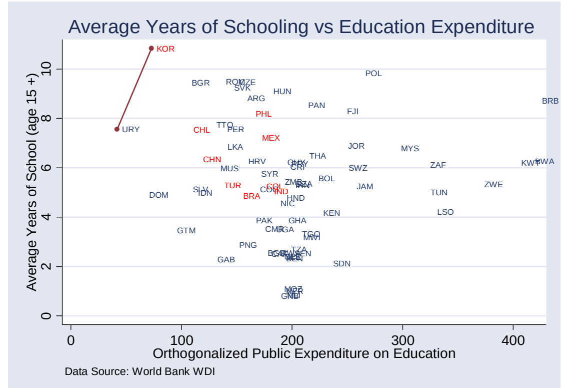


(d.1)



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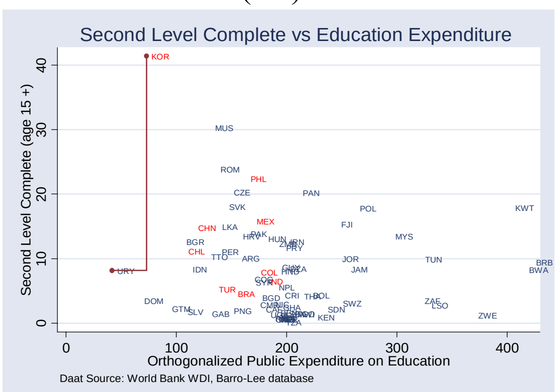

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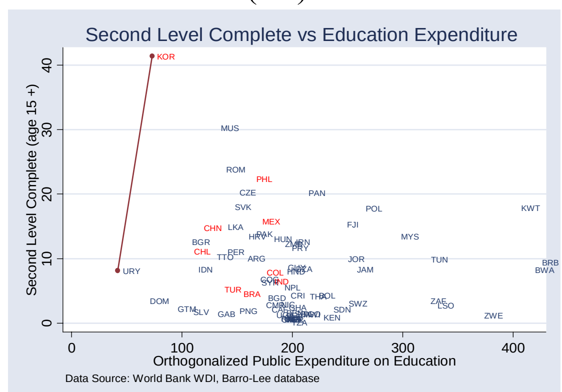
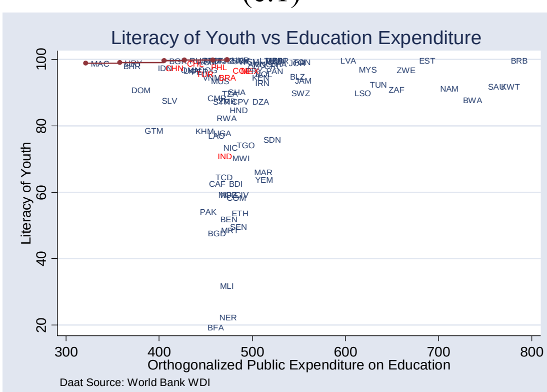
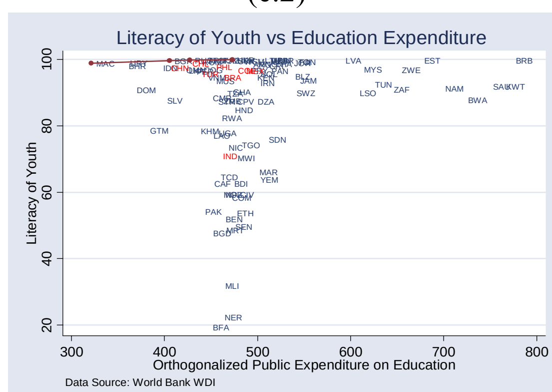


(e.2)



(f.1)



(f.2)

Appendix 2.E. Spearman Tests Table 2.E.1. Spearman Rank-Correlation on Input Efficiency Rankings (FDH)

