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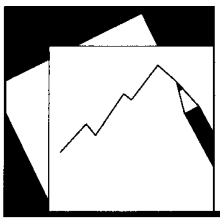

IMF Working Paper

How Can Burundi Raise Its Growth Rate? The Impact of Civil Conflict and State Intervention on Burundi's Growth Performance

Olivier Basdevant

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How Can Burundi Raise Its Growth Rate?

The Impact of Civil Conflicts and State Intervention on Burundi's Growth Performance

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Abstract

Over the last thirty years Burundi's low economic growth has led to a significant decline in per capita GDP. The purpose of this paper is to shed light on supply-side constraints that prevented Burundi's economy from growing faster. Lack of investment, civil conflict, economic inefficiencies, state intervention in the economy, and regulatory restrictions explain a large part of the weak growth performance for the last thirty years.

JEL Classification Numbers: O11, O55, C53, C82

Keywords: Burundi, Growth, Investment, Capital Stock, Kalman Filter.

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I. INTRODUCTION

1. **For the last thirty years, Burundi's low economic growth has led to a significant decline in per capita GDP**. The purpose of this paper is to analyze the factors that contributed to this poor performance and to shed light on supply-side constraints that prevent Burundi's economy from growing faster. The empirical evidence shows that lack of investment, civil conflict, economic inefficiencies, state intervention in the economy, and restrictions explain much of the weak growth performance.

2. **To analyze growth potential, a simple model is used that blends a structural approach with a Kalman filter**. Economic inefficiencies are captured with a time-varying depreciation rate of the capital stock. The model estimates capital stock consistent with the growth pattern observed. The results show that, to improve its economic performance, Burundi needs to raise the level, and the effectiveness, of investment, both public and private.

3. **Increasing investment and improving economic efficiency will both require a business-friendly environment and solid institutions**. The growth potential requires private investment. According to the World Bank study, *Doing Business*, Burundi is still among the least business-friendly countries in the world, although its ranking improved slightly from 2007 to 2008 (Table 1). If that situation continues, it will be difficult to secure the private investment needed for sustained growth.

Table 1. Doing Business 2007–08 [1]

Ease of...	2008 rank	2007 rank	Change in rank
Doing Business	174	175	+1
Starting a Business	124	114	-10
Dealing with Licenses	171	171	0
Registering Property	122	133	+9
Getting Credit	170	170	0
Protecting Investors	147	147	0
Paying Taxes	109	108	-1
Trading Across Borders	167	164	-3
Enforcing Contracts	148	147	-1
Closing a Business	178	178	0

Source: World Bank "Doing Business" (2008).

[1] 178 Countries were ranked Ranked. Doing Business 2007 rankings have been recalculated to reflect changes to the methodology and the addition of three new countries.

4. **The rest of the paper is organized as follows**: After analyzing the stylized facts of Burundi's growth (Section II), we present a simple model where capital stock accumulation plays a major role in explaining the growth pattern (Section III). Policy recommendations are then derived to increase both the amount of investment and its effectiveness (Section IV).

II. THE CONTINUED DECLINE IN GDP PER CAPITA

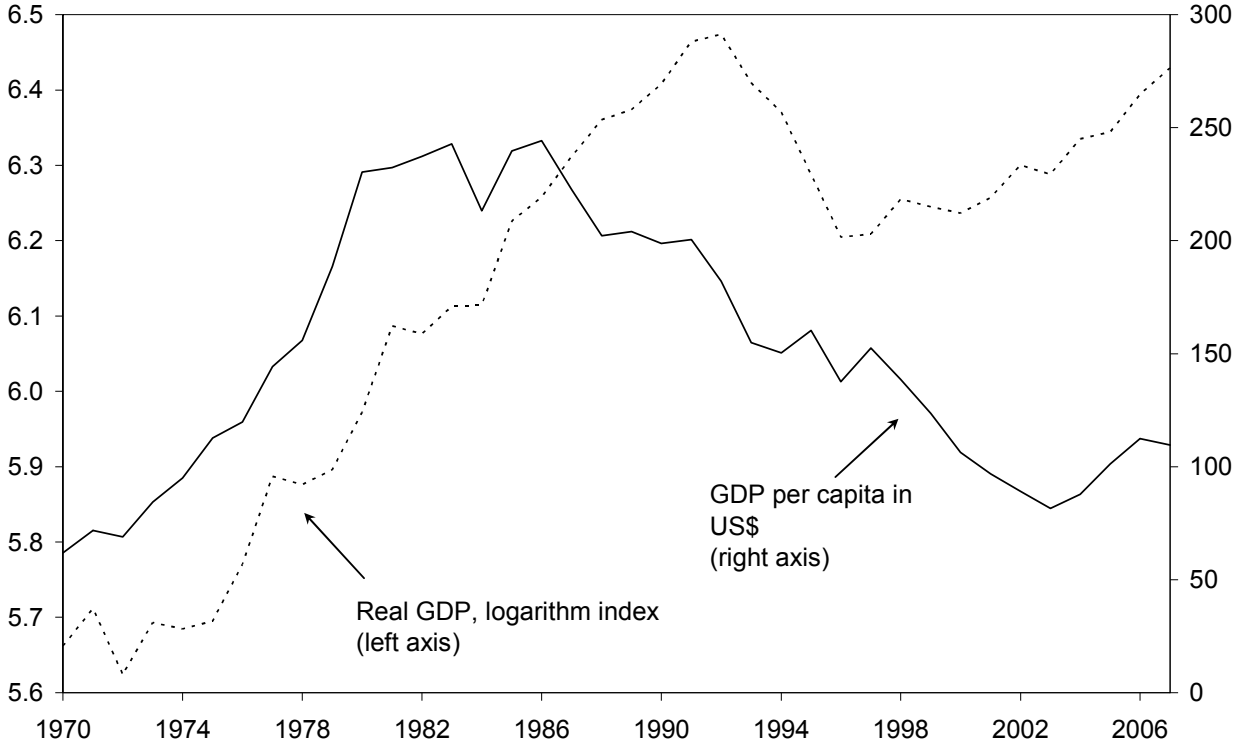
5. **From 1970 through 2007, Burundi saw its real GDP per capita decline, exacerbated by a deep recession caused by civil conflict in 1993–96** (Table 2 and Figure 1). Over the last 37 years, annual GDP growth averaged 2 percent, and GDP per capita declined by 0.6 percent a year. Burundi is today one of the poorest countries in the world, with per capita income just over $100 per year on a purchasing power parity basis. Until 1992, the growth rate was positive, and GDP per capita increased moderately. Between 1993 and 1996, Burundi's economy contracted sharply as the civil war intensified. Only in 1997 did growth turn positive, for the first time in years, but the real growth since has not been enough to reverse the downward trend in per capita GDP. By 2007 Burundi's GDP had still not recovered to its 1992 level.

