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RESEARCH ARTICLE

MEASURING TOTAL FACTOR PRODUCTIVITY FOR ETHIOPIA: *REGRESSION-BASED GROWTH ACCOUNTING* THE CASE OF THE POST 1991 PERIOD

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ABSTRACT

This paper examines the determination of the role TFPG to aggregate output growth in Ethiopia for the post 1991 period and checks if growth can be sustained with enhanced factor efficiency or not . It used the regression based growth accounting technique to decompose output growth. The research finding shows that the post-1991 notable growth in Ethiopia has been a result of factor accumulation. Physical capital explained more than half of the growth in output. However, the role TFPG has been significant that it accounted for above 34 percent of the GDP growth. On the basis of these empirical findings, it may be proposed that an economic policy focused on the promotion of public and private investment on physical capital could further enhance economic growth. Along with this, investments to augment the quality and employment of labor are also vital sources of growth. Furthermore, more openness, political stability and higher investment to GDP ratio are related to better factor productivity. Finally, policy makers should intensify their efforts to encourage investment in the industrial sector as the share of capital investment to GDP growth is strong.

Introduction

1.1. Country Background

Ethiopia is located in the eastern horn of Africa with a total surface area of about 1.1 million km^2. It is the second most populous country in Africa with a population of above 73 million people (CSA, 2008). The history of human evolution regards Ethiopia as the origin of human beings and its history as a political entity stretches back to antiquity. Ethiopia hosts diverse topography that results in diverse ecological zones and a great deal of endemic species. The country belongs to the top five African countries with key agriculture related natural resources. The Ethiopian economy still derives a vital share of its income, employment and foreign exchange earnings from the small holder peasant-based agricultural sector. However, the service sector began to dominate the GDP share since 2008/2009 revealing a major structural transformation of the economy. Agriculture contributed 41.1 percent to GDP, employed above 80 percent of the labor force, and accounted for above three-fourth of the total export earnings obtained between 2009 and 2011. The industrial and services sectors accounted for 46.6 percent and 13.4 percent to GDP respectively (EMH, 2010). The main exportable agricultural products are Coffee, pulses, oils seeds & spices, Chat and Horticulture produces. Except in the flower sector, the agricultural exports are largely grown by small-holder farmers.

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Ethiopia is one of the developing countries with lower measures of overall development indicators. Per capita GDP in the year 2009 approximated $ 779 at PPP (UNDP, 2009). The percentage of population earning below 1 dollar a day approximated 23 % during 1990-2004(UNDP, 2006). The poor social services are indicated by the high child, maternal and illiteracy rates of (126.8/1, 000), (871/100,000) respectively. The infrastructural development is inadequate with only 2,358 electricity connected towns, a road network of 44,359 km, and only 2 million mobile telephone subscribers by 2007 (MoFED, 2009).

1.2. Statement of the problem

Economic performance in Ethiopia is highly correlated with conflict and political processes. The last four decades have witnessed a cyclic evolution of policy and growth regimes. Economic growth during the final phase (1960-1974) of the market economy of the imperial regime averaged 4 percent. A large proportion of such growth was attributed to capital accumulation via huge investment in infrastructure (Alemayehu *et al.*, 2005). Quite the reverse, GDP growth during the market repressive economic system of the Derg decelerated to 2.3 percent. The growth share of capital and factor efficiency was very weak and negative (Alemayehu, 2003a). Growth highly depended on Agriculture and hence was uneven due its vulnerability to the vagaries of nature. Ethiopia registered rapid economic growth over the post 1991 period. The structural adjustment policies of EPRDF led to quite impressive growth records during 1990/91-1999/00. Real GDP growth averaged 4.0 percent during 1991/92-2003/04. The Ethiopian economy registered a double digit consecutive growth rate over the period from 2004/05 to 2013/14. Ethiopian economy has become the fastest growing non-oil exporting economy in the world (UNDP, 2012). In 2012, poverty levels declined to 29.6%, down from 38.7% in 2005. Real GDP grew by 11 percent, on average, between 2004/05 and 2013/14. The growth was broader-based and less volatile that Growth in industrial, services and agricultural sectors went up from 5.1 percent, 5.2 percent and 6 percent in 2000/01 to 12.5 percent, 15 percent and 9 percent in 2010/11 respectively (MoFED, 2011). A crucial issue in relation to such growth episode is the sources of the output growth and if it can be lastingly sustained in the long run.

Few studies have been undertaken to explain the long-run growth process in general and chiefly the recent notable performance of the Ethiopan economy. Evidences from the first ten years of the post 1991 period put factor efficiency as the key driver for economic growth (easterly, 2006). Other studies attribute output growth to labor and capital accumulation (Alemayoh and Befkadu, 2005). The fact that an economic growth is factor accumulation-driven, factor efficiency-driven or both has a considerable implication on the sustainability of the long run growth process. Input driven growths are not sustainable since the returns to capital are subject to diminishing returns. A research done by WB (1993) reveals that a growth is deemed poor and requires a policy review if TFPG accounts for the 30 percent of GDP. The empirical determination of the components of output growth helps policy makers to realize the growth makeup and predict appropriate economic policy measures to further sustain economic growth and enhance welfare of the society. Hence, this study is generally an attempt to disclose if growth over the post 1991 period was factor accumulation or factor efficiency-driven. It tries to decompose aggregate output growth in the stated period in to its essential components using the regression based growth accounting technique.

1.3. Objectives of the Study

This study on the whole is an attempt to estimate the contribution of total factor productivity growth to aggregate output growth during the post 1991 period. Furthermore, the paper addresses the following specific objectives: It will try to:

- Review the evidence on the growth and macroeconomic performance of the Ethiopian economy over the post 1991 period – from 1991 to date
- Empirically determine the contribution of Total Factor Productivity growth (TFPG) to aggregate economic growth and evaluate relative role of TFPG and factor accumulation
- Scrutinize the major components of total factor productivity

1.4. Significance of the Study

This study is supposed to substantially contribute to further research investigation, policy making and amendment, and consolidating the body of theoretical and empirical literature. In particular, it may serve as a reference material for further related research work. Likewise, policy makers may use it to evaluate the nature of the economic performance, and plan and manage the economy. Finally, the study represents an addition to the growth literature, and provides the general reader with the comprehensive analysis of the Ethiopian economy for the last 20 years or above.