	Gross Primary Enroll.	Gross Secondary Enroll.	Net Primary Enroll.	Net Secondary Enroll.	Literacy of Youth	Avg. Yrs. of Sch.	First Level Comp.	Second Level Comp.	Life Expectancy	Immunization DPT	Immunization Measles	DALE
Gross Primary Enrollment	1.00 (125)	0.63 (125)	0.84 (114)	0.63 (97)	0.55 (98)	0.71 (73)	0.53 (73)	0.60 (73)	0.22 (124)*	0.15 (124)***	0.21 (124)*	0.22 (123)*
Gross Secondary Enrollment		1.00 (125)	0.64 (114)	0.83 (97)	0.76 (98)	0.81 (73)	0.51 (73)	0.63 (73)	0.16 (124)***	0.17 (124)***	0.25 (124)	0.20 (123)**
Net Primary Enrollment			1.00 (114)	0.57 (95)	0.61 (91)	0.80 (67)	0.71 (67)	0.76 (67)	0.17 (113)***	0.11 (113)#	0.17 (113)***	0.23 (113)*
Net Secondary Enrollment				1.00 (97)	0.83 (77)	0.81 (53)	0.55 (53)	0.69 (53)	0.09 (96)#	0.17 (96)***	0.24 (96)*	0.17 (96)***
Literacy or Youth					1.00 (98)	0.88 (65)	0.54 (65)	0.75 (65)	-0.01 (96)#	0.21 (97)**	0.36 (97)	0.07 (96)#
Average Years of School						1.00 (73)	0.67 (73)	0.84 (73)	-0.01 (73)#	0.09 (73)#	0.29 (73)*	0.19 (72)***
First Level Complete							1.00 (73)	0.70 (73)	0.05 (73)#	0.07 (73)#	0.20 (73)***	0.19 (72)***
Second Level Complete								1.00 (73)	0.09 (73)#	0.23 (73)**	0.36 (73)	0.28 (73)*
Life expectancy at Birth									1.00 (135)	0.74 (135)	0.66 (135)	0.87 (134)
Immunization DPT										1.00 (135)	0.87 (135)	0.73 (134)
Immunization Measles											1.00 (135)	0.66 (134)
DALE												1.00 (134)

Note:

1. Figures are correlation coefficients from Spearman test with number of observations in parentheses.
2. All coefficients are significant at 1% level, unless indicated otherwise, * 2% significance, ** 5% significance, *** 10% significance, # insignificant

Table 2.E.2. Spearman Rank-Correlation on Input Efficiency Rankings (DEA)

	Gross Primary Enroll.	Gross Secondary Enroll.	Net Primary Enroll.	Net Secondary Enroll.	Literacy Youth	Avg. Yrs. of School	First Level Comp.	Second Level Comp.	Life expectancy	Immunization DPT	Immunization Measles	DALE
Gross Primary Enrollment	1.00 (125)	0.80 (125)	0.88 (114)	0.74 (97)	0.58 (98)	0.70 (73)	0.60 (73)	0.73 (73)	0.30 (124)	0.24 (124)	0.23 (124)	0.30 (123)
Gross Secondary Enrollment		1.00 (125)	0.74 (114)	0.94 (97)	0.81 (98)	0.83 (73)	0.65 (73)	0.83 (73)	0.30 (124)	0.29 (124)	0.28 (124)	0.32 (123)
Net Primary Enrollment			1.00 (114)	0.69 (95)	0.64 (91)	0.78 (67)	0.76 (67)	0.80 (67)	0.22 (113)*	0.19 (113)**	0.17 (113)***	0.23 (113)*
Net Secondary Enrollment				1.00 (97)	0.86 (77)	0.88 (53)	0.75 (53)	0.87 (53)	0.20 (96)**	0.24 (96)*	0.24 (96)**	0.26 (96)*
Literacy or Youth					1.00 (98)	0.91 (65)	0.73 (65)	0.88 (65)	0.02 (96)#	0.18 (97)***	0.28 (97)	0.09 (96)#
Average Years of School						1.00 (73)	0.85 (73)	0.97 (73)	0.03 (73)#	0.09 (73)#	0.24 (73)**	0.09 (72)#
First Level Complete							1.00 (73)	0.83 (73)	0.14 (73)#	0.21 (73)***	0.29 (73)*	0.18 (72)#
Second Level Complete								1.00 (73)	0.13 (73)#	0.21 (73)***	0.36 (73)*	0.19 (73)#
Life expectancy at Birth									1.00 (135)	0.85 (135)	0.77 (135)	0.94 (134)
Immunization DPT										1.00 (135)	0.88 (135)	0.89 (134)
Immunization Measles											1.00 (135)	0.80 (134)
DALE												1.00 (134)

Note:

