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IS MINING INCOME SUSTAINABLE INCOME IN DEVELOPING COUNTRIES ?

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Abstract

I attempt to measure whether the mining sector contributes to the achievement of sustainable development or detracts from that goal in a number of developing countries. Most economic interpretations of sustainability regard sustainable development as development that provides for a non-decreasing level of welfare in the long-run. Treating income per capita as an imperfect proxy of welfare we can measure whether increases in mining sector income lead to sustainable increases in income despite the exhaustible nature of mineral deposits. This is a more encompassing criterion than the conventional Solow-Hartwick criterion which sets necessary conditions for the achievement of a similar definition of sustainability. A seven variable vector autoregression model (VAR) is estimated for each of nineteen non-OPEC developing countries with large mining sectors. The variables are mining GDP, non-mining GDP, net foreign factor payments, imports, manufactured capital, labor, and an index of human capital. Other aspects of the natural environment are treated as unobserved variables that may systematically affect parameter estimates or affect the random error terms. Using the impulse response functions, I determine the long-run multiplier of mining income on GNP. Information is also provided on the multipliers of the mining sector on manufactured and human capital accumulation which could be used in a test of the Solow-Hartwick weak sustainability criterion or used in a more comprehensive assessment of the effects of mining on development.

Is Mining Income Sustainable Income in Developing Countries ?

1. Introduction

The aim of this paper is to estimate whether income generated from the extraction of mineral deposits is sustainable over the long term. A case study is made of nineteen non-OPEC developing countries with large mining sectors.

Elsewhere I address a more general critique of the mining sector in developing countries [Stern (1994)]. This critique which has come from both proponents of dependency theory and from mainstream policy analysts asserts that the mining sector has been a poor generator of economic development in developing countries. However, it seems that some countries do get mining to work better for them than do others [Nankani (1979); Tilton (1992)]. There is, though, a possibility that this accelerated economic growth and development may be coming at the expense of the welfare of future generations.

Mining depletes high-quality mineral resources. Barnett and Morse (1963) made the argument that if minerals were exported early on in the development of an economy the economy would be disadvantaged later on in its development by a depleted resource base. This disadvantage would be mitigated if the proceeds of mineral sales were invested in productive assets that could substitute for the depleted resources. Solow (1974) presented a formal model of long-term growth, where mineral extraction could be a sustainable source of economic growth if revenues from extracted resources are used to finance investment. This idea was later formalized in the principle known as the Hartwick Rule [Hartwick (1977), (1978a), (1978b)]. More recently, this condition has been proposed as the criterion for determining the sustainability of the exploitation of exhaustible resources under the conditions for the achievement of sustainability known as "very weak sustainability" [Pearce and Atkinson (1993)].[1] If the mining sector does not generate net capital accumulation when natural capital depreciation is taken into account, then the sector might contribute to the unsustainability of development. An economy that depends on the growth of mining income alone is clearly unsustainable. The problem with criteria based on the Hartwick rule and its variants is that the indicators that are developed from particular models are dependent on the truth of those models [Common (1993)]. It is certainly unknown whether the criteria are sufficient conditions for

[1] More on definitions of sustainability below.

sustainability, and they might even not be necessary conditions for sustainability [Common and Perrings (1992)]. It should be noted that some argue that strictly speaking sustainability, in terms of a resource constraint on the possible level of sustainable welfare, is a concept that applies to a closed system ie. the world as a whole. This is the reason why that in general in this paper I refer to the sustainability of mining income. If sustainability is defined as non-declining income (see below) then any activity that raises current income above long-run possibilities is unsustainable - whether this activity is related to natural resource exploitation or not. On the other hand, in a world with imperfectly mobile factors of production and private property rights a resource constraint may be binding even in a partially open system.

Whereas most previous research has attempted to predict the future on the basis of various necessary or sufficient conditions for the achievement of sustainability, I instead measure whether development to date has been sustainable. If those countries that in the past have acted sustainably were to be able to continue their behavior into the future then we could expect current development also to be sustainable. The empirical study below will provide information on the multipliers of mining income on manufactured and human capital accumulation and also on the long-run multiplier of mining income on GNP which can be seen as an approximation to a much more general sustainability criterion that mineral extraction must have a permanent positive effect on the level of income.

There are dangers in taking these results too far, as analysis of historical time series relationships is not necessarily a guide to the future in the absence of a tested model that explains how the multiplier effect is actually mediated. If historical data show that mining income has been unsustainable in the past we can reject the null hypothesis that mining income is sustainable, however if it shows that mining income has been sustainable in the past we should be very cautious about accepting the null hypothesis. This is because there is an asymmetry to the loss function associated with this test. Policies that act under the assumption that mining income is sustainable when in fact it is not will have greater costs than the costs of policies that assume that mining is currently unsustainable when in fact it is sustainable [compare Orr (1992)].

In order to estimate these historical relationships, I use a multivariate time-series technique, vector autoregression (VARs). This modelling approach has been advocated [Sims (1980)] as an appropriate method in the presence of great uncertainty regarding the ways in which variables interact in the economy. The impulse response functions derived from the VAR can be used to estimate the mutual multipliers of all the endogenous variables in the model over an extended forecast period. I develop tests that can assess whether mining income is sustainable on the basis of these multipliers.

In the second section of this paper I survey the literature on definitions of sustainable development and analysis of the necessary and sufficient conditions for its attainment. In the third section I develop a test of the sustainability of income generation. The fourth section presents the VAR model, the fifth section some results from the VARs, and the sixth the sustainability tests. Finally I present some conclusions.

2. Sustainability : Definitions and Applications

In the 1980's much of the literature on sustainable development was vague [see Lélé (1991); Rees (1990); Simonis (1990)]. There was a general lack of precision and agreement in defining sustainability, its goals, and the appropriate policies that are required to attain those goals.

There are two major areas of debate regarding the theory and economics of sustainable development. Part of the confusion results from imprecise demarcation between these two issues :

1. The meaning of sustainable development : different practitioners and researchers have referred to different end-goals of sustainable development when they have invoked the sustainability "slogan". Tisdell (1988) has discussed this point in detail.

2. Among those who agree on a particular goal, there is often considerable debate concerning what means are appropriate in order to achieve that goal. These arguments reflect our uncertainty about the workings of natural and human systems, and uncertainty regarding likely futures. Some have concluded that no form of sustainable development is possible.

In the last few years many people have put forward much more precisely articulated definitions of sustainable development, conditions and policies required to achieve sustainability, and criteria to assess whether development is sustainable. This activity has made clear that sustainable development is a meaningful concept but that the claims of the Brundtland Report [WCED (1987)] that growth just had to change direction were far too simplistic.[2] There has been a shift in the debate from being largely politically driven to a more theory driven dialogue. With this has come a clearer understanding of what kinds of policies would be required to move towards alternative sustainability goals, and what the limits of our knowledge are. It is impossible to make precise statements about the sustainability of any course of economic

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[2] Many researchers still argue that sustainable development is a meaningless concept (eg. Amir, 1992).

development even when sustainability is clearly defined. The concept is only useful if one attempts to determine whether, to the best of our current knowledge, a specific aspect of the economic system adds to, or detracts from, overall sustainability, in some limited sense, in the short-run.

> "It is not meaningful to measure the absolute sustainability of a society at any point in time. The best that is likely to be possible is to articulate general principles to assess the relative sustainability of the society or the economic activity compared to earlier states or economic activities." [Folke and Kåberger, (1991, 289)].

I believe that significant progress can be made by adopting this approach. My general definition of sustainable development is the same as that of Pearce *et al.* (1989, 1991) : Non-declining human welfare over time. Note that this refers to per capita welfare and not aggregate welfare [Pearce *et al.* (1989)]. This definition encompasses many but not all definitions of sustainability. For example, it excludes a definition of sustainability based on a sustainable ecosystem rather than a sustainable economy, which seems to be implied by the Holling-sustainability criterion [Common and Perrings (1992); Holling, (1973), (1986)].[3] All precise definitions of sustainability imply an optimimizing principle of intertemporal equality rather than of maximizing net present value as in traditional cost benefit analysis [Pezzey (1989)].

Given the above definition of sustainability, an approach that has been seen as promising by many ecological economists, but which seems opposed to the above relative sustainability approach, suggests that the focus of research and policy must be on the means of maintaining the level of natural, manufactured, human,[4] and institutional capital [also known as : ethical or moral capital [Hirsh (1976)] and cultural capital [Berkes and Folke (1992)], or the 'integrative system' [Boulding (1978)]. This is because some theoretical models argue that nondeclining income implies a nondeclining capital stock [Victor (1991)]. This could almost be seen as a consensus as it was the topic of the ISEE conference in Stockholm in 1992 [Jansson *et al.*

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[3] That is not to say that a sustainable ecosystem is an undesirable goal but it could be too strict a criterion [Kardenas (1992)] and may lead to declining human welfare.

[4] The former three categories are used by Costanza and Daly (1992). They correspond to the classical division of the factors of production into land, capital, and labor. Human capital, as in neoclassical economics, refers to the combination of the quantity of labor and the quality of labor. Costanza and Daly sometimes use the term human-made capital to refer to the aggregate of human and manufactured capital. They do not discuss the various forms of institutional capital.

(1992)]. There are, however, many dissenters from the view that this is a useful way to address sustainability [eg. Common (forthcoming)] and it is important to assess the advantages and shortcomings of this approach. The attractiveness of this approach is that in juxtaposition to the approach I advocate above, it suggests relatively simple rules that countries need follow to ensure sustainability and relatively simple indicators of absolute as opposed to relative sustainability.