Table 2. Average Growth Rates (percent)

	1970–92	1993–96	1997–07	1970–07
GDP	3.7	-6.7	2.0	2.1
GDP per capita	1.1	-7.9	-1.4	-0.6

Sources: Burundi Authorities, United Nations, and IMF staff estimates.

Figure 1. A History Marked by a Decline of Real GDP per capita, 1970–2007

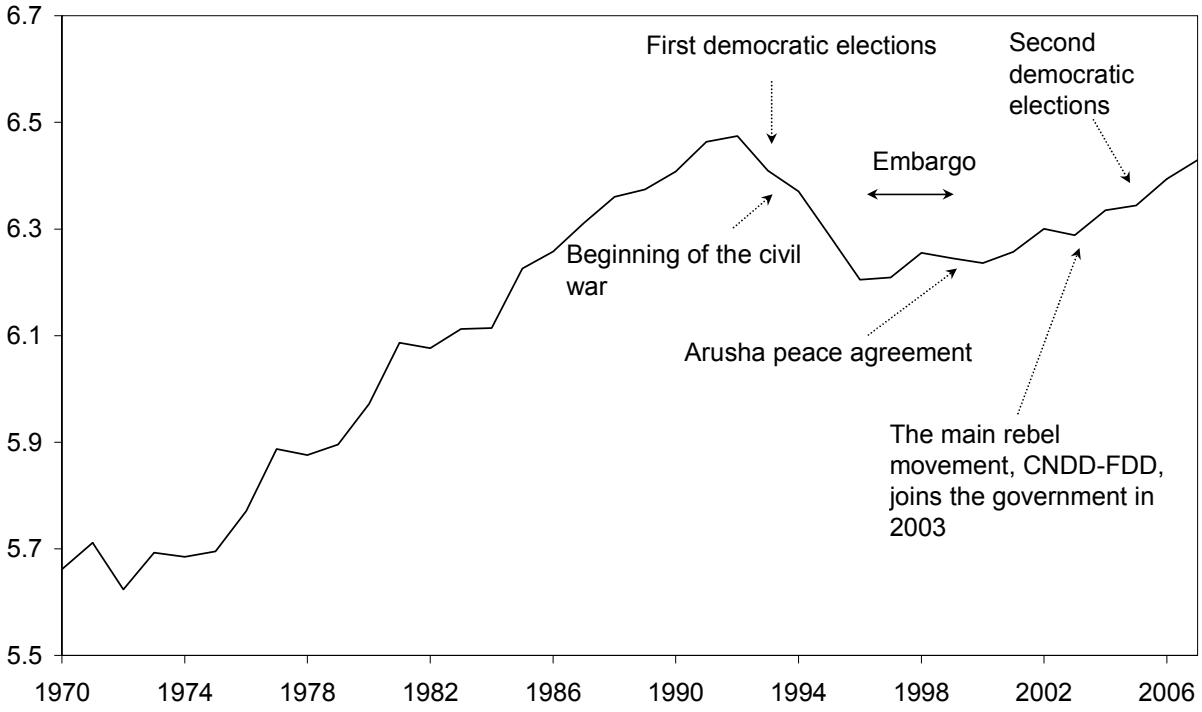


Source: Burundi authorities; and IMF staff estimates.

6. **The absence of periods of sustained high growth suggests that capacity constraints prevented Burundi from growing much faster**. Although Burundi experienced continuing political tension after 1962, until 1992 the economy managed to grow despite sporadic conflicts (see Nguessa-Nagnou and Mabushi, 2007, for a detailed discussion). A recession that began in the early 1990s (Figure 2) was aggravated not only by the civil

conflict of 1993–2000 but also by the economic embargo by neighboring countries in 1996–99. However, the moderate recovery that began in 1997, before the August 2000 Arusha peace agreement, has continued since, though very slowly. Thus, the civil conflict of 1993–2000 is not enough to explain the lack of sustained high growth over prolonged periods; Burundi faces capacity constraints, rooted in political tensions and civil conflicts. They are also linked to a dominant presence of the state in the economy.