1.5. Scope and Limitation of the Study

The study emphasizes on determining the relative role of factor accumulation and total factor productivity growth to aggregate output growth restricted to the post 1991 period. As regards the limitation of this research work, I have had hard time in obtaining consistent data on the vital macroeconomic variables from different sources that I eventually inclined to government statistics. Likewise, capital input is not available in the national income accounts and is rather estimated from the gross fixed capital formation data. Finally, I depended on my already tiny financial resources to conduct this study.

2.1. Theoretical Literature Review

2.1.1. Definition of concepts: GDP and TFPG`

Economic growth is often defined as the Quantitative change or expansion in a country's economy. Economic growth is conventionally measured as the percentage increase in real Gross Domestic Product/GDP or Gross National Product/GNP during one year. Growth can be nominal which includes inflation or real that growth adjusted for inflation. Economies can either grow "extensively" by using more resources such as physical, human, or natural-capital or "intensively" by using the same amount of resources more efficiently/productively.
Total Factor Productivity Growth can be defined as the change in output holding measured inputs constant or net of the growth of measured inputs. It represents the improvements in the production technology accruing from the growth in the stock of unmeasured intangible investments such as human and R&D capital, advertising, good will, market development, information system, software, business methods, land, natural resource, water resources, the environment, and genuine technical and allocative efficiency. It also reflects the way in which technological innovation allows capital and labor to be used in more effective and valuable ways. It is also called as 'measure of ignorance' of the effects of all other range of variables not included to output growth. Total factor productivity growth is usually measured as a "residual" or as the effect of a time trend variable.

2.1.2. Methods of Measuring Total Factor Productivity Growth

There exist a number of methods for decomposing sources of growth over time and for estimating total factor productivity in the growth literature. The most widely used ones namely: The Growth Accounting Method; The Index Number Method and The Econometric Method are reviewed here.

Each of these approaches is explained below for better understanding of the empirical analysis.

2.1.2.1.Growth Accounting Method

This approach utilizes the standard neoclassical production function as a starting point for decomposing the contribution of factor inputs and technological change to output growth.

$$Y = F(K, L, t) \qquad \text{(2.12)}$$

Where Y represents output, K capital input, L labor input and t for the time.

Differentiating equation (2.12) with respect to time, dividing it by Y, and rearranging it, yields

$$\frac{dY/dt}{Y} = \frac{\partial F/\partial K}{Y}\frac{dK/dt}{K} + \frac{\partial F/\partial L}{Y}\frac{dL/dt}{L} + \frac{\partial F/\partial t}{Y} \qquad \text{(2.13)}$$

The term $(\partial F/\partial t)/Y$ in the above equation represents the proportional rate of shift of the production function. It is also known as technical change or TFP. The terms $(\partial F/\partial K)/Y$ and $(\partial F/\partial L)/Y$ are the factor shares of capital and labor respectively. If we denote growth rates of output, capital and labor inputs by small letters like y , k and l and the shares of capital and labor by S_K and S_L respectively, then, equation (2.13) can be rewritten as:

$$y = S_K k + S_L l + TFPG \qquad \text{(2.14)}$$

Using the data for growth rates of Y, K and L and for the factor shares of K and L, equation (2.14) can be used to calculate the total factor productivity growth. Hence, TFPG is calculated as a residual. It proxies a "catch-all" variable and accounts for that part of output growth not explained by the growth of factor inputs. Besides, it measures the shift in production function which might be due to technical innovation, institutional change, change in the societal attitude, fluctuation in demand, changes in factor shares, omitted variables and measurement error. To avoid the bias due to omitted variables, human capital is included in equation (2.14) in two ways. One way is to treat human capital as one factor of production and repeating the above steps modifies equation (2.14) as:

$$y = \alpha k + \beta l + \lambda h + TFP \qquad \text{(2.15)}$$

Where $\alpha + \beta + \lambda = 1$, $h = H^{\bullet}/H$ =growth of human capital and λ is its share in national income. Average years of schooling of adult population are used as proxy for human capital.

The other is to adjust the labor input for variation in labor quality as measured by wage differentials between groups of distinct education attainment. Education or training is embodied in the workers and thus better to adjust the input for variations in its quality instead of including it separately. Denoting the growth rate of adjusted labor and capital inputs by l^* and k^*, yields:

$$y = S_K k^* + S_L l^* + TFP \qquad \text{(2.16)}$$

Barro (1998) suggested a dual approach to estimate sources of growth through growth accounting method using growth rates of factor price rather than growth rate of factor quantities. This approach states that a linear homogenous production function equates output to total factor income, which may be written as

$$Y = rK + wL \qquad \text{(2.17)}$$

Where, w is wage rate and r is rental price of capital. Differentiating the above and dividing, on both sides, by gives

$$\frac{Y^{\bullet}}{Y} = \frac{1}{Y}\left[r^{\bullet}K + rK\right] + \frac{1}{Y}\left[w^{\bullet}L + wL^{\bullet}\right] \qquad \text{(2.18)}$$

Multiplying and dividing the first bracketed term by rK and the second by wL and rearranging yields the dual measure:

$$\frac{Y^{\bullet}}{Y} - S_K\left[\frac{K^{\bullet}}{K}\right] - S_L\left[\frac{L^{\bullet}}{L}\right] = TFPG = S_K\left[\frac{R^{\bullet}}{R}\right] + S_L\left[\frac{L^{\bullet}}{L}\right] \qquad \text{(2.19)}$$

This method requires rates of return on capital and wage rate which are not normally available especially in developing countries. The rate of interest may be used as proxy for rate of return on capital but biases the estimation for it is fixed by government authorities.

The growth accounting method to estimate growth sources has certain merits. First, it is very simple and easy to apply. Second, it can be applied when data is missing or scarce for some periods. Finally, it provides detail estimation for each period enabling regular monitoring of the economy. However, it also suffers from various pitfalls. One relates to the assumption of stable production function which may not be the case in the long run. Second, this method assumes linear homogeneity or constant returns to scale where as in reality there could be increasing returns to scale. Third, it assumes technological progress as hicks neutral that it increases the efficiency of labor and capital at the same rate while it may affect efficiencies of inputs differently. Fourth, this method is incapable of decomposing TFPG in to its constituent sources. Fifth, it is difficult to separately identify the factor shares of fixed or quasi-fixed labor share in GDP. Finally, the estimates of this model are not amenable for tests of significance. In sum, the growth accounting method is sensitive to the improvement in the quality of factor inputs, the share of factor inputs and the assumption related to the returns to scale; and overestimates the importance of local factors and does not measure the global impact.