Costanza and Daly (1992), Daly (1992), and Turner *et al.* (1992) have made a contribution to conceptualizing the limits of different viewpoints on the conditions for the attainment of sustainability within the capital theoretic approach. They classify the varying views of what constitutes the requirements for sustainable development into four categories: Very weak sustainability [also called Solow sustainability, Common and Perrings (1992)], weak sustainability, strong sustainability, and very strong sustainability. The criterion that differentiates between the categories is the degree of substitutability believed to be possible between natural capital and the other forms of capital. The distinction between the main categories weak and strong sustainability is already clear in Pearce *et al.* (1989) though the terminology is not used. This terminology is in itself confusing as it suggests that the various writers have differing ideas of what sustainability is, when in fact they all agree on that point but differ on the conditions that would be either necessary or sufficient to achieve sustainability. The concept of natural capital appears to have originated with Smith (1977). There are a number of problems with this concept as discussed below.

According to those who subscribe to the very weak sustainability viewpoint, there is no critical natural capital. That is, there are no natural resources that contribute to human welfare that cannot be fully replaced by other forms of capital. There is perfect substitutability between natural capital and other forms of capital. Growth could continue indefinitely as long as the economy obeys the sustainability criterion that it invests income derived from the exploitation of exhaustible natural resources in manufactured and human capital that can yield a stream of income of the same size in the future. This principle is known as the Hartwick Rule [Hartwick (1977), (1978a), (1978b)].

However, this assessment of the necessary conditions for sustainability violates the Second Law of Thermodynamics, as a minimum quantity of energy is required to transform matter into economically useful products [Hall *et al.* (1986)], and ecological principles regarding the importance of diversity in system resilience [Common and Perrings (1992)] which imply that there is critical natural capital. Costanza and Daly (1992) point out that the mere existence of manufactured capital demonstrates that natural capital is not a perfect substitute for manufactured capital and *vice versa*. This is also supported by various econometric studies of energy-manufactured capital complementarity in the manufacturing sector [Berndt and Wood (1979)]. Weak sustainability assumes that there are lower bounds on the stocks of natural capital required to support the economy, in terms of the supply of materials and energy, and in terms of the assimilative capacity of the environment, and that certain categories of critical natural capital cannot be replaced by other forms of capital.

The strong and very strong sustainability positions are characterized by the belief that natural capital can only be substituted to a very limited degree, or not at all, by other forms of capital and by increasing degrees of concern with the various forms of institutional capital. The work of Daly and his associates, who call for a steady-state economy is characterized by this *Weltanschaung* [Daly (1977); Daly and Cobb (1989); Costanza and Daly (1992)]. Costanza and Daly (1992) specifically state : "It is important for operational purposes to define sustainable development in terms of constant or nondeclining total natural capital, rather than in terms of nondeclining utility." (39). This would imply increasing stocks of renewable resources to counter the depletion of non-renewable resources [5] and as sustainability must be defined on a per capita basis, increasing total natural capital with increasing population. Actually it is debatable whether there is any substantial difference between the proponents of weak and strong sustainability apart from terminology. For example two proponents of the strong sustainability viewpoint state :

> "There are clear economic limits to growth, but not development. This is not to assert that there are no limits to development, only that they are not so clear as the limits to growth, and consequently there is room for a wide range of opinion on how far we can go in increasing human welfare without increasing resource throughput. How far can development substitute for growth ? This is the relevant question, not how far can human-made capital substitute for natural capital, the answer to which, as we have seen, is 'hardly at all'" [Costanza and Daly (1992, 43)].

Costanza and Daly (1992) use growth to mean an increase in output [6] proportional to an increase in the inputs to the economy. Any increase in output beyond a one to one relationship,

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[5] Cutler Cleveland suggested that the definition of capital includes adjustment for changes in productivity. In that case improvements in the productivity of both renewable and non-renewable natural capital could also be used to counter the decline in stocks of non-renewable resources. In that case this definition does not vary a great deal from the weak sustainability case - also see further comments below.

[6] Output = gross income.

or any change in the composition of output broadly defined, is termed development. As any increase in income is normally termed growth in the neoclassical literature, they are admitting the possibility of infinite growth in a finite world. The difference is that this would be achieved through applying unlimited quantities of knowledge to a fixed aggregate capital base rather than in the Solow-sustainability models applying increasing quantities of manufactured capital to decreasing quantities of natural resources. Daly (1992) specifically argues that "No one denies the reality of technical progress, but to call such changes the substitution of capital for resources is a serious confusion". This is true, but the primary question is whether human society can get more output out of less resources, and is only secondarily about whether more manufactured capital or more knowledge is required to substitute for natural resources. In most cases technical progress cannot be separated from the installation of new manufactured capital [Sen (1970)] or the use of more energy and natural resources [Cleveland *et al.* (1984); Jorgenson (1984); Hall *et al.* (1986)]. Human-made capital cannot totally replace natural capital in the production of natural resource services or commodities but it can substitute for it to a relatively large degree in the production of final goods and services.

There have been many recent attempts to provide a conceptual basis for estimating natural capital stocks and estimating sustainable levels of income based on the capital theory approach [eg. Ahmad *et al.* (1989)] and to provide actual empirical estimates of the value of natural capital depletion [eg. Repetto *et al.* (1989)] and sustainable income. Pearce and Atkinson (1993) present some data on savings and depreciation of natural and manufactured capital as a proportion of GNP in eighteen countries. Only eight countries had non-declining stocks of total capital and thus passed a weak sustainability criterion of a constant aggregate capital stock. These results are not adjusted for population growth to determine a constant per capita capital stock. So the test is only valid if the rate of technical change is equal to the rate of population growth plus the rate of improvement in the quality of human capital. These latter variables are not considered in any of the literature on the capital basis of sustainable development.

The basic problem with all the literature that attempts to develop sustainability indicators on the basis of the natural capital conditions required for sustainable development is that all of them are only true indicators that society is on a sustainable development path under very limited and unlikely conditions. The problem of aggregating a natural capital stock or an aggregate capital stock are formidable and these procedures are only valid under certain production structures [see Berndt and Christensen (1973)]. Kardenas (1992) points out that some natural assets are not limiting factors, it is only the natural assets which are limiting factors with which we need be concerned. The condition of a constant stock of natural capital implies that the economy is on the boundary of unsustainability with regard to every component of the natural capital vector beyond which depletion would threaten system stability. Norgaard (1991) points out that capital aggregation depends on a set of prices for the individual capital stocks being aggregated. This price vector will change over time with changing scarcities and changing technologies. Thus society may pass on assets to the next generation worth more in their valuation than those they received from the previous generation but yet the course of development might still not be sustainable. Going further, Perrings (1987) argues against placing prices on in situ environmental resources under any circumstances, stating "Few other ideas in economic theory can be so obviously misplaced" (94).

All this has been expressed very clearly by Common (1993) :

> "There is no prospect of a unique measure of PNDP [proper net domestic product]. What this approach would measure is PNDP for a model, not PNDP for an actual economy. And, the nature of adjustments to conventionally assessed NDP seen as required would also be model dependent ... [Sustainability] is not a problem that can be reduced to the dimensions of a single number indicator." (8-11)

In sum it is basically impossible to determine whether the economy as a whole is sustainable on the basis of indicators derived from some investment rules. It is pretty clear though that some individual economies are on unsustainable paths as shown by their actually declining incomes per capita. Also the world economy as a whole appears to be on an unsustainable path as far as CO_2 accumulation is concerned. Whether this has already caused an increase in the average temperature of the atmosphere is immaterial. To the best of our current knowledge, if fossil fuels continue to be burned at current rates the build-up in CO_2 will eventually cause warming. Here is a case of the accumulation of too much natural capital ! This is a serious point, because up to a certain point CO_2 is a necessary natural good, but beyond that point excess becomes a bad [compare O'Connor (1993)]. This means that it would be very difficult to aggregate the CO_2 stock into an overall measure of natural capital.

Finding ways to deal with sustainability empirically are still important - they are necessary to aid policies that might guide the economy in a *more* sustainable direction. We might want to curtail activities that "threaten" sustainability [Common (forthcoming)]. Not that we know for sure that they will lower the level of income in the future, but we might have good reason to suppose so and there may often be other benefits to adopting the policy eg. increased employment from policies to reduce greenhouse gases by shifting taxes from labor to fossil fuels. There are two directions we can go in trying to grapple with the sustainability issue. Various sustainability indicators can be developed to determine whether activities are likely to add or detract from the sustainability goal [see Cleveland and Stern (1993)]. The second approach is to develop models of the economy that at least to some degree take into account the processes that affect sustainability. These models could then be used to assess the impacts of policies or activities on the level of income in the future. The indicators derived from the first type of analysis could be used in models of the latter type. Basically this approach is that taken by the Limits of Growth [Meadows *et al.* (1972)], Carrying Capacity [Gever *et al.*, (1986)], and Beyond the Limits [Meadows *et al.* (1992)] studies.

Let us assume for the moment that a country obeys the Hartwick rule and invests all the rents derived from mineral exploitation in manufactured assets, and examine what further pitfalls may be encountered by such a country. Nankani (1979) argues that mineral extraction can only lead to development if the social milieu and policy environment are supportive. "The success of the mineral economies will depend significantly on the quality and mobility of their internal factors of production, and on the policy environment they establish for economic decision-making. Together, these two sets of factors will determine their capacity to transform as their mineral rents wither away or as demand for their mineral decreases" (p6). Bomsel (1992) goes further showing that some governments have used mining rents not just in wasteful or unproductive ways but in ways that damaged other sectors of the economy. Daniel (1992) points out that if governments try to use mining rents to fund domestic investments they may quite quickly run into capacity constraints in terms of the economy's ability to produce the necessary capital goods or to utilize them effectively. He recommends that governments invest abroad that part of the rent that cannot usefully be used domestically as in the example of Kuwait's investment funds.

