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Analysis

Assessing sustainability, a comprehensive wealth accounting prospect: An application to Mozambique

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ABSTRACT

We estimate the wealth of Mozambique in 2000 and 2005 in order to assess the sustainability of its development path. Our methodology builds on Arrow et al. (2010). We show that Mozambican wealth increases through human and physical capital accumulation, while the pressure on natural capital remains low. The growth of total factor productivity enhances the outcome of the different capital assets, but population growth has a strong downward effect on wealth per capita. Results suggest that Mozambican development was sustainable between 2000 and 2005, but these remain ambiguous and are highly sensitive to data and assumptions used.

1. Introduction

Beginning in the mid 1990s, empirical approaches to evaluate a society's "productive base" or "wealth" and to assess the sustainability of a country's development have developed. David Pearce, among others, laid the foundations of empirical wealth accounting exercises (Pearce and Atkinson, 1993; Asheim, 1994; Hamilton and Clemens 1999). These contributions build on the theory of green national accounting which dates back to earlier papers such as (Weitzman, 1976; Hartwick, 1977; Solow, 1986; Hartwick, 1990; Mäler, 1991). One recent empirical contribution is the book *Where is the Wealth of Nations?*, published in 2006 by the World Bank, which provide natural capital, total wealth and adjusted net saving estimates for 120 countries. Technological progress is however not taken into account in these estimates, although it is a key aspect of sustainability issues. Actually, technological progress has long been ignored in most of the green accounting literature,[1] though in a broader growth accounting literature the growth of the total factor productivity has been commonly used as a proxy for technological progress. One of the recent green accounting empirical exercise including technological progress through the growth of total factor productivity is (Arrow et al., 2004). Arrow et al. (2010) further refined the treatment of human capital by estimating the shadow price of increase in life expectancy. They also included capital gains in non-renewable resources, gains that appear in open economies because of international prices increases.

In line with those contributions, this paper is a detailed empirical application of this theoretical framework to the case of Mozambique between 2000 and 2005. Mozambique is an interesting case study as it heavily relies on its natural wealth.[2] The main contribution of our work is thus on the empirical side. To assess the sustainability of Mozambique's development path, we collected extended datasets and numerous studies from international organizations (World Bank, Food and Agricultural Organization of the United Nations, French Agency for Development, etc.), national ministries (agriculture, fisheries, environment and forestry, national institute of statistics, health, finance, etc.), non-governmental organizations (World Wide Fund for Nature, Justice Ambiental) and Eduardo Mondlane University, Mozambique's largest centre for higher education. We have also had in-depth discussions with experts on the reliability of the data collected. This work thus relies on a compilation of almost all existing studies and databases on Mozambican natural, human and physical capital.

Basically, we use the methodology developed in Arrow et al. (2010), but with several improvements. First, we revise the method used to estimate physical capital so as to accommodate the fact that the quality of investments in sub-Saharan African countries is often low. Second, we improve the empirical treatment of the health dimension of human capital by including the variation of life

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[1] One significant exception is (Weitzman, 1997).

[2] Current mega-projects in Mozambique involve exhaustible natural resources (gas, coal and heavy sands). In addition, the population relies strongly on its renewable natural resources: 75% of the population works in the agricultural sector, which in 2005 contributed 26% of GDP (World Bank, 2005b).

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expectancy in our calculations. Third, we correct the available total factor productivity (TFP) growth estimate, which is usually estimated through a production function without natural capital, to take account of the natural capital variation that we estimate separately.

The paper is organized as follows. Section 2 recalls the theory of wealth accounting and sustainability assessments. In Section 3 we detail the methodology used to estimate the different assets and to include technological and institutional progress, population growth and climate change into the accounting. Then we present the results. In Section 4, we carry out a sensitivity analysis and we conclude in Section 5.

2. The Theoretical Framework

In this section, we briefly recall the theoretical framework on which we rely in this work. We start with a definition of the sustainability criterion used. Then we present how intertemporal social welfare variations are assessed, and the link with capital assets variations.

2.1. The Sustainability Criterion

Various economic approaches to sustainability exist, since the choice of a sustainability criterion is a complex issue. While an overview of all these approaches is not within the scope the paper, it is necessary to keep in mind that the choice of an intergenerational equity criterion is purely ethical and thus exogenous to economics. For example, such an ethical criterion could be formulated as "maximizing the wealth of the poorest generation", thus expanding Rawls' "theory of justice" to intergenerational equity. In this paper, we have rather chosen a commonly used sustainability criteria described thereafter.

Let us define intertemporal social welfare V_t at t as:

$$V_t = \int_t^{\infty} u(c(s))e^{-r(s-t)}ds \tag{1}$$

where u is a utility function, t is time, c is a vector including marketed goods consumption flow, but also non-marketed goods or services consumption such as ecosystem services, and r is the discount rate. Economic growth will be considered sustainable at time t as long as $dV_t/dt \geq 0$. To assess the sustainability of a country's development, one has thus to estimate dV_t/dt. This is what we do for Mozambique between 2000 and 2005.