1. Figures are correlation coefficients from Spearman test with number of observations in parentheses.
2. All coefficients are significant at 1% level, unless indicated otherwise, * 2% significance, ** 5% significance, *** 10% significance, # insignificant

Table 2.E.3. Spearman Rank-Correlation on Output Efficiency Rankings (FDH)

	Gross Primary Enroll.	Gross Secondary Enroll.	Net Primary Enroll.	Net Secondary Enroll.	Literacy of Youth	Avg. Yrs of School	First Level Comp.	Second Level Comp.	Life expectancy	Immunization DPT	Immunization Measles	DALE
Gross Primary Enrollment	1.00 (125)	0.50 (125)	0.74 (114)	0.34 (97)	0.32 (98)	0.37 (73)	0.44 (73)	0.31 (73)	0.33 (124)	0.23 (124)	0.26 (124)	0.30 (123)
Gross Secondary Enrollment		1.00 (125)	0.69 (114)	0.91 (97)	0.85 (98)	0.84 (73)	0.53 (73)	0.79 (73)	0.72 (124)	0.70 (124)	0.84 (124)	0.76 (123)
Net Primary Enrollment			1.00 (114)	0.64 (95)	0.60 (91)	0.66 (67)	0.57 (67)	0.60 (67)	0.63 (113)	0.46 (113)	0.45 (113)	0.59 (113)
Net Secondary Enrollment				1.00 (97)	0.87 (77)	0.82 (53)	0.33 (53)*	0.77 (53)	0.69 (96)	0.73 (96)	0.73 (96)	0.72 (96)
Literacy or Youth					1.00 (98)	0.85 (65)	0.56 (65)	0.63 (65)	0.62 (96)	0.67 (97)	0.68 (97)	0.67 (96)
Average Years of School						1.00 (73)	0.62 (73)	0.8 (73)	.072 (73)	0.73 (73)	0.76 (73)	0.73 (72)
First Level Complete							1.00 (73)	0.48 (73)	0.49 (73)	0.45 (73)	0.48 (73)	0.56 (72)
Second Level Complete								1.00 (73)	0.75 (73)	0.64 (73)	0.67 (73)	0.78 (73)
Life expectancy at Birth									1.00 (135)	0.67 (135)	0.69 (135)	0.94 (134)
Immunization DPT										1.00 (135)	0.95 (135)	0.66 (134)
Immunization Measles											1.00 (135)	0.70 (134)
DALE												1.00 (134)

Note:

1. Figures are correlation coefficients from Spearman test with number of observations in parentheses.
2. All coefficients are significant at 1% level, unless indicated otherwise, * 2% significance, ** 5% significance, *** 10% significance, # insignificant

Table 2.E.4. Spearman Rank-Correlation on Output Efficiency Rankings (DEA)

	Gross Primary Enroll.	Gross Secondary Enroll.	Net Primary Enroll.	Net Secondary Enroll.	Literacy of Youth	Avg. Years School	First Level Comp.	Second Level Comp.	Life expectancy	Immunization DPT	Immunization Measles	DALE
Gross Primary Enrollment	1.00 (125)	0.48 (125)	0.74 (114)	0.32 (97)	0.30 (98)	0.32 (73)	0.38 (73)	0.25 (73)**	0.34 (124)	0.23 (124)	0.27 (124)	0.30 (123)
Gross Secondary Enrollment		1.00 (125)	0.68 (114)	0.95 (97)	0.86 (98)	0.86 (73)	0.52 (73)	0.78 (73)	0.73 (124)	0.73 (124)	0.86 (124)	0.76 (123)
Net Primary Enrollment			1.00 (114)	0.65 (95)	0.61 (91)	0.69 (67)	0.58 (67)	0.62 (67)	0.64 (113)	0.47 (113)	0.45 (113)	0.61 (113)
Net Secondary Enrollment				1.00 (97)	0.87 (77)	0.83 (53)	0.35 (53)	0.81 (53)	0.69 (96)	0.73 (96)	0.73 (96)	0.72 (96)
Literacy or Youth					1.00 (98)	0.86 (65)	0.56 (65)	0.64 (65)	0.63 (96)	0.66 (97)	0.67 (97)	0.68 (96)
Average Years of School						1.00 (73)	0.62 (73)	0.84 (73)	0.73 (73)	0.74 (73)	0.75 (73)	0.73 (72)
First Level Complete							1.00 (73)	0.46 (73)	0.48 (73)	0.46 (73)	0.48 (73)	0.54 (72)
Second Level Complete								1.00 (73)	0.76 (73)	0.67 (73)	0.66 (73)	0.77 (73)
Life expectancy at Birth									1.00 (135)	0.67 (135)	0.69 (135)	0.95 (134)
Immunization DPT										1.00 (135)	0.94 (135)	0.67 (134)
Immunization Measles											1.00 (135)	0.71 (134)
DALE												1.00 (134)