The Dutch disease occurs in an economy where one booming, typically extractive sub-sector, where natural resources are a sectorally specific factor, coexists with a declining (typically manufacturing in developed countries and agricultural in developing countries) sub-sector within the traded goods sector. Basically, a rise in wages and the exchange rate, due to the sectorally specific factor causes the decline in non-extractive output.[7] The majority of empirical studies [eg. Gelb (1986), Forsyth (1986), Warr (1986)] corroborate this model. All of this suggests that investments of rents may be ineffective in generating income and that mining may have external effects on the macroeconomy. Things are much more complicated in reality than suggested by the conditions of optimal depletion and investment models. Therefore, it would be unwise to use criteria derived from such models to examine whether mineral extraction yielded a sustainable income in a real-world economy.

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[7] See Corden and Neary (1982) for more details.

3. A Test of Sustainability

In the following paragraphs I develop a model, that can be used as a general test of the historical sustainability of income derived from an industry that extracts an exhaustible resource. The model does not require any assumptions regarding the conditions necessary to achieve sustainability. It uses historical data to assess what the links between long-run income and mining have been in the past. As discussed above, It provides no guarantee that these will be maintained in the future and the results must be assessed with this caveat in mind. However, if countries that behaved sustainably in the past were able to maintain the same behavior in the present and the future then they would achieve sustainability.

First, treat GNP per capita as an imperfect proxy of welfare. The aim of the exercise is to determine whether the income derived from the mining sector is transitory and therefore not sustainable or whether it generates, through a 'multiplier' effect, increases in income in the rest of the economy that are sustained indefinitely, in which case income from the mining sector is sustainable. This multiplier effect is probably mediated through the accumulation of manufactured and human capital in the economy which can be used in the future to obtain an alternative source of income. However, my test is not dependent on any assumptions regarding the 'transmission mechanism'. My approach has the same motivation as the Hartwick type models but rather than deriving rules that should be followed in order to ensure that per capita income is non-declining, I estimate whether there are long-run gains in income per capita that stem from the exploitation of depleting resources. My approach is much more general than the Hartwick criterion as the estimated multiplier may be an unknown function of many other variables besides manufactured capital. It encompasses all the other viewpoints on the conditions for sustainability.

Income from the mining sector is calculated as GDP originating in that sector deflated by the general GDP deflator. If we assumed that the capital and labor employed in mining were fully mobile and could be redeployed elsewhere when the mineral deposits were exhausted then the relevant quantity would be the rents derived from mining as in the Hartwick-Solow model. However, information on rents is in most case non-existent and this is an extreme assumption in any case. Also note that an increase in the relative price of mining output to GDP is regarded as an increase in mining income.

Treating all generations equally we can say that mining income is sustainable if cumulative mining induces a permanent annual increase in income per capita that is as great as the highest annual mining income per capita ever achieved. In other words, if annual mining income rises above the permanent level of income increase caused by cumulative mining then mining income in that year or years would be unsustainable, while if mining income is always at or below the level of the permanent increase in income then the income from mining is sustainable. The permanent change in long-run income ΔY due to mining activity is given by:

$$\Delta Y \equiv \sum_{t=1}^{n} \frac{\partial Y}{\partial M} M_t \qquad (1)$$

where n is the extractive lifetime of the resource in years, M_t is mining income in year t, and $\partial Y/\partial M$ is the long-run multiplier of mining income on income. A temporary one period exogenous increase in mining income would result in a series of multipliers on income in all future years. The long-run multiplier is simply the last in this time series. As stated above, the sustainability criterion is that the permanent increase in income per capita must be greater or equal to the maximum level of M_t per capita in any period :

$$\Delta Y / N_n \geq \mathrm{Max}(M_t / N_t) = M_i / N_i \qquad (2)$$

where i is the year of maximum mining income per capita, and N_n is the long-run level of population. In other words income from mining never exceeds the long run improvement in annual income per capita. Multiplying both sides of (2) by N_n and equating the RHS of (1) and (2), the level of the multiplier that just satisfies the sustainability criterion is :

$$\frac{\partial Y}{\partial M} = \frac{M_i N_n}{N_i \Sigma M_t} \qquad (3)$$

If the long-run multiplier is above that level then the level of mining income in all years is sustainable. If it is below that level then mining income is not always at a sustainable level. This criterion can be understood intuitively as follows :

- The larger total deposits ΣM_t are, the smaller the multiplier need be to ensure sustainability, because there is more time available in which to gradually raise the level of long-run income.
- The greater future population N_n will be, the higher need be the multiplier to ensure sustainability, because there will be more people in the future to share the raised level of aggregate income.
- The higher income in the peak year M_i is, the higher the multiplier need be to ensure sustainability, because a higher long-run level of income is required to ensure 'non-declining income'.
- The higher population in the peak year N_i is, the lower the multiplier need be to ensure sustainability, because per capita mining income is lower in the peak year and therefore a lower long-run level of income is sufficient to ensure 'non-declining income'.

It is impossible to accurately calculate what the necessary level of the multiplier is due to uncertainty regarding total extractable deposits, future mineral prices, rates of extraction, and population growth. The tests carried out below are done for a variety of possible sizes of total deposits. It is assumed that the long run populations in each of these countries is the stationary population projected by the UN, published in IBRD (1992).

An interesting corollary is that assuming no change in the multiplier, if a country is operating on or close to the sustainability criterion, a rise in mineral prices, will require a reduction in the rate of extraction in physical terms to maintain sustainability. This is of course the opposite to what is likely to happen in a free market. It seems therefore that the government should not attempt to meet the sustainability criterion by controlling the rate of extraction. If they did reduce output during a period of higher prices they would forfeit income. Instead they should attempt to meet the sustainability criterion by attempting to manipulate the multiplier. For example, all windfall income deemed to be unsustainable could be taxed and invested in foreign financial instruments and assets, as in the Kuwaiti example. This could also provide an incentive for mining industries to attempt to increase the multiplier, eg. by developing more local linkages, so that they could retain a greater share of profits in periods of higher prices.

I also provide information on the multipliers of the mining sector on manufactured and human capital accumulation which could in theory be used to test some sort of weak sustainability hypothesis. I consider these to be a means to check on the consistency of the model as well as being important from a general development perspective.

The difference between my approach and the weak sustainability approach used by El Serafy (1989) in assessing sustainable income in the mining context should be clear. El Serafy discusses methods of dividing revenues from extractive industries between an income component and a capital component. This is only useful as a method of adjusting output to reflect the level of sustainable income if the specific weak sustainability conditions hold ie. manufactured capital is a substitute for oil. It does not test whether countries do set aside this income or whether if they did it would be a successful policy for achieving sustainability.

4. Development of the Empirical Model

Despite the extensive literature on the problems of mining industries in developing countries it seems that there has been no quantitative multi-country study on the effects of the mining sector on economic development and growth. Research has been mainly limited to non-quantitative or non-econometric case studies [O'Faircheallaigh (1984)], and has tended to focus on foreign investment alone [eg. Girvan (1972) and Mikesell (1971, 1975)]. Case studies such as those by Mikesell (1974) on copper in Zaire, Fry and Harvey (1974) on copper in Zambia, and Killick (1974) on mining in Sierra Leone are quantitative but non-econometric. Their technique is to list the contribution of the mining sector in a particular year to taxation, employment, purchases of the outputs of particular industries, and other quantities. This type of analysis omits dynamic effects. Similarly one of the few multi-country surveys of the impact of mining on LDC economies [Gluschke, Iwase, and Zorn (1980)] lists the shares of the minerals sector in GNP, exports, employment etc. in a range of countries and describes other impacts, but backward and forward linkages and other dynamic effects are ignored. A small group of studies produced by researchers at the University of Pennsylvania [Adams and Behrman (1981); Lira (1980); Lasaga's (1981); Nziramasanga and Obidegwu's (1981)] applies econometric techniques to the linkages between the primary commodity sectors and the general economy in single developing countries. Gelb (1986), Warr (1986), Taylor *et al* (1986), and Benjamin *et al.* (1989) have all examined Dutch Disease effects in developing countries due to shocks to oil extraction sectors. Naturally, none of the above studies was constructed with the intention of examining whether the mining sector contributed to sustainability.

Multi-country empirical studies of the impact of trade on economic development can contribute to the development of an empirical approach to the question of the effect of the minerals sector on economic development and growth. Rather than examine the impact of a general exports producing sector on growth I am interested in examining the effect of a minerals sector, that may produce largely for export, on growth. Three main approaches have been taken in the multi-country empirical analysis of the effects of exports on growth : Simple correlations, single equation models and multi-equation econometric models.

There are problems with all the three main types of model found in the exports and growth literature in estimating the size and sign of the multiplier between two sectors of the economy. The bivariate correlation models [eg. Michaely (1977)] attribute all the systematic change in the dependent variable to the change in the independent variable, therefore probably exaggerating the strength of the relationship, as there may be other variables that act on both the dependent and independent variable resulting in a spurious correlation and neither is the direction of causality defined.

Single equation regression models [eg. Feder (1983)] go to the opposite extreme, arbitrarily selecting a single dependent variable. There is a tendency to underestimate the size of the multiplier in these models. All the conditioning variables are treated as exogenous variables. For example if the capital stock is one of the conditioning variables in an equation explaining non-mining income, all the effect of a change in the capital stock on income will be attributed to an exogenous movement in the capital stock. If the change in the capital stock is partly due to a change in mining income, this channel of influence of the mining sector on the non-mining sector will be ignored.