2.2. The Calculation of the Inter temporal Social Welfare Variation

The consumption path C(s), and thus inter temporal welfare V_t, is determined by the evolution of the economy's productive base, the set of producing capital assets (Dasgupta, 2009). To assess V_t and its variation over time, we thus need to know the state of the productive base of the economy at time t, and we need also to assume a resource allocation mechanism to forecast the evolution of these stocks of assets over time. We will describe the economy's productive base by distinguishing three different capital assets: produced capital *K* (buildings, machines, roads, etc.), human capital *H* (education, health, etc.) and natural capital *N* (exhaustible and renewable natural resources, ecological services). At any given time, the output generated by this productive base is allocated between consumption and investment in the different capital assets, according to a given resource allocation mechanism. This mechanism can be governed by optimizing behaviours or by exogenous rules that make it non-autonomous. We assume that the resource allocation mechanism is non-autonomous, meaning that V_t is an explicit function of time. Thus we have:

$$V_t = V[K(t), N(t), H(t), t] \tag{2}$$

The allocation rules can be non-autonomous for several reasons. Dasgupta (2009) gives five examples: an exogenous technological or institutional change, global public goods (like climate), capital gains, population change and uncertainty. If we differentiate Eq. (2) with respect to time, we obtain:

$$\frac{dV_t}{dt} = \frac{\partial V}{\partial t} + \frac{\partial V}{\partial K}\frac{dK}{dt} + \frac{\partial V}{\partial N}\frac{dN}{dt} + \frac{\partial V}{\partial H}\frac{dH}{dt} \tag{3}$$

The marginal increase in intertemporal welfare from a one unit increase of the capital stock *K* (resp. *N* and *H*) is $\frac{\partial V}{\partial K}$ (resp. $\frac{\partial V}{\partial N}$ and $\frac{\partial V}{\partial H}$), and can thus be interpreted as the shadow price of the capital stock *K* (resp. *N* and *H*).

The intertemporal welfare variation, V_t thus results from two factors: i) the evolution of the three capital stocks defined previously, which we will call "comprehensive wealth", a term coined by Arrow et al. (2010), and ii) exogenous factors described by $\frac{\partial V}{\partial t}$. In this study, we assess $\frac{\partial V}{\partial t}$ through the technological and institutional change measured by the growth of the TFP, and we add the impact of climate change on the Mozambican economy. Finally, we make an adjustment to account for demographic change to obtain an estimate of the change of the productive base per capita.

3. Methodology and Results

In this section we detail the methodology used to provide our estimates of the physical, human, and natural capital. Section 3.4 deals with the calculation of the exogenous factors. Section 3.5 compiles the results and assesses the sustainability of Mozambique's development path.

3.1. Physical Capital

3.1.1. Methodology

The perpetual inventory method derives capital stocks from the accumulation of investment series. The aggregate capital stock value in period *t* is given by:

$$\sum_{i=0}^{25} I_{t-i}(1-\alpha_i)^i \tag{4}$$

where *I* is the value of past investment at constant prices (gross capital formation, from World Bank, 2005a) and α_i the depreciation rate. We derive depreciation rates over time from Jones (2006). These figures may be biased upward because the quality of investment is often very low in sub-Saharan African countries (leading to so called 'white elephants'). As a consequence, the cumulated investment flows could be a poor proxy for physical capital stocks. A variety of calculations suggest that in developing countries, less than 50% of capital is created for each public dollar invested (Pritchett, 2001). We use the same assumption. As in the World Bank study of 2006, we assume that urban land value represents 24% of produced capital (Kunte et al., 1998). Our concept of sustainability, as in Arrow et al. (2010), focuses on the changes in the productive base owned by a given country's residents. Therefore, we are interested in capital owned by Mozambicans, not capital owned by foreigners. Conversely, Mozambican residents own some physical capital outside the country. To calculate physical capital adjusted for international holdings in 2000 and 2005, we use the work of Lane and Milesi-Ferretti (2007), which constructs net holdings of international assets.

3.1.2. Results

Table 1 shows the value of physical capital in 2000 and 2005, distinguishing the Mozambican-owned physical capital from the total physical capital within the country.

This table shows a large increase in physical capital in Mozambique between 2000 and 2005. It also shows that a significant characteristic of

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Table 1
Physical capital in 2000 and 2005.

Year	All physical capital ($2005 million)	Mozambican-owned physical capital ($2005 million)
2000	7621	3712
2005	12,292	8541

Table 2
Human capital stock in 2000 and 2005.

Year	Average educational level	Average per capita human capital	Active population (over 15)	Human capital stock
2000	2.2	1.32	7,459,000	9,818,592
2005	2.6	1.38	7,765,000	10,707,736

the country's physical capital is the relatively high share of foreign capital, linked to the large number of megaprojects (especially in the mining sector) in the country.

3.2. Human Capital

3.2.1. Methodology

The Organization for Economic Cooperation and Development (OECD, 2001) defines human capital as "the knowledge, skills, competencies, and other attributes embodied in individuals that are relevant to economic activity". In this study, we focus mainly on the educational and health dimensions of human capital. During the colonial era, education of the indigenous population in Mozambique was neglected, resulting in low literacy rates. Even after the abolition of the *indigenato* in 1961, education was limited to primary schooling, so as not to produce educated opponents of the colonial power. After independence, education became a priority for the Frente de Libertaçao de Moçambique (FRELIMO) (Jones 2006). Basic education indicators have only recently begun to improve. For example, the number of children in lower primary grades rose from 1.7 million in 1997 to 2.8 million in 2003. The number of schools has been increasing, and the net enrolment rates for lower primary grades reached 69% in 2003, compared to 44% in 1997. Nevertheless, the quality of education remains low. The rate of completion of primary schooling is also low, and the number and qualifications of teachers have not increased proportionally to the number of children in primary schools.

Assessing human capital is here based on the idea that a human being, like other kinds of capital asset, generates a stream of income over time, an idea key to the method of Arrow et al. (2010), which itself builds on the seminal work of Mincer (1974). A person's human capital stock depends on the average educational attainment and the return to education. We assume here a perfect labour market, so the marginal productivity of human capital equals wages. The value of human capital is estimated through the formula $p_H * H$ in which:

- the stock of human capital H equals $P.e^{\delta A}$, where P is the working population, δ the rate of return on education and A the average educational attainment of the working population;
- the shadow price p_H of one unit of human capital equals $\int_t^{t+m} w.e^{rt}dt$, where w is the annual rental value of one unit of human capital (equals total wages divided by the total stock of human capital), r the discount rate, and m the average working years remaining until retirement or death.

