Trends in Resource Extraction and Implications for Sustainability in Canada

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January 1999

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99-378

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ABSTRACT

There is a disagreement on the concept, definition and application of the paradigm of sustainable development. The definition that has been accepted by many involves several components, and it is difficult to measure or quantify indicators. Depending on the structure of the economy, it is possible to identify important variables and examine some aspects of sustainability. In this respect, analysis of indicators related to the extraction of natural resources seems to be appropriate for a resource-based economy.

For resource-based economy such as Canada is the speed with which natural resources are extracted greatly influence patterns of growth and development. Indicators can be established to measure the progress toward to or demise of sustainability. Indicators that deal with the speed with which resources such as non-renewable energy, minerals, forests, soil, water, etc., have been utilized to examine aspects of sustainability. However, these indicators have been argued to provide less guidance for the implementation of feasible public policies unless supplemented by other kinds of analyses that relate resource use with socioeconomic parameters.

The utilization of resources could be evaluated in relation to available stock as a proxy for progress toward sustainability. The extraction of resources may also cause major environmental problems due to the release of pollutants or wastes that requires an increasing amount of expenditure for environmnetal protection. This is crucial for countries such as Canada whose major export is dependent on availability of natural resources and heavily impacted by external public debt.

The present study will examine stock, depletion and addition of natural resources to evaluate sustainability of consumption patterns. In addition, the consumption of these resources will be

compared with selected socioeconomic indicators such as GDP, employment, etc., to anticipate whether or not these factors may have contributed to increased consumption of natural resources. Furthermore, attempts will be made to investigate the patterns of expenditure to protect the environment from wastes and pollutants. The findings of this study could serve as an early warning system with respect to depletion of resources and their consequent environmental impacts.

1. INTRODUCTION

1.1. What is Sustainable Development

There are two most contentious issues related to the paradigm of sustainable development. The first is related to the meaning or definition of development or sustainable development. Is there a unified definition of development? The second is related to the possibility of attaining development that could be maintained or sustained indefinitely.

Several studies have presented different kinds of definitions of development. The conclusion is that there is no unified theory of development. If there is no unified definition of development, the question thus becomes; can we discuss about universal sustainability of a phenomenon that may not be applicable for every segment of a society, region or country?

There are several definitions of sustainable development advanced by many disciplinary thinkers. In economics for example, the core idea of sustainability is the concept that current decisions should not impair the prospects for maintaining or improving future living standards.[2] Other economists have emphasized constancy of extraction of non-renewable resources or natural capital or imposed the principles of steady-state.[3,4,5] In this regard, sustainable development was implied to refer to the use of renewable natural resources in a manner which does not eliminate or degrade them, or otherwise diminish their usefulness for future generations. Sustainable development further implies depleting non-renewable energy resources at a slow enough rate so as to ensure the high probability of an orderly society transition to renewable energy sources.[4] Among the physical scientists, sustainable development is often correlated with biogeophysical sustainability.[6]

Despite the controversies and disagreements among the basic and social scientists with respect to the definition of sustainable development, however, one of the most widely accepted definitions of sustainable development found in the literature is:

> "The ability of humanity to ensure that it meets the needs of the present without compromising the ability of future generations to meet their own needs. Sustainable development is not a fixed state of harmony, but rather a process of change in which the exploitation of resources, the direction of investments, the orientation of technological development and institutional changes are made consistent with future as well as present needs."[1]

Aside from the controversies regarding the definition of sustainable development, there has been a heated debate about the measurement of sustainability. The literature in this area is also abundant. The consensus seems to be that non-renewable resources should be extracted at a rate with which renewable substitutes could be found or at the rate at least equal to additions to the stock.[7] Using this consensus as a base, the present study intends to examine trends in extraction of non-renewable resources and identify key parameters that may be associated with the patterns of extraction of natural capital.

1.2. Sustainable Environment and Development

Since the industrial revolution of the 1800s, the production of economic goods and services has increased significantly, and has been accompanied by an unprecedented destruction of the most fundamental, scare and consequently economic good at human disposal, namely the environment. If this process was permitted to continue, it poses a great threat to the future generations. This should be the starting point in any discussion of sustainable development.

The relationship between the economy and environment or sustainable development and sustainable environment, however, has become an area of concern only very recently. The environment may include terrestrial and aquatic ecosystems, including humans. Progress toward sustainable environment can be used as a proxy for progress toward sustainable development. In fact, since biogeophysical sustainability relates to environmental issues, it is plausible to argue that sustainable environment is a pre-requisite or necessary condition of sustainable development.

The environment provides two types of functions: source function, to provide the economy necessary resources, and sink function, to assimilate the waste released from economic processes. The natural resources (environment) provide factors of production and environmental services to the economy. Therefore, strategies to balance extraction of resources with additions or substitutes that releases less waste to the environment should be the best approach to ensure progress toward sustainable environment and development.

1.3. Deficiencies in Current Natural Resources Accounting Methods

Economists have developed several measures of economic growth. The conventional measure such as gross domestic product (GDP) measures the volume of goods and services produced in the specified boundaries during a given period of time. This parameter is commonly used to compare economic success of management strategies or economic policies.