Finally, simultaneous equation models [eg. Salvatore (1983)] overcome some of these problems as long as they allow sufficiently for lagged effects [which is not the case in the Salvatore (1983) model] and do not make too many restrictions on which variables enter which equation [Sims (1980) critique]. Both mining and non-mining income should be endogenous variables as they are produced using labor, capital, natural resources etc. This raises problems with the traditional method of estimating multipliers from exogenous to endogenous variables. Salvatore (1983) makes dX/dt and Y exogenous (X is exports, Y is GNP) and X and dY/dt endogenous. This seems rather arbitrary.

Edwards (1993) surveys the econometric studies on the topic of trade and growth. He is not impressed by the results of the cross-country regression approach and argues that most of the results purporting to show that exports specifically have increased the rate of economic growth in developing countries are "unconvincing results whose fragility has been exposed by subsequent work" (1389) [see also Stern (1994)]. He points to two directions for further research : investigators should approach the issue from the new growth theory perspective discussed below, while employing more sophisticated econometrics; and that microeconomic analysis could shed new light on the issue. I adopt the former of these approaches.

Edwards' (1993) assertion has been supported by Levine and Renelt (1992), who carried out a sensitivity analysis of the regression coefficients of particular variables that previous studies had suggested were correlated with either growth per capita or the investment / output ratio in cross-country regressions using period averages. They estimated regressions which always included a particular subset of variables and a changing group of other conditioning variables. They found that few relationships are robust to changes in the conditioning set. Those that are, are investment, initial income per capita, and secondary school enrollment, in regressions of the growth in per capita income; and exports and measures of trade openness, in regressions of I/Y. Particularly noteworthy is that the trade variables do not have a robust relationship with income growth. Trade appears to have positive effects through accumulation of capital. Also they found that substituting imports for exports in the investment equation did not have much of an effect on the estimated coefficients or levels of significance.

Hence I have chosen to adopt the vector autoregression (VAR) approach to modeling the interactions between the mining sector and the rest of the economy. The VAR approach treats all the variables as endogenous, though exogenous variables can also be added. More importantly it allows the estimation of dynamic multipliers between the endogenous variables by means of the impulse response functions. Its main problem is that with limited numbers of observations, either the degrees of freedom or the number of lags that can be used is limited. The approach does not allow the pooling of time series and cross-section data which limits the number of observations in each model. An individual model has to be estimated for each country unless the data are aggregated for the "World Economy". As discussed above, I have chosen not to aggregate the data, as the dynamics are not necessarily in phase in each economy, most of which are fairly closed with the exception of their mineral exports.

I have tried to take into account some recent developments in growth theory in selecting variables for this model. Lucas (1988) emphasized the central role of the formation of human capital in economic growth both through its function in the improvement of labor inputs and through an additional externality effect. He points out that exports industries can help in the formation of human capital through learning by doing. Romer (1986) emphasized the possibilities of increasing returns to scale emerging from the effects of the formation of knowledge or human capital. This is as knowledge behaves as a public good and knowledge created by one agent in the economy has an external effect on the production activities of other agents.

Both Barro (1989) and Otani and Villanueva (1990) have explored the empirical implications of these theories and in particular the effects of human capital endowments and formation on rates of economic growth. Barro (1989) examines what factors could account for variations between GDP growth rates among 98 developing and developed countries. Though there is no formal model, he attempts to test whether 'classical' neoclassical growth theory or the 'new' theory of growth is the best explanation of observed growth performance. Neoclassical growth theory suggests that there should be a negative correlation between GDP per capita at the beginning of the period and the GDP growth rate throughout that period, but there is no correlation in the sample. But if human capital at the beginning of the period is held constant then the hypothesis is shown to hold true. The main measure of human capital used is primary and secondary school enrollment. Further regressions show that countries with higher initial levels of human capital also have higher investment rates and lower fertility rates. Barro argues that this lends some support to the new growth economics. Otani and Villanueva's (1990) paper provides further empirical evidence to support the inclusion of human capital as an independent variable in any model purporting to explain growth rates.

The VAR is used to linearly approximate a dynamic transformation frontier :

$$g(N_t, M_t, F_t, K_t, L_t, H_t, I_t) = 0 \qquad (4)$$

where there are three outputs : M, mining GDP; N, non-mining GDP; and F, net foreign factor payments; and three inputs : K, capital; L, labor; H, quality of human capital; and I, imports, though use of the VAR methodology means that no variable is strictly an input or an output. Due to limited degrees of freedom only one annual lag was used in each VAR model. The variables were used in the simple levels form. This was due to consideration of the implications of different functional forms on the meaning of the estimated multipliers. In order to obtain time-invariant multipliers values rather than logarithms were chosen. This form also simplifies treatment of net-foreign factor payments which can be either positive or negative. The levels form implies that the multiplier measures the impact of a temporary change in mining income, the differences form implies that the multiplier measures the impact of a permanent increase in mining income. The proxy used for the quality of human capital is the sum of primary, secondary and tertiary enrollment rates. This is similar to Barro (1989) but with the addition of the tertiary level. Sources are in Appendix A. This formulation is inaccurate as current school enrollment rates reflect improvements in the workforce in the future. However, economic growth contributes to human capital growth through current education. Due to both this and the fact that school education does not include all the improvement in human capital, current school enrollment seems a reasonable proxy. Tertiary education is added because in some countries such as Chile, secondary enrollments were fairly high at the beginning of the period. Labor is estimated as the population multiplied by the participation rate. The VAR model consists of the following equations :

$$N_t = \alpha_{11} + \alpha_{12} N_{t-1} + \alpha_{13} M_{t-1} + \alpha_{14} F_{t-1} + \alpha_{15} K_{t-1} + \alpha_{16} L_{t-1} + \alpha_{17} H_{t-1} + \alpha_{18} I_{t-1} + u_{1t} \quad (5)$$

$$M_t = \alpha_{21} + \alpha_{22} N_{t-1} + \alpha_{23} M_{t-1} + \alpha_{24} F_{t-1} + \alpha_{25} K_{t-1} + \alpha_{26} L_{t-1} + \alpha_{27} H_{t-1} + \alpha_{28} I_{t-1} + u_{2t} \quad (6)$$

$$F_t = \alpha_{31} + \alpha_{32} N_{t-1} + \alpha_{33} M_{t-1} + \alpha_{34} F_{t-1} + \alpha_{35} K_{t-1} + \alpha_{36} L_{t-1} + \alpha_{37} H_{t-1} + \alpha_{38} I_{t-1} + u_{3t} \quad (7)$$

$$K_t = \alpha_{41} + \alpha_{42} N_{t-1} + \alpha_{43} M_{t-1} + \alpha_{44} F_{t-1} + \alpha_{45} K_{t-1} + \alpha_{46} L_{t-1} + \alpha_{47} H_{t-1} + \alpha_{48} I_{t-1} + u_{4t} \quad (8)$$

$$L_t = \alpha_{51} + \alpha_{52} N_{t-1} + \alpha_{53} M_{t-1} + \alpha_{54} F_{t-1} + \alpha_{55} K_{t-1} + \alpha_{56} L_{t-1} + \alpha_{57} H_{t-1} + \alpha_{58} I_{t-1} + u_{5t} \quad (9)$$

$$H_t = \alpha_{61} + \alpha_{62} N_{t-1} + \alpha_{63} M_{t-1} + \alpha_{64} F_{t-1} + \alpha_{65} K_{t-1} + \alpha_{66} L_{t-1} + \alpha_{67} H_{t-1} + \alpha_{68} I_{t-1} + u_{6t} \quad (10)$$

$$I_t = \alpha_{71} + \alpha_{72} N_{t-1} + \alpha_{73} M_{t-1} + \alpha_{74} F_{t-1} + \alpha_{75} K_{t-1} + \alpha_{76} L_{t-1} + \alpha_{77} H_{t-1} + \alpha_{78} I_{t-1} + u_{7t} \quad (11)$$

Output and imports are measured in local currency deflated by the GDP deflator and multiplied by the real international dollar exchange rate in 1980 derived using the Penn World Table. These units were chosen to facilitate comparisons of the multipliers of mining GDP on the labor force and human capital which are not in monetary units. As the model is linear this does not affect the estimates of the other multipliers. Deflating mining income by the GDP deflator rather than by the mining sector deflator means that both a change in the price of minerals or a change in the volume of mining output can have an effect on the other variables. A separate VAR model is estimated for each country. Nineteen countries were selected as described in Appendix A. This appendix also presents details of the time period and sources of data for each country. If possible the time period covers 1963-1988, but data were not always available for the entire period. Details of the construction of the capital input are described in Appendix B.

The multipliers are estimated using the impulse response functions of the VAR [see Sargent (1979) and Sims (1980)]. The mean of the multipliers in the sample is examined to determine what the effect of the mining sector is on current income and on investment and the consequent implications for sustainability in the sample as a whole. The estimates of the multipliers in the individual countries are also compared to determine whether they are similar or whether countries with particular characteristics share similar size multipliers.

The impulse response function is the series of responses of each of the variables in the VAR system to a shock to one of the variables in the first time period. The impulse response functions are based on the moving average representation of the vector time series [see Doan (1989), Sargent (1979)] :

$$y(t) = \sum_{s=0}^{\infty} G(s)\, u(t-s) + X(t)\beta \qquad (12)$$

where y is the n-vector of variables, the G are matrices of coefficients, $X(t)\beta$ is the deterministic part of the VAR, and u is an n-variate white noise process. If $t \neq s$, u(t) and u(s) are uncorrelated. If G(0) is normalized to be the identity matrix, each component of u(t) is the error that results from the one-step forecast of the corresponding component of y(t). These are the non-orthogonal innovations in the components of y, known as such because, in general, the covariance matrix $\Sigma = E(u(t)\, u(t)')$ is not diagonal. It is generally recommended to use instead a moving average representation with orthogonalized innovations [Doan (1989)]. For any non-singular matrix A, G(s) can be replaced by G(s)A and u by $A^{-1}u$. If the matrix A is chosen such that :

$$A^{-1} \Sigma A'^{-1} = I \qquad (13)$$

then the new innovations $v(t) = u(t) A^{-1}$ satisfy $E(v(t) v(t)') = I$. These orthogonalized innovations have the convenient property that they are uncorrelated both across time and across equations. Such a matrix A can be any solution of $AA' = \Sigma$. The standard choice which I use is the Choleski decomposition so that A is a lower triangular matrix. There is a different factorization for each ordering of the variables that compose y and this will affect the resulting estimates of the impulse response functions. A variable can only be affected contemporaneously by other variables if those variables are higher up in the ordering. As only the impulse response functions to a shock to mining GDP are to be considered it is logical to place mining GDP as the first variable in the ordering. Otherwise the ordering is immaterial.