The annual rental value of human capital is assumed to be constant between 2000 and 2005. The evolution of human capital value will then result from the evolution of the stock (thus the evolution of the educational attainment of the population) and the evolution of the shadow price of human capital—not the human capital of rental value, because it is assumed to be constant, but rather of the average remaining working years, which is closely linked to life expectancy in Mozambique.

3.2.2. Results

The first step is to assess the total stock of human capital. Because of data limitations, we were obliged to assess only the working population over the age of 15. From Jones (2006) we obtain a distribution of the average educational level for the working population into four categories: skilled workers, subdivided into those with primary, secondary or higher education, and unskilled workers.[3] From data on consumption and educational level in the Mozambican population, we derive a 12.5% rate of return on education.[4] Data used (average educational level and active population) and the calculated human capital stocks are shown in Table 2.

The data shows that human capital stock increased significantly between 2000 and 2005, thanks to an increase of both the active population and the average educational level.

The second step is to assess the value of one unit of human capital. One major problem is that people in Mozambique are mostly self-employed, so that it is difficult to obtain from income surveys an average annual wage or the total wage bill for the country as a whole. We therefore take the labour share in total output from the growth accounting framework used by Jones (2006). One of the baseline cases involves a simple Cobb–Douglas production function with constant returns to scale. The labour share is assumed to be 60% of total output. From the Cobb–Douglas properties, and assuming that wages reflect the marginal product of labour, we can conclude that the total wage bill amounts to 60% of GDP. This method is rather crude, but more consistent than any of the surveys on incomes that we found. We derive average remaining working years for the age 30–35 population segment—which corresponds to the average age of the working population both in 2000 and 2005—from WHO life tables and population pyramids (US Census Bureau database). Data used and results are shown in Table 3.

The shadow price of human capital has been decreasing between 2000 and 2005, mainly because of a sharp decrease in remaining working years, which is due to a corresponding decrease in life expectancy.

The stock of human capital, in Table 2, and the shadow price of human capital, in Table 3, are then used to assess the total human capital in 2000 and 2005. Results are compiled in the first row of Table 6, revealing a significant increase in human capital between 2000 and 2005. This evolution is driven by two opposing factors. On the one hand, there was a significant increase in the overall educational level over that period. Indeed, investments in the education sector were important during the 90s in Mozambique. On the other hand, the shadow price of human capital decreased, mainly a result of a fall in life expectancy, probably due to AIDS (the prevalence rate is around 16% for adults) and tuberculosis.

3.3. Natural Capital

3.3.1. Methodology

Natural capital includes exhaustible resources, renewable resources (forests, land resources, and fisheries) and environmental services produced by ecosystems (water filtration, waste assimilation, etc.). Market prices for natural assets are often missing. Thus, the

[3] We assume that primary education correspond to 7 years of schooling and secondary or higher education to a minimum of 11 years of schooling at least.

[4] We obtain this rate through a linear regression between consumption level (not wages) and logarithm of educational level, using data from (Jones, 2006) who compiled data from the *Inquerito aos Agregados Familiares sobre o Orçamento Familiar* 2002/2003 household survey.

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Table 3
Computation steps of the shadow price of human capital.

	2000	2005
Rental value of one unit of human capital ($2005)	396	372
Remaining working years	34.1	31.9
Shadow price of one unit of human capital ($2005)	7379	7178

different natural resources are valued as the present value of resource rents during the asset's lifetime:

$$\sum_{i=t}^{T} \frac{p_i q_i - C(q_i)}{(1+r)^i} \quad (5)$$

where p_i is the price at time i, q_i is production, C the production costs and r the discount rate. For each natural resource, we apply the following assumptions: a constant rental rate[5] over time, a 25-year accounting period (2005–2030), a zero value of the resource at the end of the discounting period and a 4% discount rate. The latter is of course critical. By choosing a discount rate reflecting both a potential GDP per capita rate of growth and a long term real interest rate, we implicitly choose an intergenerational equity criterion heavily in favour of those generations already born. With such a rate, the net present value of the revenues yielded by a natural resource after 25 years can be ignored. The methodology we use for natural capital calculation is similar to that of the World Bank (2006). We consider the following resources: cropland, pastureland, forests (timber, non-timber forest resources, or NTFR), protected areas, fish and mineral resources. The detailed calculations, data (on prices, production costs, and production quantities) and sources are reported in Appendix A.

3.3.2. Results

3.3.2.1. Value of Natural Capital for 2005. From Table 4, which presents the composition of natural capital for the year 2005, we can conclude that land resources are the most important part of Mozambique's natural wealth, with cropland constituting around a third of its total natural capital value. Mineral resources (gas, coal, and heavy sands) also represent also an important share, accounting for more than 40% of the natural capital. The importance of forests is understandable, given the share of timber production in the GDP, but the relatively weak role of non-timber forests is more surprising. Fisheries are also a small part of the natural wealth, mainly because economic rents are low.

3.3.2.2. Changes in Natural Capital Between 2000 and 2005. Having calculated the value of Mozambique's natural capital for 2005, we can derive the value of the different natural capital stocks in 2000 by tracing back the evolution of these stocks. We focus on subsoil assets (mainly natural gas), cropland and forest resources.