2.1.2.2. Index Number Method

It is an extension and a complement of growth accounting method. This method does not necessitate the aggregate production function but selects an approximate index number. Measurement of productivity is complicated when more than one factor, say labor and capital, are used to produce more than one output, say x and y. There happens a problem of selecting the weights for each output and input to form an index. Standard forms of TFP index are:

$$A = Y / L^{\alpha} K^{\beta} \text{ And } A = Y / \alpha L + \beta K \quad \text{--------(2.20)}$$

Where A is TFP index, Y output index, L and K inputs, and α and β are respective weights. Two approaches are used for the selection of TFP index number.

First, properties of various index numbers forms are compared with desirable properties and the one with the maximum number of desirable property is used. Second, a particular index number is linked to a particular production function. In view of its superiority over the other index number forms, the Divisia –Tornqvist index is often used (Ahmed, 2007). Divisia –Tornqvist index assumes linear homogenous trans-logarithmic function, profit maximization and perfect competition and is defined as:

$$x_{jt} \text{ And } R_{it} = p_{it} y_{it} / \Sigma p_{it} y_{it} \quad \text{---------(2.21)}$$

Where Y_t refers to output index, y_{it} to quantity of i^{th} output and R_{it} to share of i^{th} output in total revenue.

Similarly, the Tornqvist input quantity index is defined:

$$I_t = \prod_{j=1}^{n} (x_{ji} / x_{ji-1})^{(1/2)} \left[s_{jt} + s_{jt-1} \right] \text{ and } s_{jt} = w_{jt} x_{jt} / \Sigma w_{jt} x_{jt} \quad \text{--- (2.22)}$$

Where I_t is for input quantity index, x_{jt} quantity of j^{th} input, and s_{jt} share j^{th} input in total cost.

The Tornqvist index is simply the ratio of output quantity index to input quantity index as:

$$TFP_t = Y_t / I_t \quad \text{\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ (2.23)}$$

This method requires the factor payments to equal the marginal productivities and reliable data series for factor incomes. The merits and limitations of this approach are similar to the growth accounting method above.

2.1.2.3. Econometric Approach

The econometric approach specifies production, cost or profit functions and then estimates it with a suitable econometric tool. The Cobb-Douglas, trans-log and CES production functions are often used for the purpose of growth regressions and each of these functions is explained below.

a)The Trans-log Production Function

There exist direct and indirect ways of estimating this production function. The direct estimation with two inputs, capital and labor, can be written as

$$Y = \exp[\alpha_0 + \alpha_L \ln L + \alpha_L \ln K + \alpha_T T + 1/2 \beta_{KK} (\ln K)^2 + \beta_{KL} \ln K \ln L + \beta_{KT} T \ln K + 1/2 \beta_{LL} (\ln L)^2 + \beta_{LT} T \ln L + \beta_{TT} T^2] + \varepsilon \quad \text{............... (2.24)}$$

Where Y , K , L and T are output, capital and labor inputs and technology respectively. This requires a large number of observations a problem in case of developing countries and presence of large number of parameters may result in multi-collinearity problem.

In the indirect method, first the cost or profit function is estimated and the duality theory is used to derive the production function. Ordinary Least squares is first used to obtain the residuals which then are employed to compute co-variances and Generalized Least Squares is applied along with restrictions on parameters. The Generalized Least Squares procedure is repeated again and again until the residuals are minimized.

b) The Cobb-Douglas Production Function

The Cobb-Douglas production function, common in growth literature, takes the form;

$$Y_t = A_t K^{\alpha}{}_t L_t^{\beta} \quad (2.25)$$

Where Y_t refers to output, K_t to capital, and L_t to labor each at time t . A_t Represents technology (TFP) parameter and α and β denote output elasticities with respect to capital and labor inputs. The technology parameter, A_t , grows at exponential rate λ and can be specified as

$$A_t = A_0 e^{\lambda t} \quad \text{---(2.26)}$$

Substitution of the above equation in to equation (2.26) yields

$$Y_t = A_0 e^{\lambda t} K^{\alpha}{}_t L_t^{\beta} \quad \text{\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_(2.27)}$$

Assuming variable returns to scale and taking logarithms on both sides of equation (2.27) gives

$$\ln Y_t = \ln A_0 + \lambda t + \alpha \ln K_t + \beta \ln L_t + \varepsilon_t \quad \text{\_\_\_\_\_\_\_\_(2.28)}$$

An estimable form of equation (2.28) may take the form

$$\ln Y_t = \beta_0 + \beta_1 t + \beta_2 \ln K_t + \beta_3 \ln L_t + \varepsilon_t \quad \text{-----------------(2.29)}$$

But under the constant returns to scale, the estimable form of equation (2.29) becomes

$$\ln Y_t / L_t = \beta_0 + \beta_1 t + \beta_2 \ln K_t / L_t + \varepsilon_t \quad \text{----------------------(2.30)}$$

Where β_2 represents the share of capital in output and partial elasticity of value added with respect to capital. The share of labor input will be one minus the share of capital.

C. The Constant Elasticity of Substitution (CES) Production Function

The general form of the CES production can be written as:

$$Y_t = \lambda\left[\delta K_t^{-\rho} - (1-\delta)L_t^{-\rho}\right]^{-\frac{v}{\rho}} e^{\varepsilon_t} \ (\gamma > 0, 0 < \delta < 1; v > 0; -1 \leq \rho) \quad \text{--(2.31)}$$

Where γ, δ, v and ρ stand for efficiency, distribution, returns to scale and substitution parameters respectively. The constant elasticity of substitution production function includes other functions such as CD and "fixed proportions" and the substitution parameter ρ is responsible for the degree of generality. Taking natural logarithms on both sides of equation (2.31) gives us

$$\ln Y_t = \ln\gamma - v/\rho \ln\left[\delta K_t^{-\rho} + (1-\delta)L_t^{-\rho}\right] + \varepsilon_t \quad \text{----------(2.32)}$$

Equation (2.32) can be linearized through the Taylor expansion process around $\rho = 0$ by dropping the terms involving powers of ρ higher than 1 and adding a time trend t to represent effect of technical change, and the estimable equation will be:

$$\ln Y_t = \beta_0 + \beta_1 t + \beta_2 \ln K_t + \beta_3 \ln L_t + \beta_4 (\ln K_t - \ln L_t)^2 + \varepsilon_t \quad \text{--------(2.33)}$$

The constant elasticity of substitution δ is equal to $1/1+\rho$. The estimable form of the CD production is nested to the estimable form of the CES function and the choice of production function specification between CD and CES is based on the test of the nested hypothesis. If the estimate β_4 is statistically significant, the CES is the appropriate model otherwise the CD is preferred.