For some countries the initial unrestricted VARs exhibited severe oscillations in the time paths of the impulse response functions. To help reduce these oscillations Bayesian VARs were used. I used the prior distribution for the coefficients recommended as standard in the RATS manual [Doan (1989)]. For a single lag model this is defined by the following :

- Non-informative (flat) priors are put on the constant coefficient in each equation.
- The prior distributions on all other coefficients are independent normal. The mean of the prior distribution of the coefficient of the lagged dependent variable is one. The mean of the coefficients of the lags of the other endogenous variables is zero.
- The standard deviations of the coefficients of the lagged endogenous variables are defined by the following functions :

$$S(i,j) = \gamma f(i,j) \frac{s_i}{s_j} \qquad f(i,i) = 1.0, \quad f(i,j) = 0.5, \quad \gamma = 0.2 \qquad (14)$$

  where s_i is the standard error of a univariate autoregression on equation i.

5. Econometric Analysis

Figures 1 through 3 present some background information on the economic performance of the countries in the sample. Figure 1 compares the mean annual growth of mining and the growth rate of GNP. The units for the mining sector are percentage points of GDP which are calculated as the multiple of the growth rate and the sector's share in GDP. There is clearly a positive relationship between the two variables and the correlation coefficient is 0.84. The four countries with the greatest relative growth in their mining sectors are labelled. All four countries have mining sectors that effectively commenced production during the sample period and experienced very rapid rates of growth. Oman and Botswana appear to have been more successful in generating growth in the remainder of the economy. The remainder of the observations show a steep relationship between the growth rate of GNP and mining GDP. This is primarily because in all these countries the non-mining sector is much bigger than the mining sector.

Figure 2 presents the relationship between the growth rate of the capital stock and the growth of the mining sector. The correlation between the two variables is 0.85. In this case Cameroon has been more successful in generating capital accumulation than either Papua New Guinea, or Oman. Botswana remains the star performer. Finally Figure 3 presents the relationship between the growth rate of human capital (labor force multiplied by quality of human capital) and mining growth. Oman achieved an outstanding growth rate by starting from a base of almost zero schooling. The correlation between the two variables is 0.26.

The econometric model produces large quantities of statistics and data most of which is not relevant to the sustainability issue, anyway. Therefore, I only present the relevant long-run multipliers of mining GDP on the other endogenous variables.

The multiplier of mining GDP on GNP is the sum of the impulse response functions of mining GDP, non-mining GDP, and net foreign factor payments to a shock to mining GDP. The time path of the mean multiplier is illustrated in Figure 4. The dashed lines are a two standard error confidence interval for the sample mean. The long-run multiplier is simply the multiplier in the twenty-sixth period. In theory one could derive the asymptotic long-run multiplier from the VAR model. But as the VAR is only an approximation over the sample period this could be very misleading.[8] Though a shock is only applied to mining income in the first period this shock can induce higher or lower mining income in subsequent years [see Stern (1994) for more details]. The adjusted long-run multiplier deflates the long-run multiplier by the induced increase in mining income over the period to obtain the increase in GNP per unit increase in mining income over the entire time period. The value of this multiplier in each country is presented in Table 1. The mean is insignificantly different to zero indicating that in the mean mining income is unsustainable income. This test holds irrespective of population sizes etc. as a necessary condition for passing the test in equation (3) is that the estimated multiplier is positive.

However, there are several economies where the adjusted long-run multiplier is positive indicating that mining may be a sustainable activity in those economies. There are no statistics to test these individual multipliers. Calculation of confidence intervals for impulse response functions is difficult [Doan (1989)]. The long-run multiplier is positive in : Cameroon,

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[8] Experiments show that the resulting multiplier in these cases is most likely to be negative or positive infinity.

Colombia, Mexico, Oman, Peru, Tunisia, and Zimbabwe. Botswana stands out in that it is not included in this list despite being the star perfomer in terms of growth rates. Independent confirmation on Botswana is available from Unemo (1994) who estimates a computable general equilibrium model for Botswana using 1985 data. [9] The question of whether these multipliers meet the sustainability criterion is discussed in the next section.

Figure 5 presents the time-path of the mean multiplier on the capital stock. The mean impact multiplier is negative but not significantly different from zero. Only from the third period is the multiplier positive but insignificant. None of the multipliers is significantly different from zero at the 10% level. The adjusted long-run multiplier is negative but also not significantly different from zero. Therefore, we cannot reject the hypothesis that the mining sector does not contribute to the long-term accumulation of capital. Though it is likely that there is some induced capital accumulation with a lag of a number of years (some t statistics greater than one), it appears that this capital is then allowed to depreciate to at least a certain degree. This result is not sensitive to a variety of reasonable depreciation assumptions (see Appendix B). Those countries where the adjusted long-run multiplier is positive are : Cameroon, Jamaica, Mexico, Oman, Peru, Togo, Tunisia, Zambia, and Zimbabwe.

Figure 6 presents the time path of the mean of the multiplier of mining GDP on the labor force. The mean of the multiplier is insignificantly different from zero, negative for the first sixteen periods and thereafter positive. The first six t statistics are greater than one in absolute value. The mean adjusted long-run multiplier is negative. However, some countries experienced gains in the labor force : Jamaica ($408000 of increased mining GDP generates one extra worker), Liberia ($84000 per worker), Oman ($1 million per worker), Peru ($457000 per worker), Togo ($61000 per worker), Tunisia ($131000 per worker), and Zimbabwe ($263000 per worker). Though these figures may seem large they should be compared with a worker's lifetime earnings.

Figure 7 presents the time path of the mean multiplier of mining GDP on the quality of human capital. None of the multipliers is significantly different from zero. We can, therefore accept the null hypothesis that growth of the mining sector does not contribute to the improvement of the quality of human capital. From the seventeenth period on, the t-statistics are greater than one in absolute value so that it is likely that there is in fact some negative effect and that the long-run multiplier is negative. Positive adjusted long-run multipliers occur in : Cameroon ($32 billion required to raise enrollment in one of the three levels of education by 1% !), Jamaica ($18 billion), Mexico ($43 billion), Oman ($2.4 billion), Peru ($31 billion), Tunisia ($4 billion),

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[9] This is discussed in Stern (1994)

and Zimbabwe ($1.1 billion). These figures represent around 25 years mining income in Cameroon (at the sample average level of mining GDP), 33 years in Jamaica, 3 years in Mexico, 8 months in Oman, 8 years in Peru, 3 years in Tunisia, and 2 years in Zimbabwe. So that clearly in only four countries would mining-based development be an effective strategy to increase the quality of human capital.

Is there a relationship between the factor accumulation multipliers and the GNP multiplier ? In other words is the model consistent with growth theory and the Hartwick criterion that is based on it ? The correlation between the capital and GNP multipliers is only 0.1184. However, the correlation between the capital multiplier and the sum of the mining and non-mining multipliers (GDP multiplier) is 0.7957, though the correlation between the human capital multiplier and the GDP multiplier is -0.2002. Capital accumulation explains permanent GDP growth, though there appears to be no relation between human capital accumulation and permanent GDP growth. But in several of the countries where mining had a positive impact on GNP it also had a positive impact on capital accumulation or on the quality of human capital: Cameroon, Mexico, Oman, Peru, Tunisia, and Zimbabwe. Only the results for Colombia are inconsistent. The large role played by net foreign factor payments in determining GNP in these developing countries means that just looking at the accumulation of factors in the domestic economy does not help very much in explaining GNP. So the empirical results are broadly consistent with growth theory and the Hartwick criterion.

6. Testing for Sustainability

In this section the tests for sustainability proposed above are applied to those economies with positive adjusted long-run multipliers of mining GDP on GNP : Cameroon (0.1636), Colombia (0.4257), Mexico (0.0087), Oman (0.025), Peru (0.0089), Tunisia (0.0993), and Zimbabwe (0.0203). Tables 2 through 8 present the multiplier necessary to ensure sustainability for each of the years for which data is available in each of the countries under the assumption of differing total deposits. It is assumed that the long run populations in each of these countries is the stationary population projected by the UN and published in IBRD (1992).

In Cameroon it is necessary to assume that remaining deposits are at least five times cumulative extraction between 1975 and 1988, in order to ensure that that rate of extraction (in income terms) in every year generated a sustainable income (see Table 2). At lower estimated deposit sizes (or future price levels) extraction is currently at an unsustainable level. In Colombia under the same assumption that remaining deposits are the same size as extractions in 1963-1988 the test is passed in every year (Table 3). The rate of income generation would have to almost double to reach an unsustainable level.

As the estimated multiplier for Mexico is much smaller, deposits must be very large in order to ensure that current rates of income generation from mining are sustainable (Table 4). In order to accommodate the peak year of 1983, total deposits would have to be 34.5 times larger than cumulative extraction over the last 26 years. This seems unlikely as the principal mineral involved is petroleum. Mining income in 1988 would only be sustainable if deposits were five times cumulative extraction. One might think that it is more likely that mining income in Oman is sustainable as the estimated multiplier is greater than in Mexico. However, projected population growth rules this out. Total deposits must be at least 26.5 times cumulative extraction in 1970-1988 in order to meet the sustainability criterion in all years (Table 5).