Subsoil asset depletion—To assess the depreciation of subsoil resources, we use a method coined the “quasi-optimal approach” by Atkinson and Hamilton (2007), first developed by Vincent (1996). This method assumes constant prices and an isoelastic extraction cost function with increasing marginal costs. The expression of the depletion cost is:

$$\frac{\varepsilon(pq-c)}{1+(\varepsilon-1)(1+r)^N} \quad (6)$$

where p is the price of the resource, q its production, c its extraction cost, $\varepsilon = 1.15$ is the curvature of the cost function, $r = 4\%$ the discount rate and N the resource lifetime. The quasi-optimal approach provides interesting results, as Atkinson and Hamilton (2007) find, because it is

[5] Rental rate = economic rent/output 100.

Table 4
Breakdown of natural capital.

		Net present value	
		per capita ($2005)	Total ($2005 million)
Mineral resources		940	17,860
Forest land	Timber	347	6593
	NTFR	133	2527
	Protected area	30	570
Agricultural land	Cropland	694	13,186
	Pastureland	109	2070
Marine resources	Fisheries	19	361
Total		2272	43,168

a both compromise evolved from existing accounting methods and relies on more realistic assumptions. We use data from World Bank datasheets (compiled for the calculation of genuine savings and available on the World Bank website). Natural gas and hardcoal depletion are assessed here.

Cropland degradation—Soil erosion and degradation reduce soil fertility and thereby future agricultural productivity. To estimate the cost of soil degradation on cultivated areas, we use the net nutrient replacement cost method. Folmer et al. (1998) provides figures on soil nutrients (nitrogen, phosphorus, and potassium) depletion on a national scale: 33 kg per hectare for nitrogen, 6.4 kg per hectare for phosphorus and 25 kg per hectare for potassium. These nutrients contents are converted into forms in which they exist as fertilizers (nitrogen, phosphoric acid and potassium oxide) so as to monetize the depletion.[6] In the end, the nutrient depletion described above is equivalent to a depletion of 172 kg of fertilizer per hectare. Assuming a $0.42 per kg fertilizer price (Uaiene, 2004), we estimate that soil degradation costs around $72 per cultivated hectare.

Some important limitations—first, the nutrient depletion assessed here is on a yearly basis although there may not be any depletion of nutrient stocks on a longer time scale (because of fallows and crop rotations) and second, chemical fertilizers may not be the cheapest substitute[7]—force us to consider only Mozambique's relatively small permanent crop area of around 235,000 ha. We ultimately obtain a low annual cropland capital depletion of around $17 million per year.

Forest stock depletion—We distinguish two different stocks: the roundwood stock (of commercial value) and the woody biomass stock (mainly for fuelwood). We assess the evolution of each stock, balancing annual wood harvest against annual regeneration. On a national scale, there is no depletion of these two stocks. For roundwood stock, the quantities harvested each year (135,000 m^3), even if we assume high rates of illegal logging, are below annual regeneration (500,000 m^3) as reported in Mozambique's last National Forest Inventory (Marzoli, 2008). For the woody biomass stock, the annual potential biomass productivity on a national scale (47 million tons) remains much higher than current fuelwood consumption (14 million tons) (Drigo 2008). As a consequence, we do not consider any depletion of these two stocks.[8]

One shortcoming of these calculations is that we consider one service per natural asset, although each asset can provide several services. For example, cropland degradation not only reduces agricultural productivity, but also affects soil erosion (which can in turn affect downstream dams). Externalities, and more generally interlinkages between the different assets, are poorly included.

The breakdown of natural capital depletion is presented in Table 5. The subsoil assets included are gas and coal resources, currently the

[6] The coefficients used for this conversion are: kgP*2.29 = kg P_2O_5, kg K*1.2 = kg K_2O. We assume that a bag of fertilizer contains 15%N, 15% and 15%K.

[7] Organic fertilizer or new lands would be certainly more appropriate.

[8] For the roundwood stock, there may not be a significant depletion of the overall stock (including all commercial species), but many local observers point to a rapid degradation of the quality of the forest. There would be a depletion of the most valuable roundwood species.

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Table 5
Natural capital depletion between 2000 and 2005.

	Depletion value ($2005 million)
Subsoil resources (natural gas and hardcoal)	−455
Soil resources	−85
Natural capital	−540

most important exhaustible resources of the country. Their depletion, along with cropland soil degradation, accounts for the majority of natural capital depletion.

3.4. Exogenous Factors

Having detailed how to assess the value of natural, physical, and human capital stocks, we now describe successively three exogenous factors: technological and institutional progress that enhances the overall productivity, the growth of population to obtain per capita figures and damages from carbon emissions.

3.4.1. Technological and Institutional Progress

Technological and institutional change has to be understood in the broad sense of every change that enhances the productivity of the different production factors. It can involve new technologies as well as better-performing institutions. We assume technological change to be exogenous and costless. The costless hypothesis seems reasonable for Mozambique, since we can assume that most technological progress in Mozambique results from technology transfers from foreign direct investments. Arrow et al. (2004) demonstrate under a set of assumptions (such as a Hicks neutral technology, an elasticity of output with respect to all forms of capital equal to one and a Cobb–Douglas production function) that the growth rate of intertemporal social welfare V_t is proportional to the growth rate of comprehensive wealth plus the TFP growth rate. We use TFP calculations from a recent growth accounting exercise (Jones, 2006). Jones measures TFP growth rate through a Cobb–Douglas production function that includes produced capital, labour force and human capital (measured through a human capital quality index based on the mean years of schooling). Thus, our human capital specification is not exactly the same as Jones', which is surely a shortcoming. In Jones' calculations, growth is explained by the accumulation of physical capital, the labour force and “educational capital”. TFP captures the accumulation of others types of capital (the residual), mainly natural, social (through institutions), and knowledge (technological progress). The growth rate of TFP is thus broad and heterogeneous. Since this specification of the production function does not include natural capital, the TFP growth rate produced by Jones (2006) may provide a biased estimate of the growth of intangible capital. As a consequence, we propose in Appendix B a change to the TFP growth rate to correct this bias by using a production function with natural capital.