As the econometric approach is based on parameter estimates, it can be subjected to statistical tests. However it requires the availability of consecutive data series for sufficiently large period and measures average contributions of factors for the entire period and does not give detailed estimates of sources of growth. This approach avoids the systematic measurement error in factor shares.

3. Data And Research Methodology

3.1. Description and Source of Data

Time series data about output and labor and capital inputs over the post 1991 period are required to estimate total factor productivity growth. Adequate data on these variables was not available in any single publication. Hence, the MoFED data that included better details and alternative measures is exclusively used. Likewise, the data on the stock of capital is not available in the national income accounts and the Gross Fixed Capital formation measure taken from MoFED data was used to estimate it using the perpetual inventory method that determines the present stock of capital from past streams of investment. The detail of the estimation procedures for the stock of capital is given in the appendix-B of B1. The number of economically active population for Ethiopia obtained from UN data is used to measure the labor input. The measurement of labor in this study doesn't make adjustments for variations in quality of labor and hours worked as a result of improvement in education and training in the former and due to fluctuation in economic activity in the later owning to the scarcity of data on such changes for most of the study period. GDP and capital input data are given in constant local currency unit (Birr).

3.2. Research Methodology

Both descriptive and analytical tools are used to examine the growth process of the Ethiopian economy over the study period. The descriptive study reviews some major macroeconomic variables using simple statistical techniques. On the other hand, the analytical study determines TFP growth in Ethiopia through production function-based growth accounting exercise. The estimation methods involved in the later however need to be illustrated as follows.

3.2.1. Estimation Methods

3.2.1.1. Model specification

Understanding the sources of economic growth or measuring total factor productivity growth has been a major subject in economics as it is essential to improve standards of living. Measurement of economic growth is therefore essential in order to understand and quantify it. In the growth literature there exist a number of methods for the estimation of the sources of economic growth. Three approaches: the Growth Accounting, the Index Numbers and the Econometric approaches are the most widely used methods to accounting for output growth.

The Growth Accounting method which bases the standard neoclassical production function to split output growth in to its components basically utilizes the derived equation below:

$$y = S_K k + S_L l + TFPG \quad \text{-----------------------------(3.1)}$$

Where y, k and l denote growth rates of output, and capital and labor inputs. Besides, S_K, S_L and TFP refer to, respectively, the shares of capital and labor inputs in national income accounts and total factor productivity. However, the growth accounting equation can also be formulated for growth rate of factor prices instead of factor inputs; and can be augmented /modified for improvements in human capital (Baro, 1998).

Likewise, the Index Numbers method relies on the selection of an appropriate index number for each input and output which then divides growth in to the share of inputs and TFP growth using:

$A = Y / L^{\alpha} K^{\beta}$ and $A = Y / \alpha L + \beta K$ ------(3.2)

Where A is TFP index; Y is output index; L and K are inputs; and α and β are inputs weights.

The growth accounting and index numbers methods are often best used when national income account statistics about input shares in output are more dependable; data is missing or scarce for some periods; and detailed sectoral or periodic estimation to regularly monitor the economy is required. However, these methods are based on the restrictive assumptions of constant returns to scale and perfectly competitive markets. The estimates of such models are not also amenable to tests of significance and cannot be used to further analyze total factor productivity growth. Moreover, Analysis based on these methods in poor countries (such as Ethiopia) where national income statistics is fraught with difficulties may not be reliable. The detail of the concepts and derivations of the equations the above two equations is given in the second chapter under sub section 2.1.3.

The Econometric approach unlike the others; involves flexible assumptions with regard to returns to scale and market structure to show long run relationship between variables; avoids measurement errors related to determining the share of factor inputs in output; includes estimates that are amenable to tests of significance; and enables the split of total factor productivity growth at economy or sector level in to its constituent parts. Thus, the econometric approach that conforms to the long-period growth analysis has been utilized for this study and is explained below for better understanding of the empirical investigations.

a. The Econometric Model

The Econometric approach specifies production, cost or profit functions and then estimates it with an appropriate econometric tool. The Trans-log, Constant Elasticity of substitution and Cobb-Douglas production functions are often used for the purpose of growth regressions. For instance, Mankiw, Romer and Weil (1992) used the CD form; Hsieh (2000) opted for the CES form while Rafaqat (1997) used the trans-log production function to study sources of growth in Pakistan (Antras, 2004). Most of the empirical studies in Ethiopia (such as Alemayehu (2008), Alemayehu *et al* (2005) and Easterly (2006)) used the CD production function. The specification of the production function is a crucial aspect in the estimation and analysis of sources of aggregate output growth. Specification error may result in the incorrect estimates of the share of inputs and total factor productivity growth to output growth by affecting marginal products and /or elasticities of substitution.

The estimation of the Trans-log production function involves direct and indirect approaches. The direct way of estimation is specified below (equation 4.1) while the indirect one makes use of the duality theory to derive the production function from the estimation of cost or profit functions.

$$Y = \exp[\alpha_0 + \alpha_L \ln L + \alpha_K \ln K + \alpha_T T + 1/2\beta_{KK}(\ln K)^2 + \beta_{KL}\ln K \ln L + \beta_{KT} T \ln K + 1/2\beta_{LL}(\ln L)^2$$

$$+ \beta_{LT} T \ln L + \beta_{TT} T^2] + \varepsilon \text{ --(3.3)}$$

Where Y, K, L and T are output, capital and labor inputs, and technology respectively. This requires a large number of observations that are rarely available in developing countries and the existence of a large number of parameters makes it susceptible to the problem of multi-collinearity. In view of the dearth of data pertaining to Ethiopia and the excess of parameters required for estimation, this production function is not considered in this study.

The estimable form of the Constant Elasticity of Substitution (CES) Production function- the derivation of which is available in the second chapter under subsection 2.1.3.3- can be reproduced as in equation 4.2 below. Following Ahmed (2007) that he adopted it from Wizarat (2004), the viability of the Constant Elasticity of Substitution (CES) Production function depends on whether the β_4 coefficient in the nested hypothesis below is significant or not. If the estimate for β_4 is statistically significant, the CES production function would be the appropriate model.

$$\ln Y_t = \beta_0 + \beta_1 t + \beta_2 \ln K_t + \beta_3 \ln L_t + \beta_4 (\ln K_t - \ln L_t)^2 + \varepsilon_t \quad (3.4)$$

Where Y, K and L are output, and capital and labor inputs respectively. The estimation of equation 4.2 using data on output, labor and capital for the study period is provided in appendix-A of table A3. The value for the decision parameter $(\beta_4 = 0.019)$ has been found to be highly statistically insignificant at any level of significance with t-statistics value of 0.64. This ensures that the Constant elasticity of Substitution production function is not the preferable specification for the growth process and has been reduced to the Cobb-Douglass production function.