Note:

1. Figures are correlation coefficients from Spearman test with number of observations in parentheses.
2. All coefficients are significant at 1% level, unless indicated otherwise, * 2% significance, ** 5% significance, *** 10% significance, # insignificant

Appendix 2.F. Efficiency and Technical Change

Table 2.F.1. Education, Single Input (Public Spending per capita on Education), Single Output

	Region	VRSTE Output		VRSTE Input		EFFCH	TECHCH	TFPCH	# of Countries
		1975-1980	1996-2002	1975-1980	1996-2002				
Gross Primary Enrollment	AFR	.563	.650	.843	.851	1.299	1	1.299	23
	EAP	.793	.808	.897	.847	.987	1	.987	8
	ECA	.754	.735	.845	.793	.944	1	.944	4
	LAC	.787	.813	.860	.843	1.054	1	1.054	20
	MNA	.694	.692	.798	.747	1.114	1	1.114	10
	SAS	.554	.769	.882	.911	1.446	1	1.446	5
Net Primary Enrollment	AFR	.537	.651	.841	.819	1.355	1	1.355	12
	EAP	.929	.959	.927	.859	.969	1	.969	4
	ECA	.958	.907	.792	.799	.963	1	.963	2
	LAC	.870	.935	.837	.831	1.045	1	1.045	13
	MNA	.752	.842	.787	.724	1.198	1	1.198	9
	SAS	-	-	-	-	-	-	-	-
Gross Secondary Enrollment	AFR	.184	.293	.819	.830	2.072	1.038	2.150	23
	EAP	.508	.705	.874	.860	1.484	1.038	1.540	8
	ECA	.750	.864	.913	.854	1.235	1.038	1.281	4
	LAC	.564	.723	.859	.874	1.450	1.038	1.505	20
	MNA	.521	.703	.804	.774	2.443	1.038	2.535	10
	SAS	.324	.478	.880	.901	1.806	1.038	1.874	5
Net Secondary Enrollment	AFR	.179	.341	.317	.304	1.519	1.248	1.895	6
	EAP	.576	.695	.525	.623	1.555	1.248	1.941	3
	ECA	.824	.895	.747	.711	1.256	1.248	1.568	1
	LAC	.535	.678	.504	.451	1.420	1.248	1.772	10
	MNA	.385	.629	.453	.410	1.891	1.248	2.360	8
	SAS	-	-	-	-	-	-	-	-
Literacy of Youth	AFR	.554	.741	.814	.831	1.442	1	1.442	20
	EAP	.924	.988	.879	.868	1.009	1	1.009	6
	ECA	.967	.990	.940	.880	.967	1	.967	4
	LAC	.899	.952	.872	.845	1.024	1	1.024	18
	MNA	.729	.906	.778	.749	1.230	1	1.230	10
	SAS	.499	.662	.869	.871	1.430	1	1.430	5
Average Years of School	AFR	.261	.323	.340	.315	1.737	1	1.737	19
	EAP	.653	.708	.406	.495	1.342	1	1.342	7
	ECA	.750	.768	.648	.621	1.387	1	1.387	3
	LAC	.618	.625	.418	.427	1.300	1	1.300	18
	MNA	.456	.549	.389	.326	1.929	1	1.929	6
	SAS	.302	.397	.363	.379	2.137	1	2.137	5
First Level Complete	AFR	.135	.164	.340	.315	1.417	1	1.417	19
	EAP	.367	.382	.363	.342	1.066	1	1.066	7
	ECA	.764	.639	.646	.528	.913	1	.913	3
	LAC	.372	.266	.404	.349	.816	1	.816	18
	MNA	.299	.217	.389	.317	1.266	1	1.266	6
	SAS	.146	.194	.363	.370	2.101	1	2.101	5
Second Level Complete	AFR	.082	.098	.341	.339	1.417	1.77	2.509	19
	EAP	.439	.444	.470	.517	.991	1.77	1.754	7
	ECA	.284	.276	.355	.414	1.045	1.77	1.849	3
	LAC	.337	.228	.418	.381	.839	1.77	1.485	18
	MNA	.357	.266	.389	.357	1.233	1.77	2.182	6
	SAS	.202	.235	.385	.424	1.734	1.77	3.068	5