This method suffers from several other limitations, in addition to the lack of consideration of natural capital. First, TFP growth is a very rough proxy of intangible capital variations, since it relies on the assumption of a closed economy. Indeed, in an open economy, the growth of TFP can be driven by other factors such as the openness of the economy, the terms of trade variability or the financial debt. Second, the TFP growth estimate that we use relies on a set of restrictive assumptions. The interpretation of measured TFP growth can be problematic because the estimate reflects factors other than such purely technological change as increasing returns to scale, mark-ups due to imperfect competition or gains from sectoral reallocations. The specification of the production function (Cobb–Douglas or Constant Elasticity of Substitution, for example), factor weights or the growth rates of these factors of production are thus critical in the analysis. More generally, any growth accounting exercise is highly sensitive to both the quality of underlying data and the specification of the economy. However, since many of these factors can be supposed constant for the relatively short period of five years we are looking at, this remains the best available methodology, given the existence and quality of data.

Table 6
Change in comprehensive wealth.

	2000 ($2005 million)	2005 ($2005 million)	Variation ($2005 million)
Human capital	72,448	76,857	+4409
Natural capital	43,708	43,168	−540
Physical capital	3712	8541	+4829
Carbon damage	–	–	147
Comprehensive wealth	119,869	128,565	+8551

3.4.2. Population Growth Rate

We assume that population growth is exogenous. In our study, we are interested in the growth of real wealth per capita W/P (P is the population and W the total wealth). To obtain the per capita wealth growth rate, the wealth growth rate has to be adjusted downward by subtracting population growth rate:

$$\frac{1}{W/P}\frac{d(W/P)}{dt} = \frac{1}{W/P}\left(\frac{\dot{W}}{P} - \frac{W}{P^2}\dot{P}\right) = \frac{\dot{W}}{W} - \frac{\dot{P}}{P} \tag{7}$$

Under a set of conditions (constant growth rate, per capita consumption independent of population size, and transformation possibilities among goods and services exhibiting constant returns to scale), non-declining wealth per capita can be used as a criterion for sustainable development. The assumptions are somewhat unrealistic, although widely used. Refining the introduction of population growth in wealth accounting exercises, however, is a difficult task, and beyond the scope of this paper (see (Arrow et al., 2003; Asheim et al., 2007; Ferreira et al., 2008)). The considered annual population growth in Mozambique, rated over the 2000 to 2005 period, is 2.4% (CIA, 2006).

3.4.3. Carbon Damages

To calculate the damage of carbon emissions to Mozambican wealth, we subtract from the growth in comprehensive wealth the damages (now and in the future) due to CO_2 emissions over the 2000 to 2005 period (based on the methodology developed in Arrow et al. (2010)). To assess these damages on the Mozambican wealth, first, we estimate the share of the global climate change cost that Mozambique should undergo. Nordhaus and Boyer (2000) estimate that global warming will cost 1.5% of world GDP, and 3.5% of the GDP for African countries (and thus Mozambique). As a consequence, climate change cost should represent 0.027% of the world cost.[9] Then, if we assume CO_2 emissions in the world from 2000 to 2005 to be equal to 6.6 billion tons (World Bank, 2005a), with a marginal damage cost of $50 per ton of carbon dioxide (Tol, 2005), we arrive at a global damage of $545 billion for the 2000 to 2005 period. In the end, damages from carbon emissions to Mozambique wealth is thus $147 million.

3.5. Compilation of the Results

First, we present the evolution of natural, physical and human capital assets (whose sum is called “comprehensive wealth”) and subtract the damages from global carbon emissions. Second, we account for population growth and technological change to obtain the change of per capita total wealth, including the effect of technological progress between 2000 and 2005.

[9] In 2000, the Mozambican GDP was $ 3.8 billion and the world GDP $31,800 billion.

Table 7
Per capita comprehensive wealth annual growth rate adjusted for TFP growth.

	Growth rate (%)
Comprehensive wealth growth rate	+1.2
(+) TFP growth rate	+1.46
(−) Population growth rate	−2.4
Per capita comprehensive wealth growth rate accounting for TFP growth	+0.26

Table 8
Robustness checks on physical capital ($2005 million).

			Depreciation rate		
			5%	(Jones 2006)	10%
Quality of investment	50% of investment creates capital	2000	4602	3712	2700
		2005	9199	8541	6259
	100% of investment creates capital	2000	9205	7425	5400
		2005	18,399	17,082	12,519

Note: The depreciation rate in Jones (2006) varies over time between 5% and 13%, with different rates for public and private investments.

3.5.1. Evolution of Comprehensive Wealth

The value of human, physical and natural capital assets in 2000 and 2005, as well as the variation over the period, is presented in Table 6. Damages from carbon dioxide emissions on all types of assets are also included in this table.

For the period in question, we see an important increase in both human and physical capital stocks. Human capital increased because of the increase of the average educational level, and physical capital mainly because of large scale projects. The depletion of gas stocks accounts for most of natural capital depletion, which all together appears to be relatively low.[10] In the end, the stock of comprehensive wealth has been increasing.

3.5.2. Accounting for Population Growth and Technological Change

As indicated earlier, we correct the TFP growth rate estimated by Jones (2006). Following the formula in Appendix B, we obtain a 1.46% TFP growth rate. Combining this growth rate with the comprehensive wealth and population growth rates, we can derive an estimate of the per capita growth rate for comprehensive wealth accounting for TFP growth (Table 7).