As a result, the Econometric approach in this study specifies the basic Cobb-Douglas production function which is virtually used for estimation after certain derivations given by;

$$Y_t = A_t K_t^{\alpha} L_t^{\beta} \text{ ------------------------------------- (3.5)}$$

Where Y_t, K_t and L_t represent output and capital and labor inputs at time t. In addition, A_t refers to the state of technology (Total Factor Productivity growth) and the parameters α and β are the output elasticities of capital and labor inputs respectively.

Specifying the exponential growth of technology (TFP) parameter by $A_t = A_0 e^{\lambda t}$ and substituting it in to equation (3.5) yields:

$$Y_t = A_0 e^{\lambda t} K_t^{\alpha} L_t^{\beta} \text{ ---(3.6)}$$

Furthermore, taking logarithms on both sides of equation 3.6; and rearranging the parameters of equation 3.7 with the $\beta' s$

assuming variable returns to scale yields the estimable form of the Cob Douglas production function as in equation 3.8 below.

$$\ln Y_t = \ln A_0 + \lambda t + \alpha \ln K_t + \beta \ln L_t \quad \text{---------------------(3.7)}$$

$$\ln Y_t = \beta_0 + \beta_1 \lambda + \beta_2 \ln K_t + \beta_3 \ln L_t + \varepsilon_t \quad \ldots\ldots\ldots (3.8)$$

Where ε_t refers to the disturbance term. The output elasticities of capital (β_2) and labor (β_3) and the technology (TFP) coefficient of β_1 are then estimated using time series data on output, capital stock and labor (economically active population) with the help of an appropriate econometric tool. The estimation and interpretation of the CD production function is convenient because it involves only two variables particularly for poor countries where data is scarce.

The transformed Cobb-Douglas production function in equation 4.5 serves to indicate the long run (equilibrium) relationship between output and capital and labor inputs provided cointegration exists. The long run output elasticities of labor and capital inputs thus measure average (equilibrium) percentage contributions to output growth resulting from a percent change in each of these inputs over the sample period. However, in the short run, the output elasticities of change in factor inputs may deviate from the equilibrium (long run) level. According to Gujarati (2004), if a dependent and independent variable (s) are found to be cointegrated, the Error correction model can be used to make ties between the short run behaviors of output to its long run values. Therefore, the Error Correction mechanism specified below is utilized to examine how the short run disequilibrium in output adjusts in each period.

$$\Delta \ln Y = \alpha_0 + \alpha_2 \Delta \ln K + \alpha_3 \Delta \ln L + \alpha_4 u_{t-1} + \varepsilon_t \quad \text{----- (3.9)}$$

Where Δ denotes the first difference operator for the logarithm of each input, ε_t is a random error term, and u_{t-1} = $\ln Y_{t-1} - (\beta_0 + \beta_1 \lambda + \beta_2 \ln K_{t-1} + \beta_3 \ln L_{t-1})$ which is the one-period lagged value of the error term in the estimation (regression) of equation 3.8 above. The absolute value of the coefficient for the lagged disturbance term (α_4) shows how quickly the equilibrium restores.

b. The Growth Accounting Model

For the purpose of growth accounting, the estimable form of the CD production function can be further simplified by taking the first derivative of each term with respect to time on both sides of equation 3.8:

$$\frac{d \ln Y(t)}{dt} = \frac{d \ln \beta_0}{dt} + \frac{d\beta_1 t}{dt} + \frac{d\beta_2 \ln K(t)}{dt} + \frac{d\beta_3 \ln L(t)}{dt} \quad \text{---(3.10)}$$

Applying the fact that the rate of change of the logarithm of a variable equals the growth rate of that variable to equation 3.10 yields the growth accounting equation of:

$$\frac{\Delta Y}{Y} = \beta_1 + \beta_2 \frac{\Delta K}{K} + \beta_3 \frac{\Delta L}{L} \quad \text{------- (3.11)}$$

Where β_2 and β_3 are the growth elasticities of capital and labor inputs and $\Delta Y / Y, \Delta K / K$ and $\Delta L / L$, respectively, are actual growth rates of output, and capital and labor inputs. The total factor productivity growth or the Solow residual ($\Delta A / A$) is then derived as residual from equation 4.8. The Solow residual proxies a "catch-all" variable and accounts for that part of output growth not explained by the growth of factor inputs.

The actual growth in output can be split in to the contribution of the growth in inputs and total factor productivity given the output elasticities and growth rates of labor and capital input with the help of equation 3.11. The contribution of an input equals the product of the output elasticity of that input and the growth rate of the same input. Growth rates for output and inputs are computed as averages for different sub periods over the sample period. The growth accounting exercise has been undertaken for the three different regimes based on both the long run and the error correction model (ECM) estimates and data on the growth rate of output, and labor capital inputs.

4. RESULTS AND DISCUSSION

4.1 Descriptive analysis

4.1.1.The post 1991 Economic Performance Review

This period begins in 1991 next to the fall of the military regime and the ascent to power of the EPRDF. The return to relative peace after 1991 provided an opportunity for recovery to the Ethiopian economy that was in deep crisis by the beginning of 1990s. The new government adopted economic reforms, initiated in 1988 by the Dergue government as a 'mixed economy' option to the command economy, that took on the form of structural adjustment programs (liberalization) with the support of the Bretton Wood institutions (IMF and WB). Liberalizing agricultural market, price liberalization, a large devaluation, tax reforms and some steps towards liberalizing international trade included some of the early measures of the liberalization policy.

Reforms focused more on financial market liberalization, privatization, developing an investment code, government finance framework, fertilizer market reforms, initiatives regarding input and extension delivery and further international trade liberalization in the late 1990s. In addition, Sectoral policies included plans related to education, roads, health and agricultural extension, mainly involving substantial donor - financed capital expenditure. According to Dercon (2000) the increased spending on these sectors involved higher GDP share to capital expenditure and more importantly seemed to have more poverty concern than the previous ones.

The economic performance of the Ethiopian economy in the first decade of the EPRDF rule has been remarkable. First, there was smooth transition to peace and market oriented economy along with broad macroeconomic stability. Despite a large devaluation and domestic price liberalization, inflation was generally within one digit during this period. Fiscal deficit was also kept within reasonable limits. Secondly, there has been notable growth in GDP at both sectoral and national level. The detail on the key macroeconomic indicators of the Ethiopian economy for the whole period and sub periods is provided in the tables below.