Like Mexico, Peru's mining industry is possibly unsustainable as its estimated multiplier is close to that in Mexico. Deposits must be 30.3 times larger than cumulative extraction in 1968-1988 in order to ensure that the sustainability criterion is met in every year (Table 6). However, in the second half of the 1980s the rate of income generation fell so that deposits of around 10 times the size of cumulative extraction would be adequate to meet the criterion - this is still high. With a high estimated multiplier Tunisia passes the sustainability criterion (Table 7) when estimated remaining deposits are three times larger than cumulative extraction. Finally, Zimbabwe fails to clear the sustainability criterion in every year unless deposits are 12.5 times larger than cumulative extraction in 1964-1988 (Table 8).

7. Conclusions

It is not possible to reject in general the hypothesis that the income derived from the mining sector is unsustainable. However, there are a number of economies in the sample where mining income may be sustainable. These countries are : Cameroon, Colombia, Mexico, Oman, Peru, Tunisia, and Zimbabwe. With the exception of Zimbabwe, these are oil producers, but except Oman they are not exclusively so. Malaysia is not included in this group as the benefits appear to accrue in that case in the first few years after an increase in mining income. In Mexico, Oman, Peru, and Zimbabwe, the size of remaining deposits would have to be at least ten times cumulative extraction in the last twenty-five years in order to ensure sustainability. An important point is that a rise in the relative price of minerals to GDP would reduce the necessary physical size of deposits.

Though the capital stock may increase in the short term, it appears that these additions depreciate over time and are not replaced. There does not seem to be any general improvement in either the size of the labor force or the quality of human capital. Large permanent additions to the capital stock did occur in a number of countries : Cameroon, Mexico, Oman, Peru, Togo, Tunisia, and Zambia. Most of these are countries which saw increases in non-mining GDP.

Only in Mexico, Oman, Tunisia, and Zimbabwe does mining appear to make an effective contribution to the improvement of the quality of human capital.

The only conclusions are that in general income derived from mining in developing countries is unsustainable but that there tends to be a correlation between a country being an oil producer and having possibly sustainable income. Of course oil deposits are likely to be smaller than those of many other minerals.

Future research could take a number of directions. For example :

1. More sophisticated approaches could be taken to modeling the long-run behavior of the model [see Granger (1993)]. The Bayesian prior used in this paper is very arbitrary. Also it is likely that the estimated negative long-run effects for countries such as Botswana are in fact reflections of short run capacity constraints in the economy. In a linear model which does not differentiate between the long-run and the short-run the short-run effects dominate.

2. More detailed studies of individual countries could use more sophisticated models to address the same problem. This would be beneficial as such models could be more useful for policy simulations and would begin to show how governments can improve the sustainability of their economies.

3. The study could be expanded to include the OPEC economies and to determine whether they have been more successful than other developed countries in converting mining revenues into sustainable development.

4. An approach along these lines could be applied to other sustainability issues in either developed or developing countries.

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Table 1 Adjusted Long-run Multipliers of Mining GDP on Selected Variables

	Multiplier			
Country	GNP	Capital	Labor	Quality of Human Capital
Bolivia	-0.0254	-0.0947	4.46E-06	-2.14E-12
Botswana	-0.0507	-0.1045	-2.43E-06	-8.05E-12
Cameroon	0.1636	0.0463	-9.33E-08	3.08E-13
Chile	-0.5789	-0.0586	-2.50E-06	-7.81E-14
Colombia	0.4257	-0.3246	-1.03E-05	-2.74E-13
Jamaica	-0.9581	0.0243	2.45E-06	5.43E-13
Liberia	-0.0580	-0.5936	1.19E-05	-1.67E-11
Malaysia	-0.3286	-0.8417	-1.83E-05	-2.76E-12
Mexico	0.0087	0.0708	-2.86E-07	2.32E-13
Oman	0.0250	0.0704	9.39E-07	4.10E-12
Peru	0.0089	0.0562	2.19E-06	3.26E-13
PNG	-0.0030	-0.0125	-6.19E-07	-2.81E-13
Sierra Leone	-0.0028	-0.0107	-7.38E-07	-3.39E-13
South Africa	-0.0273	-0.0494	-8.05E-07	-1.91E-13
Togo	-0.0077	0.1815	1.65E-05	-7.27E-11
Tunisia	0.0993	0.3752	7.64E-06	2.52E-12
Zaire	-0.0615	-0.0022	-1.65E-05	-2.88E-12
Zambia	-0.0032	0.0591	-1.25E-06	-2.58E-13
Zimbabwe	0.0203	0.0113	3.80E-06	9.06E-12
Mean	-0.0712	-0.0630	-2.07E-07	-4.71E-12
St. Dev. of Mean	0.0643	0.0602	1.86E-06	3.84E-12
T Statistic	-1.1071	-1.0462	-0.1115	-1.2261

Critical values for two-sided t-test : 1%, 2.831; 5%, 2.080; 10%, 1.721.

Table 2 Sustainability Multipliers : Cameroon

	Remaining Deposits Relative to Cumulative Extraction 1975-1988				
Year	1	2	3	4	5
1975	0.0094	0.0047	0.0031	0.0024	0.0019
1976	0.0134	0.0067	0.0045	0.0033	0.0027
1977	0.0268	0.0134	0.0089	0.0067	0.0054
1978	0.1024	0.0512	0.0341	0.0256	0.0205
1979	**0.2900**	0.1450	0.0967	0.0725	0.0580
1980	**0.4983**	**0.2491**	**0.1661**	0.1246	0.0997
1981	**0.5473**	**0.2737**	**0.1824**	0.1368	0.1095
1982	**0.7080**	**0.3540**	**0.2360**	**0.1770**	0.1416
1983	**0.7615**	**0.3808**	**0.2538**	**0.1904**	0.1523
1984	**0.7747**	**0.3873**	**0.2582**	**0.1937**	0.1549
1985	**0.5573**	**0.2787**	**0.1858**	0.1393	0.1115
1986	**0.4000**	**0.2000**	0.1333	0.1000	0.0800
1987	**0.3865**	**0.1932**	0.1288	0.0966	0.0773
1988	**0.4015**	**0.2008**	0.1338	0.1004	0.0803

Bold figures represent unsustainable combinations

Table 3 Sustainability Multipliers : Colombia

Year		Year	
1963	0.0653	1976	0.0689
1964	0.0631	1977	0.0543
1965	0.0627	1978	0.0516
1966	0.0504	1979	0.0585
1967	0.0481	1980	0.0925
1968	0.0587	1981	0.0998
1969	0.0620	1982	0.1038
1970	0.0562	1983	0.1163
1971	0.0573	1984	0.1337
1972	0.0490	1985	0.1714
1973	0.0451	1986	0.2089
1974	0.0424	1987	0.2895
1975	0.0587	1988	0.2780

Remaining deposits are assumed equal to cumulative extraction 1963-1988. There are no unsustainable combinations

Table 4 Sustainability Multipliers : Mexico

Year	Remaining Deposits Relative to Cumulative Extraction 1963-1988				
	5	10	20	30	40
1963	**0.0147**	0.0073	0.0037	0.0024	0.0018
1964	**0.0153**	0.0077	0.0038	0.0026	0.0019
1965	**0.0155**	0.0078	0.0039	0.0026	0.0019
1966	**0.0145**	0.0073	0.0036	0.0024	0.0018
1967	**0.0153**	0.0077	0.0038	0.0026	0.0019
1968	**0.0171**	0.0086	0.0043	0.0029	0.0021
1969	**0.0168**	0.0084	0.0042	0.0028	0.0021
1970	**0.0159**	0.0080	0.0040	0.0027	0.0020
1971	**0.0143**	0.0071	0.0036	0.0024	0.0018
1972	**0.0144**	0.0072	0.0036	0.0024	0.0018
1973	**0.0136**	0.0068	0.0034	0.0023	0.0017
1974	**0.0169**	0.0085	0.0042	0.0028	0.0021
1975	**0.0124**	0.0062	0.0031	0.0021	0.0015
1976	**0.0110**	0.0055	0.0028	0.0018	0.0014
1977	**0.0145**	0.0072	0.0036	0.0024	0.0018
1978	**0.0156**	0.0078	0.0039	0.0026	0.0019
1979	**0.0211**	**0.0106**	0.0053	0.0035	0.0026
1980	**0.0358**	**0.0179**	**0.0090**	0.0060	0.0045
1981	**0.0349**	**0.0175**	**0.0087**	0.0058	0.0044
1982	**0.0539**	**0.0270**	**0.0135**	**0.0090**	0.0067
1983	**0.0603**	**0.0301**	**0.0151**	**0.0100**	0.0075
1984	**0.0288**	**0.0144**	0.0072	0.0048	0.0036
1985	**0.0238**	**0.0119**	0.0059	0.0040	0.0030
1986	**0.0176**	**0.0088**	0.0044	0.0029	0.0022
1987	**0.0260**	**0.0130**	0.0065	0.0043	0.0033
1988	**0.0165**	0.0083	0.0041	0.0028	0.0021