Figure 2. The Three Growth Periods in Burundi, 1970–2007
(log of real GDP index)



Source: Burundi authorities; and IMF staff estimates.

7. **Investment has not only been low, it has been used inefficiently, exacerbating the capacity constraint and growth problems**. For 1970–2007, investment was low, on average 10.8 percent of GDP, barely half of the average for sub-Saharan Africa, which is closely related to the lower growth rate (SSA, Table 3). Investment was used inefficiently compared to the fastest-growing SSA countries, as underlined by a higher incremental capital output ratio (ICOR) [1] (Table 4). This result is consistent with Easterly (1998), who finds that the ICOR of fast-growing countries is usually in the range of 3 to 4. However, Burundi ICOR is lower than the average for Sub-Saharan Africa, but this is mostly the result of a low investment rate.

[1] ICOR measures the incremental investment attained in the past for each additional unit of output. An ICOR of 5 means that a growth rate of 1 percent was associated with an investment–to-GDP ratio of 5 percent.

Table 3. Growth and Investment in Burundi and Sub-Saharan Africa (SSA), 1970-2007

	Growth [1]	Investment [2]
Burundi	2.1	10.8
SSA		
Average	3.8	21.3
Std. Dev.	2.4	8.4

Source: Burundi Authorities and IMF Staff estimates.
[1] Percent.
[2] Percent of GDP

Table 4. ICOR in Burundi and SSA, 1970-2007

Burundi	5.2
SSA	
Average [1]	6.4
Low Growth [2]	8.5
High Growth [3]	4.5

Source: Burundi Authorities and IMF Staff estimates.
[1] All SSA countries.
[2] SSA countries with an average growth rate of 3 percent or less.
[3] SSA countries with an average growth rate of 4 percent or higher.

8. **The lack of investment in the energy sector exemplifies the need for a higher investment effort**. Equipment and infrastructure (roads, utilities) in Burundi were destroyed during the war, but they had also suffered from a lack of maintenance and investment (Box 1). The electricity sector in Burundi demonstrates the problem: Electricity is quoted in the Enterprise Survey of the World Bank as one of the main barriers to firms investing in Burundi (Table 5). This is not surprising, considering a historical lack of investment in the sector. Moreover, population displacement[2] severely disrupted the economy, allowing land, equipment, and infrastructure to deteriorate without maintenance.

9. **Investment inefficiencies largely came from State intervention in the economy, notably in the coffee sector** (Box 2). Until the early 1990s, subsidies from the government and foreign aid were used to insure producers against the risk of coffee price fluctuations. The subsidies turned out to be counterproductive because of their costs, which eventually discouraged investment in this sector.

[2] About 700,000 people fled to neighboring countries and more than 1,000,000 were displaced within Burundi.

Box 1. Energy

The economy is severely constrained by electricity shortages, which aggravate production losses (Table 5). Electricity losses account for about 30 percent of total production (World Bank, 2007) and are explained by both technical losses (underscoring the need for investment) and commercial losses due to inefficient management of distribution. In 2006, electricity outages considerably slowed what had been the very strong production of coffee milling operations. As a result, coffee exports stagnated.

Major investment could dramatically improve Burundi's hydroelectric output. Both electricity production and distribution are controlled by the state. Burundi's current hydroelectric production capacity is about 50 megawatts (MW) could be ramped all the way up to 1,400 MW[3] – 1,700 MW[4] with massive investment. For example, along the Ruzizi river are two hydroelectric plants operated by a trinational company (Burundi, Rwanda and Democratic Republic of the Congo). Electricity production is insufficient to meet the needs of the adjacent areas of these three countries and the construction of a third plant is planned. Renovation of the first two plants and construction of a third could increase lead to a capacity increase of 287 MW, for a total cost to Burundi of about $300 million (about 30 percent of GDP).

Table 5. Top 10 Constraints to Firm Investment in Burundi, 2006 [1]

Electricity	41.3
Access to Finance	16.3
Political Instability	14.5
Practices Informal Sector	6.5
Customs and Trade Regulation	3.9
Tax Rates	3.8
Transportation	3.2
Access to Land	3.1
Crime and Disorder	2.9
Corruption	2.3

Source: World Bank, Entreprise Survey, 2006.

[1] Percent of firms identifying problem as their greatest obstacle.

[3] World Resources et al. (1996).

[4] According to the Ministry of Mines and Energy of Burundi.

Box 2. Coffee

Growth potential in the coffee sector is high. Coffee is produced by about 800,000 small farmers, most of them below the poverty threshold. Coffee exports have accounted for about 75 percent of export revenues in recent years. Burundi has ideal conditions in terms of climate, soil, and elevation for high-quality mountain-grown specialty Arabica coffee (Clay et al. 2007). Increasing quality, productivity, and private incentives could significantly raise incomes and reduce poverty. However, decisions made in the 1980s were geared not toward creating a high-quality product but on increasing quantities. As a result the price of Burundi's coffee is discounted from the international price (Figure 3), though it could potentially be sold at a premium.