From the results presented in Table 7, we conclude that Mozambique has been on a sustainable development path between 2000 and 2005, thanks to the accumulation of comprehensive wealth (human and physical capital) and to the growth of TFP. Despite such development, population growth demonstrated a strong Malthusian downward effect on per capita wealth accumulation.

4. Sensitivity Analysis

Our results rely on a set of critical assumptions, and data used can be disputed. In this section, therefore, we develop several robustness checks on critical parameters and alternative calculations to challenge our conclusion that Mozambique's development path is sustainable. First, we propose new estimates of the three assets, their variation between 2000 and 2005 and TFP growth rates using alternative parameters. Then, we build three scenarios with these results to test the robustness of our overall conclusion.

4.1. Testing the Robustness of the Capital Assets and TFP Growth Estimates

4.1.1. Physical Capital

For physical capital, the methodology used is standard, and the usual caveats apply. The calculations are particularly sensitive to depreciation rates. We use rough figures from Jones (2006), but it is quite possible that our calculations overestimate physical capital stocks because economic or climatic shocks—such as the 2000 floods which have destroyed many infrastructures—are poorly accounted for. Results also depend on the quality of investment as previously discussed. We propose in Table 8 estimates of physical capital depending on these two parameters: the depreciation rate and the quality of investment.

We can conclude from these results that both parameters are sensitive in the analysis. Their sensitivity makes clear the need to assess the quality of physical capital investments, a crucial determinant of physical capital accumulation.

4.1.2. Human Capital

Two important parameters were critical in our human capital estimate and difficult to assess: the share of total wage bill in GDP and the rate of return on education. Table 9 presents crossed robustness checks on these two parameters, presenting the value of human capital in 2000 and 2005 with different couples of these two parameters.

The values in Table 9 are not very sensitive to the rate of return of education. They are instead quite sensitive to the share of total wage bill in GDP. This result is interesting as this parameter, the contribution of labour to GDP, is particularly difficult to assess in countries such as Mozambique, in which many activities are informal and thus not recorded in official statistics.

4.1.3. Natural Capital

For natural capital, data are particularly constraining, and our accounting is not exhaustive. For example, we could not consider groundwater depletion or rangeland degradation. The limited scope of natural assets considered should be kept in mind. We concentrate the sensitivity analysis for natural capital on gas depletion, therefore, which is a critical resource for the development of the country.

In Section 3.3.2.1, we used the quasi-optimal approach to estimate the natural gas depletion cost. In Table 10, we propose more estimates made with three alternative accounting methods: marginal rent, exhaustion, and simple present value, along with quasi-optimal (see Atkinson and Hamilton (2007) for a description of these). These methods are based on different assumptions about the evolution of extraction costs and prices.

The diverse methods provide quite different results; estimates of gas depletion costs range from $180 million, with the simple present value method, to $585 million, with the net price method. These results thus confirm that the quasi-optimal approach can be considered as a compromise between all methods.

4.1.4. TFP Growth

The TFP growth rate used as a proxy for technological and institutional progress is a key parameter in our work. As mentioned,

Table 9
Robustness checks on human capital ($2005 million).

			Share of total wage bill in GDP		
			50%	60%	70%
Return on education	8.5%	2000	60,812	72,975	85,137
		2005	63,559	76,271	88,983
	12,5%	2000	60,374	72,449	84,524
		2005	64,047	76,856	89,666
	15%	2000	60,104	72,125	84,146
		2005	64,355	77,227	90,098

[10] The exploitation of gas began only in 2004; its contribution to natural capital depletion should increase significantly in the future. By 2005, the end of the period in question, coal and heavy sands extraction had yet to begin.

Table 10
Robustness checks on natural gas depletion cost.

Method	Depreciation cost ($2005 million)
Net price	585
Marginal rent	562
Exhaustion	226
Simple present value	180
Quasi-optimal	452

Table 11
Robustness checks on TFP growth rate (%).

		Growth rate of natural resource use (%)		
		2	3.3	5
Share of natural resources in production (%)	10	1.66	1.53	1.36
	20	1.72	1.46	1.12
	30	1.77	1.38	0.87

TFP estimates from growth accounting exercises are highly sensitive to the underlying data and assumptions regarding the production function, but the adjustment we propose to correct the TFP estimate to account for natural capital omission in the production function also relies also on several assumptions such as the share of natural resources in production and the growth rate of natural resource use. We concentrate the sensitivity analysis on these two parameters. Adjusted TFP growth rates using several sets of these two parameters are presented in Table 11.

We can see that the growth rate of natural resource use is particularly sensitive in the computation of this adjusted TFP growth rate.

4.2. Testing the Robustness of the Sustainability Conclusion

We use previous robustness checks from Section 4.1 to test the robustness of the overall conclusion of Section 3—that Mozambique's development path between 2000 and 2005 could be sustained. We build three scenarios to frame the results, described in Table 12.

Scenario 1 can be considered pessimistic, built as it is on the assumptions of high wealth depreciation and low TFP growth. Scenario 2 relies on the assumptions used in Section 3 and is in our sense the most plausible. The third scenario is optimistic, assuming low wealth depreciation and high TFP growth. The population growth rate is the same in the three scenarios. Table 13 presents for each scenario the per capita growth rate for comprehensive wealth, accounting for TFP growth.

Compared to the claim made in Section 3, results are here more ambiguous. Results from scenario 1 even indicate that, despite positive comprehensive wealth and TFP growth rates, the development path of Mozambique could have been not sustainable between 2000 and 2005. Such a comparison reveals how sensitive are the results to the assumptions used, demonstrating the need to improve the quality of data.

5. Conclusions and Perspectives

This paper is an empirical contribution to the wealth accounting exercises and builds on the work carried out by Arrow et al. (2010).