Bold figures indicate unsustainable combinations

Table 5 Sustainability Multipliers : Oman

Year	Remaining Deposits Relative to Cumulative Extraction 1970-1988		
	10	20	30
1970	**0.0536**	**0.0268**	0.0179
1971	**0.0465**	0.0233	0.0155
1972	**0.0447**	0.0223	0.0149
1973	**0.0384**	0.0192	0.0128
1974	**0.0511**	**0.0255**	0.0170
1975	**0.0600**	**0.0300**	0.0200
1976	**0.0613**	**0.0307**	0.0204
1977	**0.0560**	**0.0280**	0.0187
1978	**0.0477**	0.0239	0.0159
1979	**0.0489**	0.0244	0.0163
1980	**0.0532**	**0.0266**	0.0177
1981	**0.0561**	**0.0280**	0.0187
1982	**0.0547**	**0.0273**	0.0182
1983	**0.0578**	**0.0289**	0.0193
1984	**0.0598**	**0.0299**	0.0199
1985	**0.0661**	**0.0331**	0.0220
1986	**0.0516**	**0.0258**	0.0172
1987	**0.0589**	**0.0295**	0.0196
1988	**0.0525**	**0.0263**	0.0175

Bold figures indicate unsustainable combinations

Table 6 Sustainability Multipliers : Peru

	Remaining Deposits Relative .to Cumulative Extraction 1968-1988			
Year	5	10	20	30
1968	**0.0274**	**0.0137**	0.0068	0.0046
1969	**0.0293**	**0.0147**	0.0073	0.0049
1970	**0.0246**	**0.0123**	0.0061	0.0041
1971	**0.0206**	**0.0103**	0.0051	0.0034
1972	**0.0222**	**0.0111**	0.0056	0.0037
1973	**0.0265**	**0.0132**	0.0066	0.0044
1974	**0.0259**	**0.0129**	0.0065	0.0043
1975	**0.0188**	**0.0094**	0.0047	0.0031
1976	**0.0223**	**0.0112**	0.0056	0.0037
1977	**0.0276**	**0.0138**	0.0069	0.0046
1978	**0.0380**	**0.0190**	**0.0095**	0.0063
1979	**0.0542**	**0.0271**	**0.0136**	**0.0090**
1980	**0.0463**	**0.0232**	**0.0116**	0.0077
1981	**0.0388**	**0.0194**	**0.0097**	0.0065
1982	**0.0365**	**0.0183**	**0.0091**	0.0061
1983	**0.0363**	**0.0181**	**0.0091**	0.0060
1984	**0.0416**	**0.0208**	**0.0104**	0.0069
1985	**0.0381**	**0.0191**	**0.0095**	0.0064
1986	**0.0131**	0.0065	0.0033	0.0022
1987	**0.0091**	0.0046	0.0023	0.0015
1988	**0.0094**	0.0047	0.0024	0.0016

Bold figures indicate unsustainable combinations

Table 7 Sustainability Multipliers : Tunisia

Year	Remaining Deposits Relative to Cumulative Extraction 1963-1988		
	1	2	3
1963	0.0108	0.0054	0.0036
1964	0.0121	0.0061	0.0040
1965	0.0180	0.0090	0.0060
1966	0.0182	0.0091	0.0061
1967	0.0302	0.0151	0.0101
1968	0.0431	0.0215	0.0144
1969	0.0515	0.0258	0.0172
1970	0.0565	0.0282	0.0188
1971	0.0647	0.0323	0.0216
1972	0.0668	0.0334	0.0223
1973	0.0842	0.0421	0.0281
1974	**0.1568**	0.0784	0.0523
1975	**0.1368**	0.0684	0.0456
1976	0.0968	0.0484	0.0323
1977	0.1051	0.0525	0.0350
1978	0.1061	0.0531	0.0354
1979	**0.1490**	0.0745	0.0497
1980	**0.2008**	**0.1004**	0.0669
1981	**0.2120**	**0.1060**	0.0707
1982	**0.1958**	0.0979	0.0653
1983	**0.1894**	0.0947	0.0631
1984	**0.1890**	0.0945	0.0630
1985	**0.1844**	0.0922	0.0615
1986	**0.1436**	0.0718	0.0479
1987	**0.1525**	0.0763	0.0508
1988	**0.1403**	0.0702	0.0468

Bold figures indicate unsustainable combinations

Table 8 Sustainability Multipliers Zimbabwe

Year	Size of Deposits Relative to Cumulative Extraction 1964-1988 5	7.5	10	12.5
1964	**0.0245**	0.0164	0.0123	0.0098
1965	**0.0297**	0.0198	0.0148	0.0119
1966	**0.0255**	0.0170	0.0128	0.0102
1967	**0.0246**	0.0164	0.0123	0.0098
1968	**0.0243**	0.0162	0.0121	0.0097
1969	**0.0308**	**0.0205**	0.0154	0.0123
1970	**0.0313**	**0.0209**	0.0157	0.0125
1971	**0.0308**	**0.0205**	0.0154	0.0123
1972	**0.0295**	0.0197	0.0147	0.0118
1973	**0.0374**	**0.0249**	0.0187	0.0150
1974	**0.0447**	**0.0298**	**0.0223**	0.0179
1975	**0.0407**	**0.0271**	**0.0204**	0.0163
1976	**0.0414**	**0.0276**	**0.0207**	0.0166
1977	**0.0358**	**0.0239**	0.0179	0.0143
1978	**0.0345**	**0.0230**	0.0173	0.0138
1979	**0.0411**	**0.0274**	**0.0206**	0.0164
1980	**0.0476**	**0.0317**	**0.0238**	0.0190
1981	**0.0359**	**0.0239**	0.0180	0.0144
1982	**0.0270**	0.0180	0.0135	0.0108
1983	**0.0383**	**0.0255**	0.0191	0.0153
1984	**0.0288**	0.0192	0.0144	0.0115
1985	**0.0284**	0.0190	0.0142	0.0114
1986	**0.0343**	**0.0229**	0.0172	0.0137
1987	**0.0431**	**0.0287**	**0.0215**	0.0172
1988	**0.0421**	**0.0281**	**0.0211**	0.0169

Bold figures indicate unsustainable combinations

Appendix A. Data Sources and Coverage

The sample includes all developing countries as defined in the World Development Report 1992 [IBRD (1992)] which : are not members of OPEC; have a mining sector constituting more than 5% of GDP in at least one of the years 1963-88; had more than 1 million population in 1992 as reported in the World Development Report 1992 [IBRD (1992)]; and have sufficient disaggregated data available for at least ten years of 1963-1988.

The variables collected and sources used are :

GDP (Current Prices)	UN National Accounts [UNO (various years)]
Mining GDP (Current Prices)	UN National Accounts [UNO (various years)]
Gross Fixed Capital Formation (Current Prices)	UN National Accounts [UNO (various years)]
GDP Deflator	IFS [IMF (various years)]
Ratio of GNP to GDP	Penn World Table [Summers and Heston (1991)]
GDP per Capita in Real International Dollars	Penn World Table [Summers and Heston (1991)]
Imports (Nominal Prices)	Penn World Table [Summers and Heston (1991)]
Population	Penn World Table [Summers and Heston (1991)]
Participation Rate	Penn World Table [Summers and Heston (1991)]
Educational Enrollment	World Tables and World Development Report 1992 [IBRD (1990), (1992)]

Generally there was some substitution of data between the above sources to fill in any missing data. Data on educational enrollment were extensively interpolated and extrapolated. All data were collected for the period 1963-1988 with the exceptions noted :

Bolivia	Data coverage 1963-1986.
Botswana	Data coverage 1972-1986.
Cameroon	Data coverage 1975-1988. The GDP deflator was estimated using the Penn World Table.
Liberia	Data coverage 1968-1988.
Oman	Data coverage 1970-1988.
Papua New Guinea	Data coverage 1969-1988.
Peru	Data coverage 1968-1988.
Sierra Leone	Data coverage 1964-1988. The GDP deflator was estimated using the Penn World Table.
Togo	Data coverage 1964-1981.

Zaire	Mining GDP data were only available from 1968 to 1977. A mining output index was available from 1968 to 1984 so the latter was multiplied by the relative price of mining output to GDP in Zambia to obtain an index deflated by the GDP deflator for 1978 to 1984. The GDP deflator was estimated using the Penn World Table.
Zambia	Data coverage 1964-1988.
Zimbabwe	Imports figures for 1966-68 and 1973 were estimated on the basis of merchandise trade figures (IFS) for those years. Data coverage 1964-1988.

Appendix B Construction of Net Capital Stock Series

In few countries was any data available on the size of the capital stock. Where this was available it only covered the 1980s. The size of the net capital stock in the first year (in most cases 1963) was estimated using a formula derived from a regression estimated out on all the available data in the Penn World Table. Capital stock is modelled as a translog function of GDP and the labor force :

$$\begin{aligned} \ln K = \; & \underset{(5.3730)}{9.0493} + \underset{(0.8771)}{0.5356} \ln Q + \underset{(0.03955)}{0.03331} (\ln Q)^2 - \underset{(0.9944)}{0.5332} \ln L + \underset{(0.03375)}{0.05699} (\ln L)^2 \\ & - \underset{(0.07625)}{0.06031} \ln Q \ln L \end{aligned} \qquad \text{(B-1)}$$

$$\bar{R}^2 = 0.9942 \qquad n = 290 \qquad \chi(5) = 5.1631$$

where K is the net capital stock in 1985 international prices (calculated from the Penn World Table as : KAPW*RDGPCH*POP/RGDPW), Q is GDP in 1985 international prices (RGDPCH*POP), and L is the size of the labor force (RDGPCH*POP/RGDPW). The chi-square statistic is for the Breusch-Pagan (1979) test for heteroscedasticity. The estimated capital stock in international prices was converted to local currency in constant 1980 prices.