State intervention led to a continued decrease in the price paid to producers (Figure 3). The coffee sector was largely private until 1976, when the state took over. In 1992, a reform restructured the sector from a vertically integrated monopoly to functional separation, creating public companies OCIBU and SODECO and five SOGESTALs with some private participation. OCIBU was in charge of coffee marketing (until May 2007, when it was liberalized), regulation, and the strategy for the sector's development; SODECO managed the two main coffee-processing factories; and five SOGESTALs managed the washing stations. Producers thus had to pay fees to each of these entities.

State intervention failed to increase production durably (Figure 4). The most significant expansion in areas cultivating coffee was undertaken in the 1980s with a program of massive tree planting, meant to increase production from 30,000 to 50,000 tons by the early 1990s (see World Bank, 2007). The number of trees increased from 90 million in 1980 to over 220 million in the early 1990s. Meanwhile, areas planted with coffee grew from 40,000 hectares to over 85,000. Nevertheless, production never reached 50,000 tons, and except for two unusual years in 1981 and 1994, has never topped 35,000 tons. Since 1994, production has been decreasing and recently highly volatile from year to year . The main reasons are poor investment decision (tree were planted on soils inadequate for coffee), and lack of maintenance and investment (too many trees are too old to produce at peak year-to-year, washing stations need to be rehabilitated, access roads are damaged).

Figure 3. Coffee Price (dollar per kg), 1980–2007

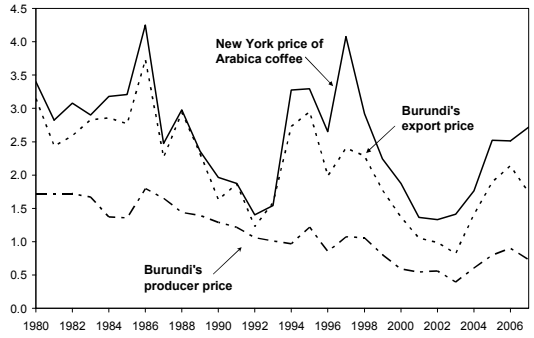
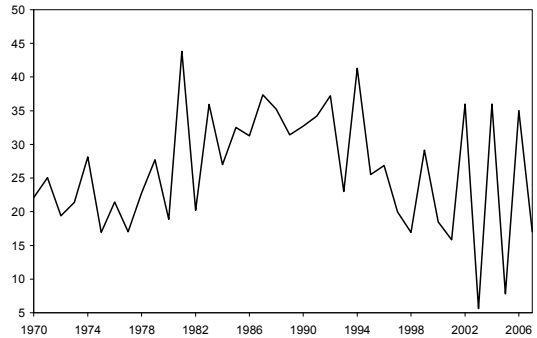


Figure 4. Coffee Production (thousand of tons), 1970–2007



10. **To raise income levels durably, Burundi needs much higher growth, which will require not only higher investment, relative to GDP, but also more effective investment expenditure**. Raising growth rates depends on the capacity of the economy to increase investment and reduce economic inefficiencies. In the following section, this capacity

constraint is modeled using a production function. The inefficiencies are captured by the depreciation rate of the capital stock, which will be estimated as a time-varying parameter. Thus, the model delivers a message in line with Jones and Olken (2005), who find that the level of investment alone has limited power to explain growth in poor countries; investment efficiency plays a much greater role.

III. Estimating the Capacity Constraint with a Production Function

11. **Using a state-space model will provide an estimate of capital stock that is consistent with observed investment data, and a time-varying depreciation rate that measures inefficiencies**. For Burundi, there is no data on capital stock, but data on investment[5] and GDP are available and can be used to estimate capital stock, following Hall and Basdevant (2002), who treat capital stock as an unobserved component of a state-space model.[6] By estimating the depreciation rate of the capital stock as an unobserved time-varying parameter, we can generate a measure of investment effectiveness. For example, periods of high investment rates but low GDP growth will result in relatively high estimated values of the depreciation rate. Conversely, a period of low investment rates and high growth will imply a low depreciation rate. Using this approach, it is therefore possible to capture the economic efficiency of investment. The impact of investment on growth can then be inferred by the rate of capital stock accumulation, and hence the supply side impact on growth.

12. **A standard Cobb-Douglas production function is used to derive an effective capital stock estimate, which will embody productivity changes and the utilization rate of productive capacities**. Since there are no official data on employment, employment data generated by the United Nations (2006) were used. These data are based on estimates of population, including refugees and migrants. Assuming homogeneity of order 1 in the production function, it is possible to decompose GDP, Y_t, between capital stock, K_t, labor, L_t, and ψ_t, a residual term:

$$Y_t = \psi_t K_t^a L_t^{1-a} \qquad (1)$$

The capital stock accumulation function depends on a time-varying depreciation rate, δ_t:

$$K_t = (1-\delta_{t-1})K_{t-1} + I_{t-1} \qquad (2)$$

$$\delta_t = \delta_{t-1} + \nu_t \qquad (3)$$

[5] For simplicity this paper does not distinguish between public and private capital stock. As a result, both public and private investments are assumed to increase the capital stock equally.

[6] See Harvey 1989 for general presentations of state-space models, or Harvey 1987 or Cuthbertson et al. 1992 for the univariate case.

with I_t being the level of investment and $\nu_t \sim N(0,Q^2)$. The model is not linear because of the multiplicative terms in equation (1) and (2). The nonlinearity in equation (2) is a direct consequence of the assumption of a time-varying depreciation rate.