Table 2.F.2 Health, Single Input (Public Spending per capita on Health), Single Output

	Region	VRSTE Output		VRSTE Input		EFFCH	TECHCH	TFPCH	#of Countries
		1997-1999	2000-2002	1997-1999	2000-2002				
Life Expectancy at Birth	AFR	.642	.618	.680	.681	.972	1	.972	42
	EAP	.870	.872	.738	.735	1.008	1	1.008	16
	ECA	.919	.911	.616	.626	1.019	1	1.019	25
	LAC	.923	.920	.739	.723	.995	1	.995	31
	MNA	.889	.892	.725	.754	1.049	1	1.049	13
	SAS	.821	.834	.713	.718	1.029	1	1.029	5
Immunization DPT	AFR	.601	.629	.686	.682	1.022	1.078	1.101	42
	EAP	.837	.824	.772	.740	.930	1.078	1.003	16
	ECA	.949	.957	.681	.633	.953	1.078	1.027	25
	LAC	.863	.883	.732	.694	.944	1.078	1.017	31
	MNA	.882	.920	.778	.751	1.063	1.078	1.146	13
	SAS	.742	.773	.736	.724	.976	1.078	1.053	5
Immunization Measles	AFR	.632	.638	.682	.681	.975	1.089	1.061	42
	EAP	.837	.827	.778	.740	.924	1.089	1.007	16
	ECA	.944	.951	.712	.634	.943	1.089	1.027	25
	LAC	.904	.912	.770	.694	.924	1.089	1.006	31
	MNA	.878	.909	.798	.755	1.055	1.089	1.148	13
	SAS	.701	.732	.735	.725	.970	1.089	1.056	5
DALE	AFR	.655	-	.563	-	-	-	-	41
	EAP	.717	-	.830	-	-	-	-	16
	ECA	.602	-	.903	-	-	-	-	26
	LAC	.698	-	.904	-	-	-	-	31
	MNA	.707	-	.863	-	-	-	-	15
	SAS	.691	-	.787	-	-	-	-	5