Table 4.3. Macroeconomic indicators by sub period

Indicator	Average, in birr		
	1991/92-2002/03	2003/04-2008/09	1991/92-2008/09
GDP per capita in 80/81 price	241	-	-
GDP per capita growth	0.9	6.3	2.7
Real GDP growth			
Total GDP	3.8	11.6	6.3
Agriculture	1.1	11.5	4.5
Industry	6.1	10.6	7.6
Services	6.7	13	9
Inflation (CPI)	4.28	-	-
Gross capital formation as a share of GDP	18.8	24.1	20.5
(%)	10.4	16	12.2
Exports as a share of GDP (%)	10.3	19	13.2
Trade deficit as share of GDP	-3282	-33071	-13211.6
Current account balance(millions)	39.6	-477.7	-132.8
Overall balance of payments (millions)			

Source: Author's computations based on data from MoFED for GDP; WB for CPI, exports, imports and trade deficit; and IMF for Gross fixed capital formation.

Table 4.4 reveals that real GDP growth between 1990/91 and 2002/03 averaged 3.8 percent per annum and this figure rises to 5.4 percent if we limit the period to 1992/03 to 2000/01. Growth was the highest in the services sector (6.7 percent on average per annum) followed by industry (6.1 percent annual average). The agricultural sector grew at 1.1 percent on average per year and its share to GDP has declined to 45 percent by the end of the decade. Growth in output was large enough to bring about net improvements of 0.9 percent in the average income of the people. Over the same period, although it peaked in the transition period, inflation generally remained relatively low averaging 4.28 percent per annum. Dercon (2001), citing (IMF, 1999) writes that exchange rate has also retained a certain degree of stability with the spread between the official and parallel market exchange rate narrowing to only about 2 percent.

Exports of goods and services as share of GDP reached 10.4 percent of GDP on average per year showing a recovery from the very low levels during the transition period. Coffee export accounted for 60 percent of the total export earning and the coffee boom during the mid 1990s contributed to the revival. Non-coffee exports remained relatively low. On the other hand, imports as a share of GDP approximated 20.7 percent exceeding exports by around two to one resulting in a deficit of the difference in the balance of trade. Gross fixed investment also increased to an average annual share to GDP of 18.8 percent from about 10 percent in the early 1990s. The share of private investment in total gross investment is still about 60 percent, similar to levels in the late 1980s. Exports and gross investment figures suggest that a more structural change has occurred with more out ward oriented economy and a picking up investment.

Fiscal policy became relatively prudent. The average fiscal deficit as a share to GDP declined to 6 percent much lower than that above 10 percent in the early 1990s largely obtained via a collapse in government expenditure in the transition period (19.2 percent) and a recovery of government revenue from the mid-1990s. Moreover, close 35 percent of the government budget was spent on capital projects and expenditure on general services declined to only 45 percent while economic and social services could jointly attract more than half of the total budget. Defense spending fell to as low as 19.6 percent.

Table 4.4. Fiscal and Monetary indicators

Indicator	Period Average		
	1991/92-2002/03	2003/04-2008/09	1991/92-2008/09
Government revenue (% to GDP)	13.2	15.8	14.7
Government expenditure (% to GDP)	19.2	24.5	21.
Fiscal deficit (% to GDP)	6	11.3	6.3
Government expenditure on:			
Economic services (% to total)	29.8	38.9	34.4
Social services (% to total)	24.9	31.8	27.8
General services(% to total)Capital	45.3	24.3	33.7
expenditure (% to total)	34.9	49.2	42.6
Defense expenditure (% to total)	19.6	9.6	14.2

Source: own calculation based on data obtained from MoFED

The war between Eritrea and Ethiopia disrupted this evolution that defense expenditure rose to about 10 percent of GDP in 1999 and 2000 weakening the fiscal stance and leading to cuts in capital expenditure to social sectors and large increases in domestic financing of the fiscal deficit.

However, Dercon (2000) argues that the overall performance does not look impressive compared with the situation in the early 1980s. According to him much of the growth has been a recovery from the low GDP per capita levels in the early 1990s and inflation, expenditure and deficit were not very different from the levels in the 1990s. Turning to the second period, economic activity has been generally strong when measured in various metrics. According to government statistics, the economy registered a consecutive six-year double digit GDP growth of above11 percent. The growth was not just higher but more broad-based and less volatile with all of the three main economic sectors growing not below 6 percent and more than 60 percent of the national income statistics categories growing 8 percent or more compared to only 30 percent in the previous six years (Access capital, 2009). Improved yields and rising land use in agriculture and rapid growth in government spending and private sector services in services sector were key drivers of growth.

Exports grew at annual average rate of 25 percent (with 13 percent average volume) which is about 3/2 times world export growth implying a rise in Ethiopia's market share. The export mix is now more diversified with coffee exports down to 36 percent from 60 percent a decade ago and oilseeds, pulses, flowers, chat, leather products and gold becoming more important. Almost all of the Ethiopia's exports are undertaken by the private sector. Foreign direct investment was up by five folds in the last six years. Total government debt has been reduced to moderate levels (36 percent of GDP) due to large scale debt relief by international lenders down from 100 percent of GDP in 2001.

The external debt service burden is now less than one fifth of what it was in start of the decade. As a result, government spending on public goods notably in health, education, roads, electricity and telecommunications expanded.

However, these significant economic improvements remain modest when evaluated in per capita terms, relative to the size of the economy (GDP), compared to Africa's leading performers, the evolutionary progress in small scale agriculture and some monetary policy failures. Measures such as GDP per capita, export per capita and others do show some gains but also a very low base. For instance, although Ethiopia's per capita GDP rose from $450 (in ppp) in 1990 to $1055 in 2007, it remains 10 percent of the average world per capita income ($9543). Despite large nominal increases in some economic indicators, progress is low relative to the overall size of the economy (share to GDP). The cumulative growth since 1992 is in the mid single digits and is just below what was achieved by the three African success stories (Mozambique, Uganda and Tanzania).

4.2. Total Factor Productivity Growth: Model Estimates

We thusfar reviewed the theoretical literature relevant to the study; and the performance of the Ethiopian economy over the post 1991 period. We will now turn to measuring the Total Factor Productivity Growth (TFPG). In particular, this section presents and discusses the estimates for the contributions of labor and capital inputs, and total factor productivity (TFP) to aggregate output growth using econometric model-based growth accounting exercise. To this end, first the unit root stationarity and cointegration tests results are examined. We will also estimate the growth elasticities and carry out the growth accounting exercise.