13. **The model is then linearized in order to estimate it with a Kalman filter**. Equations (1) to (3) are rewritten as follows, with the convention that lower cases refer to the natural logarithm of upper-cases variable, unless otherwise indicated:

$$z_t \equiv \tfrac{1}{a}\left(y_t - (1-a)l_t\right) = k_t + \varepsilon_t \qquad (4)$$

with $\varepsilon_t = \tfrac{1}{a} Ln(\psi_t)$. We calibrate a on the basis of the approximate share of total income in the economy going to capital and labor, namely a=0.7. The precise scaling of k has no impact on the estimation results, because the only thing that really matters is the difference $k_t - k_{t-1}$. Therefore, without any loss of generality, we can consider the residual to have a 0 mean, i.e. $\varepsilon_t \sim N(0,H^2)$. Equation (4) is the measurement equation. From this measurement will be extracted a trend, identified as k_t, and a residual, identified as ε_t.

Letting i_t be the investment to GDP ratio: $i_t = I_t/Y_t$, equation (2) can be rewritten as follows:

$$\begin{aligned} k_t &= k_{t-1} + Ln\left(1 - \delta_{t-1} + \tfrac{Y_{t-1}}{K_{t-1}} i_{t-1}\right) \\ &\cong k_{t-1} - \delta_{t-1} + \tfrac{Y_{t-1}}{K_{t-1}} i_{t-1} \end{aligned} \qquad (5)$$

The ratio K_t/Y_t is a measure of the capital intensity of the economy. For a given investment effort i_t, the lower the ratio K_t/Y_t , the higher the growth rate of capital stock. During estimation this ratio is treated as a constant coefficient in order to keep the model linear. Thus, equation (5) can be estimated as follows:

$$k_t = k_{t-1} - \delta_{t-1} + \gamma i_{t-1} \qquad (6)$$

Equation (4) is the measurement equation, and the two state equations, (3) and (6), are used to estimate the capital stock and its depreciation rate. Two hyper-parameters, H^2 , the variance of errors in the measurement, and Q^2 , the variance of errors in the depreciation rate of the capital stock, are also estimated.

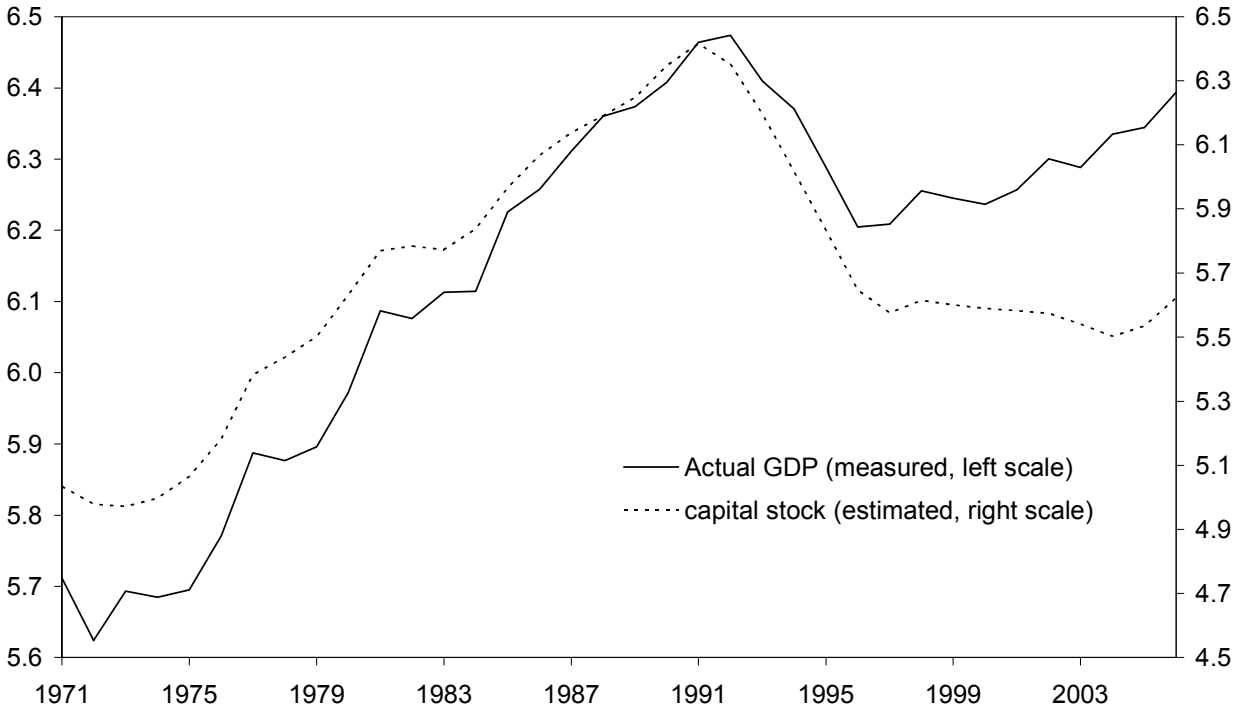
14. **Applying the Kalman filter to our specific problem yields an estimate of the effective capital stock**. The results are presented in Figure 5, which contrasts the effective capital stock (the smoothed estimate of the underlying trend) with actual GDP. The two hyper-parameters (H and Q) are estimated separately. Thus, the smoothing parameter, the ratio H^2/Q^2, is determined by the data set. When a Hodrick-Prescott (HP) filter is used, the smoothing parameter (100 for annual data) is fixed and exogenous. Such a constraint leaves aside some information that the data might provide. For