Table 13
Comprehensive wealth annual growth rate adjusted for TFP growth for each scenario.

	Scenario 1	Scenario 2	Scenario 3
Comprehensive wealth growth rate (%)	+0.9	+1.2	+1.8
TFP growth rate (%)	+0.87	+1.46	+1.66
Population growth rate (%)	−2.4	−2.4	−2.4
Per capita comprehensive wealth growth rate accounting for TFP growth (%)	−0.63	+0.26	+1.06

We offer material for analyzing and characterizing Mozambique's current development path and assessing its sustainability. At this stage, no viable conclusions are possible about the sustainability of the development path of Mozambique. Indeed, results are ambiguous, depending strongly on assumptions used.

Nevertheless, this analysis provides several important insights on the country's path of development between 2000 and 2005. First, the wealth of Mozambique has been is increasing, mainly through human and physical capital accumulation while the pressure on renewable natural capital remains relatively low. Second, compared to most sub-Saharan African countries, in which TFP growth is often negative, TFP growth in Mozambiquehas been positive, indicating that there could be accumulation of technological and social capital. Third, the increase of comprehensive wealth in Mozambique has been offset by population growth, so that per capita comprehensive wealth has not been growing by much. In one of our three scenarios, it has even been declining.

Further work is needed to refine the interpretation of the growth of TFP—a key parameter in our analysis—and assess the composition of this intangible capital or residual. The impact of exogenous factors such as world commodity price increases should be also further investigated. Moreover, because of lack of data, we had to ignore the depletion of several natural capital stocks, such as fisheries and pastureland. Nor did we take into account water and air pollution, which could be important issues. However, this study represents a first step toward creating a tool for accurately and comprehensively assessing the dynamics of Mozambique's growth path.

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Appendix A. Details, Data and Sources for Natural Capital Calculations

Cropland

Main crops in Mozambique are maize, cassava, mapira, various kinds of beans, peanuts, rice, cotton, cashew nuts, potatoes and tobacco. We consider crops covering more than 60,000 ha. We assess

Table 12
Parameters used to build the scenarios.

		Scenario 1	Scenario 2	Scenario 3
Physical capital	Quality of investment	Poor	Poor	High
	Depreciation rate	10%	(Jones, 2006)	5%
Human capital	Return on education	8.5%	12.5%	15%
	Share of total wage bill in GDP	50%	60%	70%
Natural capital	Method used to assess gas depletion	Total rent	Quasi-optimal	Net price
TFP estimate	Share of natural resources in GDP	10%	20%	30%
	Growth rate of natural resource use	2%	3.3%	5%

rental rates (economic rent/output) on the basis of various agricultural production cost (mainly fertilizers and labour) studies and local market prices (Gergely, 2005; FAO producer prices). Total rent in 2005 for each crop is estimated through the formula: *Total rent (crop i) = mean yield (crop i) * market price * rental rate * crop i area.* To project total rents into the future, we use current production trends (over the last five years) for each crop.

Crop	2005 area (ha)	Yield (tons/ha)	Producer price ($/ton)	Rental rate (%)	Production growth rate (%)
Maize	1,749,534	1004	153	0.35	0.0186
Cassava	1,038,851	7341	113	0.1	0.1603
Sorghum/mapira	364,370	637	146	0.3	0.0616
Beans (all types)	659,151	500	441	0.3	0
Peanuts (all types)	433,092	341	475	0.3	−0.0206
Pumpkin	103,413	1831	164	0.3	0.0193
Rice	278,368	902	296	0.35	−0.0177
Cashew	54,616	1193	238	0.8	0.0289
Potatoes	78,938	13,046	352	0.4	0.0043
Tobacco	85,234	1388	1671	0.5	0.0444
Sesame	65,027	661	129	0.3	0.0954

Sources: TIA 2005, FAOSTAT, SIMA, Gergely (2005), Coughlin (2006), and Benfica et al. (2005).

Pastureland

Beef, goat meat and milk constitute the main output from pastureland in Mozambique. As we found no comprehensive data on production costs, we use the rental rate from the World Bank (2006) of 45%. Future rent projections are forecast using current production volume trends.

Output	Price ($/ton)	2005 production (tons)	Rental rate (%)	Total rent production growth trend (%)
Beef	4052	38,100	45	0
Sheep meat	6931	768		
Milk	518	68,765		

Sources: FAOSTAT, (World Bank, 2006).

Timber resources

We distinguish industrial roundwood from fuelwood production. For legal logging, we use national statistics from the forest ministry. We assume illegal logging is 40% of legal logging (Mackenzie, 2006). The sustainability of wood production is introduced through the lifetime of the resource (assessed with current production trends, annual regeneration, and total wood stock). The following table summarizes data used.

	2005 Production	Rental rate	2005 producer price	Available annual increment
Fuelwood	14.10^6 tons	50%	47 $/ton	$47 \cdot 10^6$ tons
Roundwood	180.10^3 m^3	40%	350 $/m3	$500 \cdot 10^3$ m^3

Sources: DNTF (2008), Marzoli (2008), World Bank (2006).

Non-timber forest resources

We use two studies providing economic values on NTFR: Suich (2006) in Bazaruto, Vilanculos and Chirendzene districts and Lizon (2002) in the Gilé district. These consider direct values only: fruit, wild animals, honey, raffia and bark, etc. (first table thereafter). As we have no information on the time spent collecting these products (the main production cost), we use a 50% rental rate (based on figures from other southern African countries). We do not add indirect values, such as watershed protection, because they are already included in cropland (or other types of activity) downstream value (if we consider the environmental service "protection against erosion"). To extrapolate from these household surveys to a country-wide scale is a risky task as we have data from only 4 sites, all in the central part of the country. We combine the average NTFR value consumed per household derived from these studies with a qualitative assessment of the importance of NTFR in the different provinces from the last national forest inventory (second table) to derive an average per household NTFR value for northern and southern provinces. To obtain the total value at the country scale, we multiply these per household value by the number of rural households in the north, centre and south of Mozambique (from population census).