4.2.1. Regression Results

Estimation of production functions involves times series variables, such as output, capital and labor inputs that may follow a time trend. There is then a need to test the relevant variables for stationarity to safeguard against the possibility of a spurious regression before proceeding with estimation. Hence, the Dickey and Fuller (DF) unit root test has been chiefly used to check the stationarity properties of the variables. The detailed unit root (DF or ADF) test result for each variable is presented in tables A1 and A2 in appendix A. The test values in appendix B for the first differences of the logarithm of these variables provide evidence for stationary. All the variables are found to integrated of the same order (I_1) and cointegration test can be reasonably carried out. The Dickey-Fuller (DF) and the cointegrating regression Durbin-Watson (CRDW) tests are performed to check if the variables are cointegrated or not. The results of both tests are reported in appendix A of table A1. The Cobb-Douglas production function specified in equation 3.8 and reproduced in 4.1 below is, therefore, chosen for estimation and analysis.

$$\ln Y_t = \beta_0 + \beta_1 \lambda + \beta_2 \ln K_t + \beta_3 \ln L_t + \varepsilon_t \quad \text{----------} \quad (4.1)$$

Where Y_t, K_t and L_t represent output and capital and labor inputs at time t. While β_2, β_3 and β_1 stand for, respectively, the output elasticities of capital and labor inputs, and total factor productivity growth, ε_t refers to the random error term.

The estimation of the CD production is presented in the appendix in estimation B3. The coefficient for the logarithm of capital ($\ln K$) is found to be highly statistically significant at 1 percent level of significance with a long run growth elasticity value of 0.3. This implies that a one percent average growth in the productive stock of capital on average contributed 0.3 percentage points to economic growth over the reference period. Similarly, the output elasticity coefficient for the logarithm of labor input ($\ln L$) is statistically significant at 10 percent significance level indicating that an average one percent growth in employment increased output by 0.6 average percentage points during the same period.

Moreover, the sum of the growth elasticity coefficients for labor and capital inputs (that is 0.9) differs from unity supporting the assumption of variable returns to scale made in specifying the CD production function in the proceeding section. The coefficient on the time variable has a value of 0.004 and is not statistically significant at all levels of significance. It means that no meaningful progress in technology was registered on average during the study period.

4.2.2. Growth Accounting Exercise for the Post 1991Period

We previously presented the growth elasticities of labor and capital inputs. Growth elasticities measure the effect on output of a one percent change in input. The contribution of overall changes in factor inputs and total factor productivity to actual output growth however depends on the joint effect of growth rate of factor inputs and the respective output elasticities. The growth accounting exercise decomposes the aggregate output growth in to its components as below.

$$\frac{\Delta Y}{Y} = \beta_1 + 0.30\frac{\Delta K}{K} + 0.61\frac{\Delta L}{L} \quad \text{-----------}$$
(4.3)

Where 0.3 and 0.6 are partial output elasticities reported in table 4.6. The terms $\Delta Y/Y, \Delta K/K$ and $\Delta L/L$ measure the actual growth rates in output, and capital and labor inputs during the reference period. Multiplication of the partial output elasticities by the compound input growth rates yields share of each input to growth of the economy and the total factor productivity growth parameter β_1 (Solow residual) is estimated as a residual from the same equation the results of which are given in Table 4.8. The sources of growth during this period can be analyzed in two major sub-periods; the period beginning from the coming to power of the regime to 2003 and the recent special growth period (2004-2014). This is meant to examine the sources of recent fast growth records independently.

Table 4.8. Growth accounting for Ethiopia (1961-2009): time series based model

Period	Output growth	Sources of growth		
		capital		labor
		TFPG		
Long run model				
1991-1996	3.64	2.20	1.40	0.04
1997-2003	3.74	2.43	1.68	-0.36
2004-2014	11.49	4.79	2.74	3.96
1991-2014	4.18	2.36	1.62	0.40

Source: own computation based on the MoFED data for growth in output and factor inputs.

To begin with, GDP growth in the first sub period averaged 3.69 percent where capital and labor inputs, respectively, contributed 2.31 percent and 1.54 percent and total factor productivity on average declined by -0.16. The rise in the stock of physical capital explained much of the growth in output even after allowances for productivity declines. The role of increased employment was also the next important source of GDP growth during this period.

Much of the output growth during this period came from the services (5.2 percent) and industrial (4.1 percent) sectors while the role of agriculture was minimal (1.3 percent). Large and medium scale manufacturing, construction, and electricity and water works generated much of the growth in industrial sector while growth in services sector was dominated by expansion of education, health, communication and transport services. Growth in these subsectors was in turn driven by increased public and private investment as a result of the revival in external finance and policy reform initiated by the new government. Dercon (2000) emphasizes the increased share of capital expenditure on education, health and road construction to GDP during this period. The share of investment in GDP thus rose to about 17 percent. This supports the finding that physical capital had strong contribution to economic growth over the first 13 years of the EPRDF rule.

At least two evident factors can be mentioned for the negativity of factor efficiency between 1991 and 2003, particularly the last seven years. Growth in agriculture during this sub period highly fluctuated with the highest (14.7 percent) being in 1996 and the lowest (-12.6 percent) in 2003 reflecting its dependence on weather shocks. Likewise, the war with Eritrea (1998-2000) had adverse economic consequences. Compared to the pre war period, capital expenditure went down by about 2 percent of GDP and fiscal deficit increased by more than 3 percent of GDP. Even worse, private borrowing amounted 4.1 percent of GDP in 2000 (Dercon, 2000). Such declines in public investment and possible crowd out of private investment could lead to productivity slowdown.

The second period (2004-2014) witnessed a different feature about the growth process in general and mainly the sources of that growth. GDP growth averaged 11.4 percent rare in the economic history of Ethiopia and the highest among a handful of non oil producing countries of Africa and worldwide. Physical capital contributed 4.79 percent to GDP growth while the share of labor and total factor productivity, respectively, averaged 2.74 percent and 3.96 percent. Most of the output growth (42 percent), like the previous ones, is attributed to physical capital accumulation closely followed by rise in factor efficiency (34 percent). Although in total the contribution of factor accumulation dominates (66 percent), the share of productivity gain was exceptionally sizeable during this period. Growth during this period has been more broad-based with the main economic sectors strongly growing at above six percent. Agriculture grew on average at 10.7 percent while industrial and services sectors grew at 10 percent and 12.95 percent respectively (MoFEd, 2009). Expansion in the dominant agriculture sector was driven by rising land use and improved yield. Expansion in public infrastructure and social services together with rapid growth in private service sector growth – retail trade, hotels, transportation, financial services and real estate-were key drivers of growth in service sector. Construction and large and medium manufacturing constituted much of the growth in industrial sector (MoFED, 2009). Foreign direct investment was up more than five folds and the share of investment to GDP averaged 23.78 percent (Access capital, 2012). The massive public capital investment in infrastructure and social and health services, expanded foreign and domestic private investment in large and medium scale manufacturing, construction and real sate suggest for the large role of capital to economic growth.