Table 6. Estimated Coefficients

	Value	Std. Dev.	T-stat
H	0.075	0.011	6.645
Q	0.072	0.018	4.004
γ	1.778	1.021	1.741

Burundi capacity constraints and negative shocks are expected to have altered capital stock accumulation. Thus, we expect to extract a trend that fluctuates a great deal, which implies a smaller smoothing parameter (i.e., H close to Q) than that of a standard HP filter.[7] The estimated hyper-parameters (Table 6) provide a smoothing parameter, H^2/Q^2, equal to 1.1—much small than the one for a HP filter, but relatively close to values suggested by band-pass filters (10 in Baxter and King, 1999; 6.25 in Rvan and Uhlig, 2002). Thus, as expected, the trend is much closer to the actual variable but fluctuates a lot. As a result, the growth path is mostly influenced by permanent shocks that induce shifts in the GDP trend; short-term fluctuations have relatively little effect. An HP filter- based analysis would have led to the opposite result, with ample short-term fluctuations.

Figure 5. Real GDP, and Capital Stock Indices, 1970–2007
(log of real variables indices)



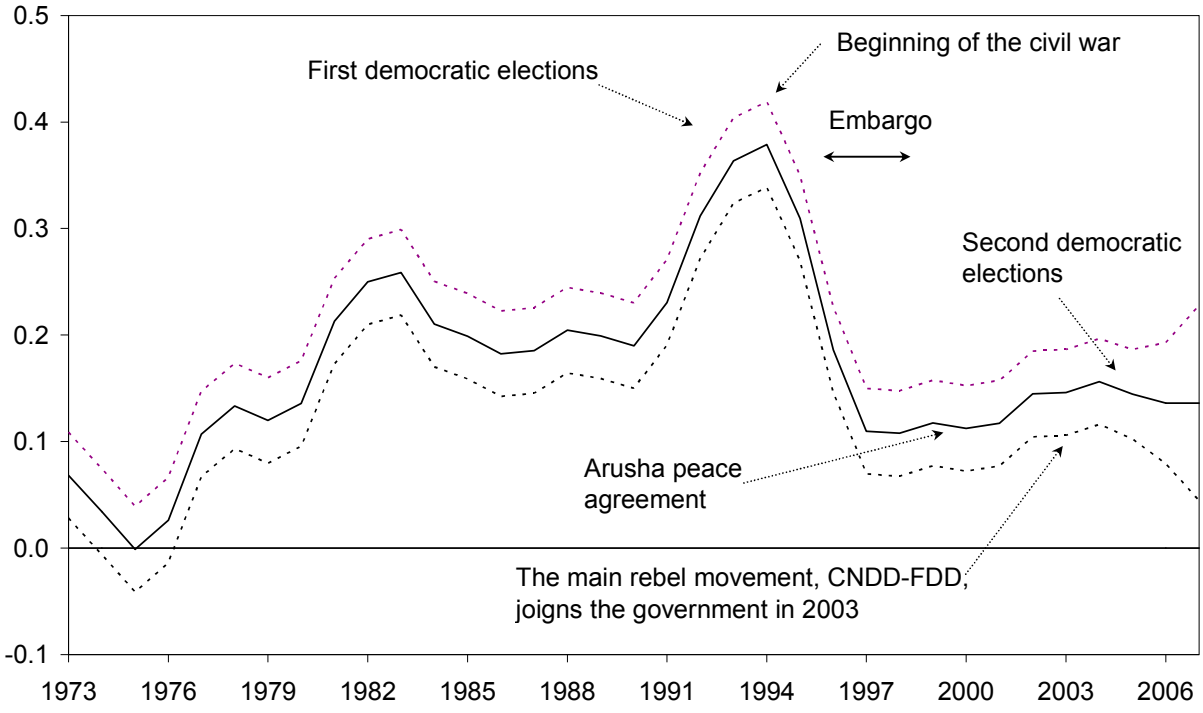
Source: Burundi authorities; and IMF staff estimates.

15. **The estimated depreciation rate of the capital stock was high for 1980–96, suggesting a long period of significant economic inefficiencies** (Figure 6). The estimation results provide fruitful insights into the relative roles of capital depreciation and investment in explaining the growth pattern. As expected, the depreciation rate is higher during most of the civil conflict period, with values peaking at about 30 percent on average. However, it stabilizes at a lower value, 13 percent on average, over 1997–2006. Thus, it appears that the lack of recovery over recent years is mostly explained by a lack of good-quality investment

[7] A more detailed discussion of the differences between the HP and the Kalman filters is provided in the appendix.

rather than an unusually high depreciation rate. However, for 1980–96 the depreciation rate was quite high, 16 percent on average. This pattern underscores the magnitude of economic inefficiencies during a period of forceful state intervention and civil conflict. The effective capital stock depreciated much faster, further reducing the effectiveness of investment. This underlines the need not only to attract further investment but also to ensure that institutions are strong enough to maximize the effectiveness of investment.