Value of NTFR	Lizon (2002)	WWF (2006)			Average
Unit: $/household/year		*Bazaruto*	*Chirindzene*	*Vilanculos*	
Food	58	27	20	0	30
Medicinal plants	–	–	–	–	–
Material and construction wood	11	46	173	91	65
Wood fuel	44	126	170	132	123

Adapted from Lizon (2002) and WWF (2006).

% use of NTFR for rural households	North	Centre	South
Food	21%	38%	52%
Fodder	2%	1%	4%
Medicinal plants	29%	20%	32%
fuel	19%	18%	1%
Construction wood and utensils	25%	21%	8%

Adapted from Marzoli (2008).

Protected areas

In World Bank (2006), protected areas are valued at the lower end of per hectare returns to pastureland and cropland—a quasi-opportunity cost. Instead, we propose a rough estimate of the net present value of the network of protected areas. IUCN (2008) suggests the principal benefits from the main protected areas are ecotourism profits (net revenues from the tourist industry amount to $45 million) and the existence value of the parks through environmental NGO investments (reflecting the willingness of people in rich countries to pay for the protection of biodiversity). WWF (2008) gives an indication of the operating costs of the parks, around $5.3 per hectare per year. This figure is based on three national parks and thus does not reflect the heterogeneity of the parks (national parks, reserves and hunting reserves). To obtain the net present value of the protected areas, we assume that their opportunity cost is low (mostly because of the quantity of land available) and profits from ecotourism growth at 5% per year (which is conservative in view of the projections for tourism by the Ministry for Tourism).

Fish resources

Production data and prices are from Wilson (2008), based on statistics from the Instituto de Investigacao Pesqueira and Instituto Nacional de Desenvolvimento da Pesca de Pequeno Escala. We upwardly adjust catches by artisanal fisheries, since official statistics do not cover the whole coastal area. In accordance with local experts,

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we add 40,000 tons to recorded catches. The table that follows summarises data used.

	2005 production (tons)	2005 prices (1000$/ton)	Rental rate (%)
Industrial and semi-industrial production	31,644	3.4	10
Artisanal production (official statistics)	57,748	2.4	5

Sources: Wilson (2008) and consultation with local experts.

Mineral resources

We use results from Bucuane and Mulder (2007). Resources considered are natural gas, coal and heavy sands. Calculations are based on the method developed in Vincent (1996). It is assumed that the unit rent grows at rate g defined by: $g = r/[1+(\epsilon-1)(1+r)^T]$ where $\varepsilon = 1.15$ is the curvature of the cost function, assumed to be isoelastic (as in Vincent, 1996), r the discount rate and T the lifetime of the resource. The effective discount rate is then $r^* = (r-g)/(1+g)$ and the value of the resource stock can be expressed as: $V_t = \pi_t^* q_t^* (1+1/r^*)(1-1/(1+r^*)^T)$ where π is the unit rent and q the production. The authors use three scenarios which differ in assumed prices. We take results from their medium scenario, which considers a 1500$/TJ price for natural gas.

Appendix B. Derivation of the Adjustment of the TFP Estimate to Account for Natural Capital Omission in the Production Function

We use the TFP estimate derived in (Jones, 2006) which is the most recent work we could find. We use the Cobb–Douglas production function case to fit the estimate with our framework. The production technology is described through the following production function:

$$Y_t = A_t K_t^a (h_t L_t)^b \tag{A1}$$

with $a+b=1$, where A is an Hicks-neutral technological change, K_t the physical capital, L_t the working population and h a human capital quality index. Let us define g(x) as the growth rate of x. The growth rate of the production Y_t is thus:

$$g(Y_t) = g(A_t) + a.g(K_t) + b.[g(h_t) + g(L_t)] \tag{A2}$$

Let us add the flow from natural capital N_t, so the production function becomes:

$$Y_t = A_t K_t^{a(1-n)} (h_t L_t)^{b(1-n)} N_t^n \tag{A3}$$

where n is the share of natural resources in production. The growth rate of production becomes:

$$g(Y_t) = g_c(A_t) + a(1-n)g(K_t) + b(1-n)[g(h_t) + g(L_t)] + ng(N_t). \tag{A4}$$

Equalizing Eqs. (A2) and (A4), we obtain an expression of the corrected TFP growth rate:

$$g_c = g + a.n.g(K_t) + b.n[g(h_t) + g(L_t)] - n.g(N_t) \tag{A5}$$

For the computation, we assume that $a = 0.4$, $b = 0.6$, $g(K) = 0.45$, $g(L) = 0.01$, $g(h) = 0.018$ (Jones, 2006). For the flow from natural resources, we assume that $n = 0.2$ and $g(N) = 0.033$. 0.2 correspond to the share of agriculture in the GDP; thus it includes agricultural land, both pastureland as well as cropland, fisheries and forests resources.[11] The growth rate of cropland through extensification is 3.3%, according to data from Aviso Previo in (World Bank, 2007). We use it as a proxy for the rate of change of the flow derived from the renewable resources. Exhaustible resources are not included here as the exploitation (of gas) really began only in 2005 and the TFP growth rate estimate was assessed for the 1999–2005 period. We made a sensitivity analysis on n and g(N).

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[11] The share of natural capital in comprehensive wealth in 2005 was around 30%, so that 20% might be an underestimate.

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