In theory, a rage of variables such as macroeconomic stability, openness of the economy, financial sector development, investment to GDP ratio, budget deficit, government consumption, foreign debt and etc influence total factor productivity in an economy(Ahmed, 2007). In addition, Rahel (2003), citing Senhadji (1999), writes the role of favorable initial conditions and terms of trade, political stability , lower external debt and public consumption to be associated with higher levels of TFP growth. Weather shocks are also important in rain fed agriculture.

Ethiopia experienced major macroeconomic imbalances –high inflation, weak revenue base, private sector credit crowd out and shortage of foreign exchange-during the last couple of years. In contrast, according to a review by Access Capital (2009), external debts drastically declined to 12 percent of GDP from a peak of 100 percent of GDP in 2001 while the ratio of investment to GDP rose to close to 24 percent from 17 percent in earlier years. Besides, the ratio of sum of imports and exports to GDP, a measure of openness, according to WDI data for 2011 has increased. Budget deficit declined to 4.3 percent of GDP from beyond 7 percent in previous periods (MoFED, 2009).

The same sources indicate that the last six years has seen an average 20 percent deposit growth, 40 percent profit growth, improved service and lower overhead costs by Ethiopian banks giving a clue of the development in the financial sector. Finally, the volatility of growth due to dominance of rain fed agriculture has been greatly reduced and agricultural production was relatively stable.

The positive and strong contribution of factor efficiency can be explained by, despite imbalances, the facts that the economy was more open; the share of investment to GDP rose; external debt greatly declined; budget deficit improved; and reduced shocks from weather.

Conclusions and Recommendations

5.1. Conclusions

The research tries to measure total factor productivity growth in the country for the post 1991 period. The regression-based growth accounting exercise on the sample period has been used to determine the sources of output growth. Hence, the study makes the following conclusions. First, it has been found that economic growth in Ethiopia for the post 1991 period was factor-driven. the growth accounting exercise reveals that physical capital has been the dominant sources of economic growth in Ethiopia for the post 1991 (EPRDF regime) period. Growth in capital on average explained more than half of the growth in aggregate output over the same period.

Second, labor has been the second most important component of the growth process. It has on average accounted for 38 percent of the output growth during the reference period. The share of labor substantially increased over the period perhaps due to the priority given to agriculture and labor intensive small and micro enterprises. The contribution of total factor productivity to growth increased to as high as 34 percent during the 2004-14 period. The facts that the economy has been more open; external debt significantly went down, budget deficit improved; investment share to GDP rose; and reduced shocks to agricultural production might have contributed to such spur in productivity. Thirdly, existing empirical studies on the sources of growth in Ethiopia utilized different approaches and came up with varying results. The findings of this study are found to be consistent with, despite the different approaches used, what was obtained by Alemayehu *et al.* (2005) and Alemayehu (2008). Both emphasized the role of physical capital in explaining the positive growth record. In the same way, studies on the sources of growth in sub Saharan Africa such as Tahari *et al.* (2004) and Bosworth and Collins (2003) obtained similar results.

5.2. Recommendation

The following policy proposals can be forwarded from the research findings on the role of total factor productivity on the growth process of the Ethiopian economy over the post 1991 period.

- The source of growth analysis points to the paramount importance of physical capital to output growth. This has often taken the form of massive public investment in infrastructure and social services. Hence, investment in infrastructure such as energy, communication, transport, and education and health are found to have growth payoffs and the government should thus continue investing on such public goods.
- The share of the Total Factor Productivity Growth (TFPG) during the growth process in the sample period exceeded 30 percent (it was above 34 percent). This, according to a research finding by a WB (1993) implies that the remarkable economic growth in Ethiopia is sustainable in that both factor accumulation (capital and labor) and factor efficiency are largely contributing to aggregate output growth.
- The fact that the Ethiopian economy is characterized by a growing service sector while it has a stagnant industrial sector calls for the government to strengthen its effort to encourage investment in the industrial sector by promoting conducive policies and incentives to exploit the considerable role capital investment to output growth.
- Finally, high TFPG was registered during the study period owning to policies that pursued free market economic systems; undertook more productive investments; and managed relative peace and stability reflecting more returns from increased investment, peace and freed markets.

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Appendix B

Estimation B1: Capital Stock Estimation

The capital stock has been estimated using the perpetual inventory method that relates the present stock of capital to accumulation of past streams of investment taken from Ahmed (2007).

$$k_t = w_t I_t + w_{t-1} I_{t-1} + ...w_{t-t} I_{t-t} \quad 0 < w_{t-1} < 1 \qquad \text{A4.1}$$

Assuming geometric decay of capital stock and denoting the rate of depreciation by δ :

$$k_t = I_t + (1-\delta) I_{t-1} + (1-\delta)^2 I_{t-2} + ...(1-\delta)^t I_{T-t} \qquad \text{A4.2}$$

Writing A4.2 for I_{t-1} ; multiplying on both sides by $(1-\delta)$; and subtracting the resulting equation from A4.2 yields

$$k_t - (1-\delta) k_{t-1} = I_t \;\Rightarrow k_t = (1-\delta) k_{t-1} + I_t \qquad \text{A4.3}$$

The initial stock of capital is estimated by running a linear regression of logarithm of investment (GFCF) against the time trend as used by Ahmed, citing Nehru and Dhareshwar (1993). The estimated regression using gross fixed capital formation data for the sample period is:

$$\ln K = 20.3 + 0.039t \qquad \text{A4.4}$$

$$(t = 12.1) \quad (std.eror = 0.003) \;\; R^2 = 0.7$$

Exponentiation of the constant term in A4.4 gives the initial investment of (654,904,512.2 birr) and the initial stock of capital can be computed using A4.5 given depreciation and output growth.

$$k_t = \frac{I_t}{\delta + g} \qquad \text{A4.5}$$

A depreciation rate of 6 percent suggested by Tahari *et al.* (2004) for Sub Saharan Africa is used.

Source: own estimates Note: *significant at 1 % percent level **significant at 10 percent level

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