Figure 6. Estimated Depreciation Rate, 1973–2007
(± Std. Dev.)



Source: IMF staff estimates.

16. **A growth-accounting exercise based on the estimated model highlights the role of the capital stock**. By construction, the residuals of the model correspond to the Solow residual. In a standard growth-accounting exercise, capital stock would be an observed variable. Thus, the Solow residual would embody qualitative aspects that are not embodied in the quantities of inputs. Here, the model is different; because capital stock is estimated as an unobserved variable, its measure has a qualitative aspect through the time-varying depreciation rate of capital. The model estimates an *effective* capital stock, not just a capital stock *quantity*. Moreover, the Solow residual measures temporary factors, permanent ones being accounted for by the capital stock estimate. Thus, the Solow residual can be viewed as other exogenous factors that have not directed affected capital stock accumulation. For example, 1993–96 shows a strong negative impact of the Solow residual (Table 7), which is related to, among other things, the economic embargo by neighboring countries during 1996–99. This embargo imposed severe supply problems on the economy and a dramatic increase

in trade exchange restrictions. In 1997 and since, the contribution of the Solow residual becomes positive, underlying the positive impact of structural reforms and the return to peace, but the contribution of capital stock during the period remains low, underscoring the need for further investment.

Table 7. Growth decomposition (percent)

	1972–92	1993–96	1997–07	1972–07
GDP	3.6	-6.7	2.0	2.0
contribution to GDP growth of:				
Capital Stock	2.1	-5.9	0.1	0.6
Labor	1.6	0.7	1.6	1.5
Solow Residual	0.0	-1.6	0.4	-0.1

Sources: Burundi Authorities, United Nations, and IMF staff estimates.

IV. Breaking the Vicious Circle of Low Investment and Economic Inefficiency

17. **This section sets out three scenarios to analyze the pace at which Burundi might grow in the future**. Income per capita in Burundi, based on the Atlas method of the World Bank, was about $100 in 2005. Three alternative scenarios investigate how quickly income per capita can reach $900 annually, the threshold to graduate from the LIC group. The projections start with the initial value of about $100, and assume a constant growth rate of population, while investment and depreciation rates of the capital stock differ.

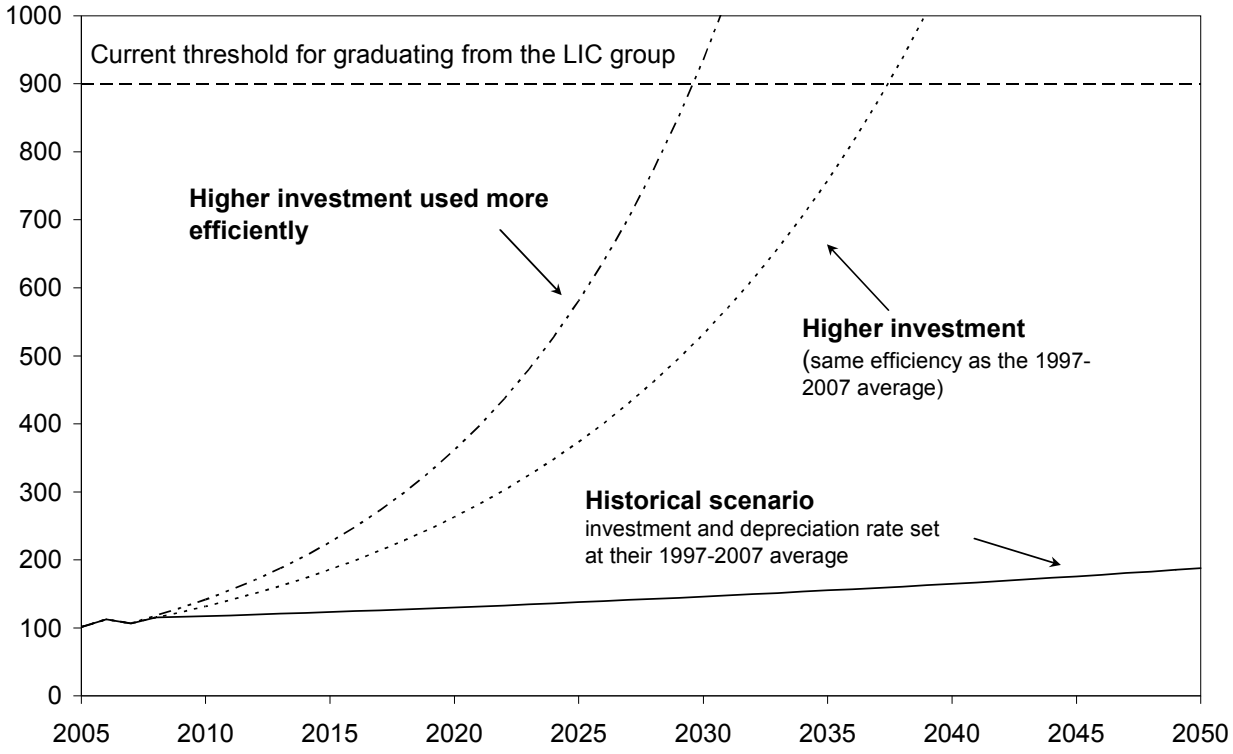
- In the "historical" scenario, the investment-to-GDP ratio and the depreciation rate of capital are set to their average value over the period 1997-2007, i.e. 10.9 percent and 13.0 percent, respectively. This scenario clearly underlines the vulnerability of Burundi's economy, as no significant improvement in GDP per capita occurs over the medium and long run.