Net capital stocks in subsequent years, K_T, were calculated using a vintage depreciation method:

$$K_T = \left(\prod_{i=10}^{T+10} d_i \right) K_1 + \sum_{t=1}^{T} \left(\prod_{i=1}^{T-t} d_i \right) I_t \qquad \text{(B-2)}$$

where I_t is the gross fixed capital formation in year t, and d_i the are depreciation factors. It was assumed that the rate of depreciation increases as the age of a particular capital vintage increases so that dd/dt = -.01 ie. in the second year 1% of the vintage is depreciated, in the third year 2% of the capital remaining is depreciated and so forth. This rate implies that the quantity of remaining capital follows a downwardly sloping S curve, and that after 10 years approximately half the initial vintage is depreciated which is why the depreciation rate on the initial capital stock in the first year is set at 10%. These arbitrary choices produced fairly good fits with the estimates in the Penn World Table for 1979-88 for the few countries with available data.

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Figure 1. Growth Rate of GNP by Growth of Mining GDP

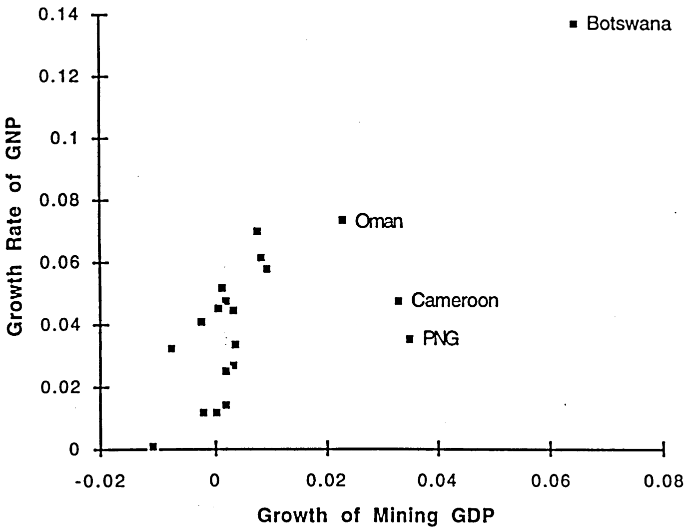


Figure 2. Growth Rate of Capital by Growth of Mining GDP

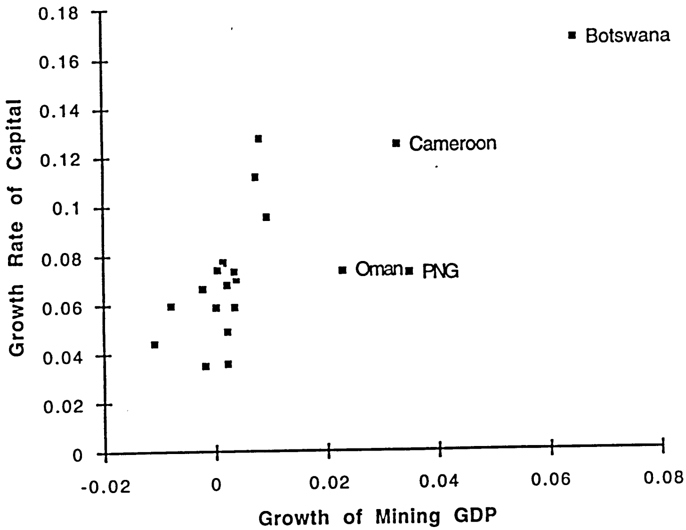


Figure 3. Growth Rate of Human Capital by Growth of Mining GDP

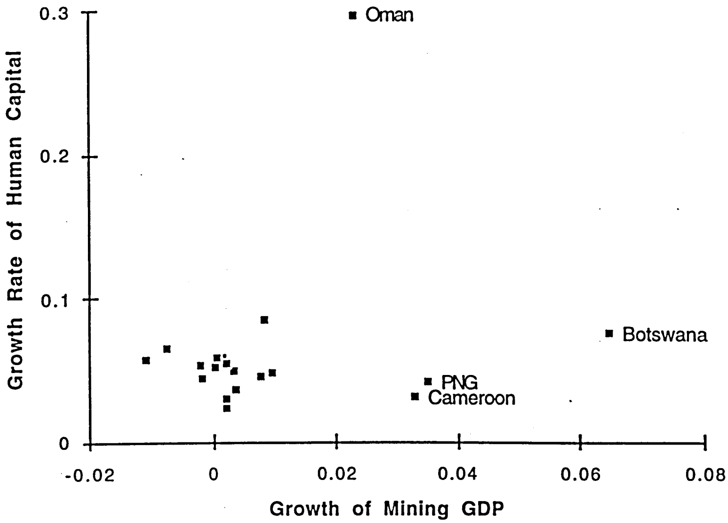


Figure 4. Mean Multiplier of Mining GDP on GNP

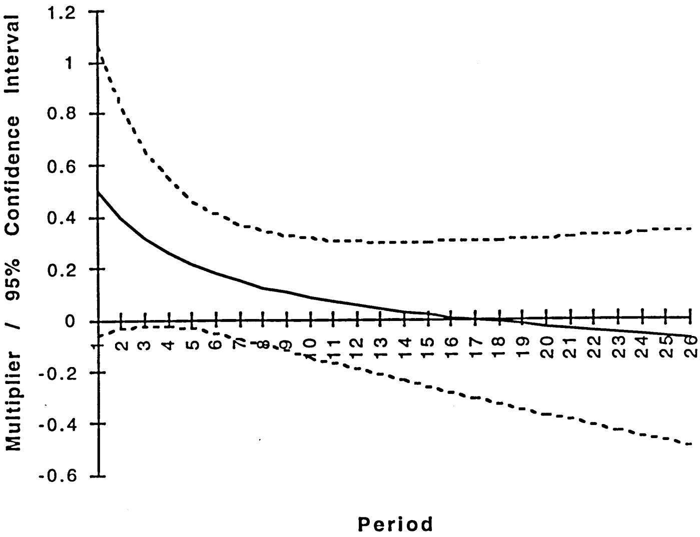


Figure 5. Mean Multiplier of Mining GDP on the Capital Stock

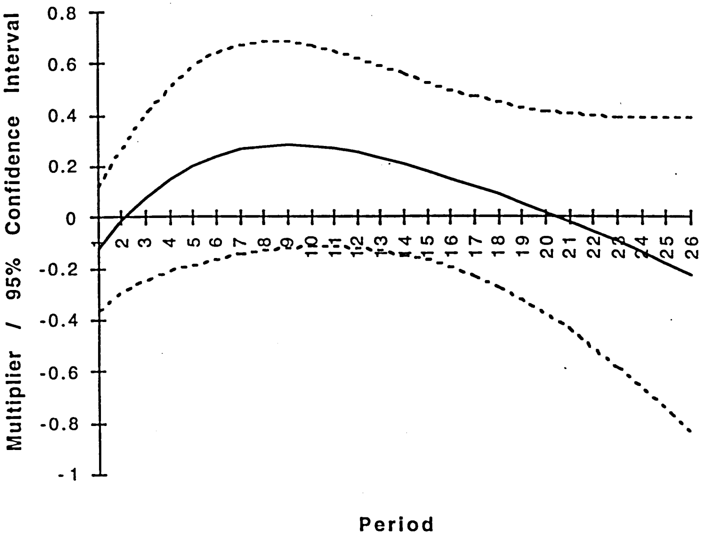


Figure 6. Mean Multiplier of Mining GDP on the Labor Force

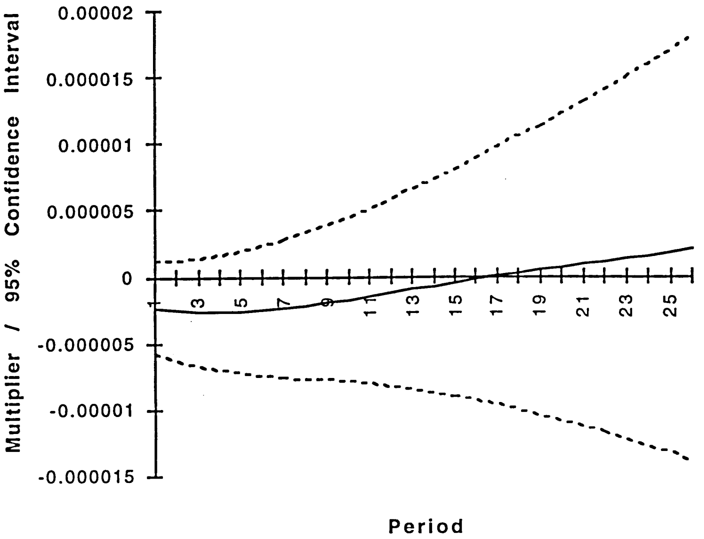
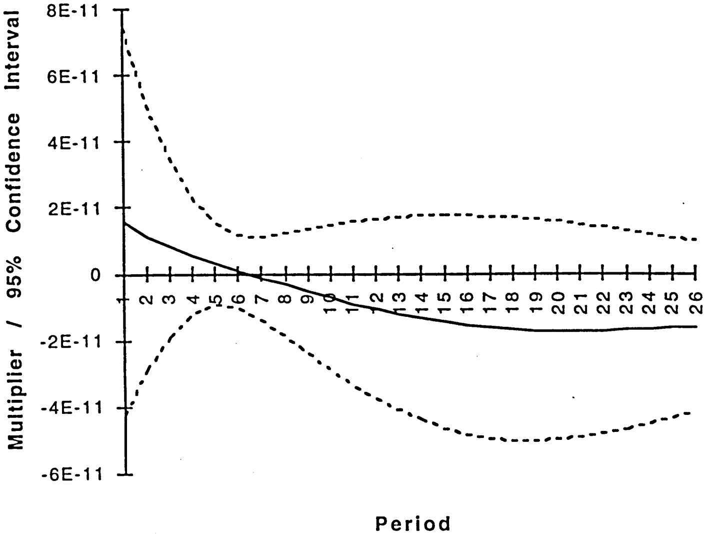


Figure 7. Mean Multiplier of Mining GDP on the Quality of Human Capital



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