Table 2.F.3. Education, Multiple Inputs, Multiple Outputs

	Region	VRSTE Output		VRSTE Input		EFFCH	TECHCH	TFPCH	#of Countries
		1975-1980	1996-2002	1975-1980	1996-2002				
EDU2-2 Gross Primary and Secondary Enrollment	AFR	.587	.685	.906	.902	1.292	1.003	1.296	21
	EAP	.860	.928	.935	.905	1.039	1.030	1.070	7
	ECA	.913	.939	.913	.842	.937	1.065	.999	3
	LAC	.854	.911	.906	.914	1.102	1.029	1.134	20
	MNA	.729	.820	.841	.793	1.278	1.029	1.314	10
	SAS	.580	.817	.940	.963	1.457	1.101	1.470	5
EDU2-2n Net Primary and Secondary Enrollment	AFR	.723	.703	.787	.750	1.062	1.009	1.076	6
	EAP	.921	.954	.905	.881	1.015	1.074	1.088	3
	ECA	1.00	.973	1.00	.836	.999	1.299	1.298	1
	LAC	.881	.942	.808	.822	1.074	1.066	1.138	9
	MNA	.782	.862	.777	.695	1.168	1.097	1.286	8
	SAS	-	-	-	-	-	-	-	-
EDU3-2 Gross Primary and Secondary Enrollment	AFR	.762	.922	.909	.909	1.043	1.002	1.045	18
	EAP	.840	.929	.896	.896	1.066	1.022	1.089	6
	ECA	.913	.917	.909	.909	1.018	1.037	1.057	3
	LAC	.849	.919	.922	.922	1.116	1.021	1.139	18
	MNA	.787	.870	.892	.892	1.235	1.008	1.245	10
	SAS	.813	.966	.982	.982	1.140	1.010	1.153	5
EDU3-2n Net Primary and Secondary Enrollment	AFR	.909	.894	.924	.897	.953	1.014	.970	6
	EAP	.937	.981	.961	.959	1.030	1.021	1.052	2
	ECA	1.00	.996	1.00	.969	.916	1.300	1.192	1
	LAC	.964	.983	.931	.948	1.045	1.063	1.109	9
	MNA	.930	.950	.934	.947	1.137	1.078	1.225	8
	SAS	-	-	-	-	-	-	-	-
EDU3-3 Gross Primary & Secondary Enrollment, Literacy of Youth	AFR	.939	.946	.950	.944	.974	1.018	.991	18
	EAP	.995	.996	.989	.968	.961	1.026	.986	6
	ECA	.999	1.00	.993	.996	.959	1.029	.987	3
	LAC	.968	.983	.966	.960	.996	1.023	1.019	18
	MNA	.959	.966	.964	.953	.956	1.008	.965	10
	SAS	.919	.930	.970	.983	1.027	1.007	1.036	5
EDU3-3bl Avg. Yrs. of School, First & Secondary Level Complete	AFR	.789	.724	.896	.876	1.025	1.167	1.201	15
	EAP	.902	.872	.942	.901	.989	1.279	1.256	6
	ECA	.957	.987	.962	.978	1.026	1.137	1.168	2
	LAC	.893	.846	.939	.883	.999	1.170	1.168	17
	MNA	.899	.811	.925	.827	.950	1.259	1.193	6
	SAS	.883	.888	.984	.956	1.129	1.375	1.547	5
EDU2-3bl Avg. Yrs. of School, First & Secondary Level Complete	AFR	.416	.451	.725	.733	1.560	1.054	1.641	17
	EAP	.730	.778	.747	.732	1.064	1.106	1.178	7
	ECA	.938	.943	.873	.773	.885	1.047	.922	2
	LAC	.690	.690	.777	.713	1.070	1.072	1.146	18
	MNA	.496	.576	.661	.599	1.393	1.105	1.509	6
	SAS	.328	.510	.673	.808	2.189	1.086	2.378	5

Table 2.F.4. Health, Multiple Inputs and Multiple Outputs

	Region	VRSTE Output		VRSTE Input		EFFCH	TECHCH	TFPCH	#of Countries
		1997-1999	2000-2002	1997-1999	2000-2002				
HEA2-2 Life Expectancy at birth, Immunization DPT	AFR	.818	.802	.861	.842	.952	1.032	.982	31
	EAP	.899	.897	.853	.818	.950	1.055	1.001	9
	ECA	.966	.965	.755	.730	.954	1.063	1.014	18
	LAC	.941	.936	.843	.824	.950	1.051	.998	23
	MNA	.973	.970	.915	.902	.983	1.041	1.023	11
	SAS	.957	.956	.939	.907	.965	1.032	.995	4
HEA3-2 Life Expectancy at birth, Immunization DPT	AFR	.823	.805	.866	.842	.952	1.031	.982	31
	EAP	.904	.903	.853	.818	.950	1.054	1.001	9
	ECA	.970	.969	.763	.736	.957	1.059	1.013	18
	LAC	.948	.943	.862	.838	.950	1.051	.998	23
	MNA	.973	.970	.907	.893	.984	1.060	1.044	10
	SAS	.957	.957	.939	.907	.970	1.031	.999	4
HEA3-2 Life Expectancy at birth, Immunization Measles	AFR	.820	.787	.866	.838	.934	1.029	.961	31
	EAP	.900	.898	.860	.817	.937	1.069	1.001	9
	ECA	.971	.970	.798	.739	.942	1.078	1.015	18
	LAC	.957	.953	.887	.848	.941	1.062	.998	23
	MNA	.972	.971	.908	.894	.986	1.064	1.050	10
	SAS	.952	.957	.937	.906	.962	1.046	1.005	4
HEA3-3 Life Expectancy at birth, Immunization DPT & Measles	AFR	.830	.812	.868	.842	.952	1.031	.981	31
	EAP	.904	.903	.860	.819	.941	1.064	1.001	9
	ECA	.977	.974	.800	.740	.944	1.075	1.013	18
	LAC	.958	.954	.887	.848	.941	1.062	.998	23
	MNA	.974	.971	.909	.895	.986	1.063	1.049	10
	SAS	.958	.957	.941	.907	.965	1.039	1.001	4

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