- The two other scenarios are based on a much higher investment effort, with an investment-to-GDP ratio of 20 percent, but with different depreciation rates of capital. Although much higher than the historical ratio, such an assumption is plausible in the light of most recent data, which was around 16-17 percent in 2006-07. These scenarios can be viewed as a result of scaled-up aid, improved public finance management that raises the quality of public investment, and progress on structural reforms. One scenario ("higher investment") is based on a depreciation rate equal to the one of the historical scenario, while the other ("higher investment used more efficiently") is based under the assumption of further improvements in the use of investment, and thus assumes a low depreciation rate (6.6 percent, which corresponds to the average over 1970-75, where the estimated values are at their lowest).

18. **Burundi could graduate from the LIC group in about 2035–40, or even sooner, with a high investment effort**. Table 8 and Figure 7 present projections for income per capita based on the three scenarios. In the scenario "higher investment", growth would be sustained at about 10 percent a year. Thus, income per capita would reach the current $900

threshold for graduating from the LIC group by about 2035–40. However, if the threshold were to be revised upward by then, Burundi might need sustained assistance over a prolonged period. Graduation could happen even sooner with improved efficiency in the use of investment (scenario "higher investment used more efficiently"). In the historical scenario, the GDP growth rate of 3.6 percent would allow only minor improvement in terms of per capita GDP growth.

Figure 7. GNI per capita in constant US$ (base value 2005), 2005–50



Source: IMF staff estimates.

Table 8. Long-Run Values of Key Variables

	Investment	Depreciation rate of capital stock	Income per capita	GDP
	(percent of GDP)	(percent)	(percent change)	
Historical	10.8	13.0	1.4	3.6
Higher investment	20.0	13.0	7.7	9.9
Higher efficiency	20.0	6.6	10.4	12.7

V. CONCLUSION

19. **Burundi's growth prospects depend heavily on the capacity of the country not only to raise investment but also to make it more efficient**. The magnitude of investment

required for Burundi to graduate from the LIC group (15–20 percent of GDP) exceeds the level observed over the period 1970-2007 (10.8 percent of GDP). Moreover, the question of efficiency is probably more crucial one because it involves several factors: Burundi will need donor assistance to invest in infrastructure (transportation, utilities), but it will also need private investment. Thus, it is of utmost importance for Burundi to continue to improve the business climate and reinforce institutions to make Burundi more attractive to investors. The moves already made toward a successful transition to democracy are a promising sign of improved prospects for a stable environment.

20. **One of the main issues facing Burundi is how to move toward a market-friendly economy and tightly limit direct intervention by the state. Burundi has significant growth potential in agriculture, notably coffee, tea, and sugar**. This potential will depend on the country's capacity to produce high-quality products and enter niche markets. State intervention has failed to accomplish this in recent years. Privatizing these sectors could raise economic efficiency and pave the way for entering niche markets. Over the medium to long run, Burundi could also exploit its mineral resources (nickel, vanadium and rare-earth elements), which have not even been fully assessed yet. Developing these sectors will require not only reforms like privatization and a better business climate, but also investment in infrastructure so as to reduce transport costs and eliminate bottlenecks like those created by the lack of reliable electrical power.

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APPENDIX: THE HP FILTER VS. THE KALMAN FILTER

21. The HP filter gives an estimate of the unobserved variable as the solution to the following minimization problem:

$$\underset{\{y_t^*\}}{Min} \quad \sum_{t=1}^{T} \frac{1}{\sigma_0^2}\left(y_t - y_t^*\right)^2 + \frac{1}{\sigma_1^2}\left(\Delta^2 y_t^*\right)^2 \qquad (7)$$

22. where y is the observed variable, y^* is the unobserved variable being filtered, σ_0^2 is the variance of the cyclical component $y-y^*$, and σ_1^2 is the variance of the growth rate of the trend component. Because this problem is of course invariant to a homothetic transformation, what matters is the ratio $\lambda_1 = \sigma_0^2 / \sigma_1^2$.

23. Hodrick and Prescott (1980) suggest some parameterization of λ_1 depending on the frequency of the data.[8] Following Harvey (1985), the HP filter can be written in a state space form as follows. The measurement equation defines the observed variable as the sum of its trend and fluctuations around the trend:

$$y_t = y_t^* + e_t \qquad (8)$$

24. with $e_t \sim N(0, \sigma_0^2)$. The state equations define the growth rate of the trend that is accumulated to compute the trend itself:

$$y_t^* = g_{t-1} + y_{t-1}^* + \nu_{1,t} \qquad (9)$$

$$g_t = g_{t-1} + \nu_{2,t} \qquad (10)$$

25. with $\nu_{1,t}=0$ and $\nu_{2,t} \sim N(0, \sigma_0^2 / \lambda_1)$. $\nu_{2,t}$ is the change in the growth rate of the filtered series or trend. In other words, the change in the trend follows a random walk. Thus, to get the HP filter estimate it is necessary to use the whole set of information to derive y^* (as was done in the minimization problem (7)), i.e., to take the smoothed estimate provided by the Kalman filter.

[8] 100 for annual data, 400 for semiannual data, and 1600 for quarterly data.