Two approaches have basically been used in the calculation of the GDP - income approach and the expenditure approach. Despite the approaches taken, the calculation of traditional measures of economic growth or development such as GDP and GNP are deficient in many respects. First, in traditional economic accounts, there is no entry for additions to the stock of natural resources parallel to the entry for additions to the stock of structures and equipment. Second, there is no explicit account for the contribution of natural resources to current production, as measured by gross domestic product (GDP). Finally, the depletion of stock of natural resources, similar to accounting for the depreciation of structures and equipment, is not considered in deriving net domestic product (NDP). Due to failure to properly account for depletion of natural resources, therefore, the system of national accounts and indicators of economic growth have contributed to policy making that resulted in destruction of the environment and its components.[8,9,10,11,12]

The absence of an entry for depletion of resources in the national accounts may, in combination with common property rights, means that the accounts do not identify over-exploitation. This issue is particularly important because a large percentage of Canada's natural resources are on public lands. Beyond the obvious omissions of natural resources from national accounts, there has been little dialogue with respect to whether or not natural resources should be treated as fixed capital or as inventories. Some studies have attempted to develop a method that would allow the proper accounting of non-renewable resources in the national accounts. [8,9,10,11,12,13,14,15,16]

In summary, natural capital is an important element of the environment and that its unsustainable extraction not only impair the attainment of sustainable environment but also progress toward sustainable development. In the past, national accounts have omitted the proper accounting of these resources. As a result it was difficult to evaluate the rate of depletion of resources and their implication to sustainable development. While there are sophisticated methods to examine the implication of depletion of resources to economic growth and sustainable development, the present study would attempt to utilize simple and defensible approaches to examine the consumption of resources and evaluate their implication for sustainable development.

2. Methodology

The determination of measures of sustainability is an extremely complicated and challenging area for a number of reasons. Firstly, there must be an acceptance of the definition of sustainability as well as what development means for a selected portion of the society, a country or continent. Secondly, indicators have to be developed for various goods and services and need to be comparable across countries. Reliable and time-referenced data is required to develop indicators from bottom-up. Therefore, substantial time and effort is required to identify the kind of variables and related measurement issues that are necessary to develop indicators that need to be related to growth in the overall economy and improvements in the quality of the environment. However, developing acceptable sets of indicators is still a contentious or controversial issue. Therefore, simple measures related to trends in extraction of resources, ratio of depletion to stock, etc., will be used as proxy indicators for progress toward sustainable development.

The present study will examine the case of non-renewable natural resources or capital. With respect to extraction of natural capital, progress toward sustainable development implies that nonrenewable resources should be depleted at a rate at least equal to additions or the rate of creation of renewable substitutes. It has also been suggested that sustainability should incorporate two ingredients. These include: i) rates of use of renewable and non-renewable resources should not exceed rates of regeneration or development of renewable substitutes, and ii) rates of emissions of pollutants or releases of wastes should not exceed assimilative capacities of the environment.[17]

Other studies have suggested that a minimum necessary condition for sustainability be taken to be maintenance of the total natural capital (TNC) stock at or above the current level.[18,19] This condition is sometimes referred to as strong sustainability as opposed to weak sustainability, which requires only that the total capital stock (including both human-made and natural capital) be maintained.

On the other hand, economic activity produces outputs with minimal economic value, especially wastes or emissions. The impact of these wastes on the environment and human health has resulted in significant financial expenditure to protect humans and the environment from the unwanted side effects or byproducts of unsustainable production and consumption decisions. The present study will also examine trends in defensive expenditure to show that in situation where depletion or extraction of natural resources or capital is not sustainable or where depletion is greater than addition, the magnitude of this parameter will increase at an accelerated rate, thus seriously eroding scarce financial resources that could be used for other development activities. For the purpose of this study, defensive expenditure is defined as "those expenditures that are necessary to defend humans from the unwanted side effects of own production and consumption decisions." Similarly, natural capital or natural resources are defined as those resources and amenities provided by the environment. Due to problems with respect to measurements, proxies for defensive expenditure and natural capital would be used in this study (see data section).

There are sophisticated macroeconomics models that are designed to calculate the impact of depletion of natural capital on the over all of economy. Analysis using macroeconomic models requires substantial amount of data, time and resources. Therefore, the present study will utilize econometric time series and trend analysis to investigate depletion of natural resources in order to anticipate progress toward relatively constant state of growth with respect to the patterns of consumption of non-renewable resources. Furthermore, Spearman's correlation analysis and construction of indices of growth will be performed with respect to depletion of natural capital, selected socioeconomic and environmental variables, and other resources. Using these simple analyses, the paper intends to show whether or not Canada is moving away or to relatively sustainable level of resource extraction as a proxy for sustainable resource consumption or sustainable development.

In summary, the methods that will be used in this study are divided into three: i) descriptive analysis of available data (ratio and trend analysis), and ii) forecast of stock, depletion and addition of resources as well as expenditure using time-series econometric methods, and iii)correlation analysis of trends in depletion of resources with selected socioeconomic and environmental parameters, and other resources; and analysis of indices of growth in these parameters.

2.1. Econometric time series analysis

The techniques used in this study are well known in the field of econometrics time-series analysis.[20,21,22,23,24,25] However, they are not widely used in the estimation and forecasting of time-series environmental or natural resource variables. In this study, moving averages(MA), autoregressive(AR), autoregressive moving averages (ARMA), and autoregressive integrated moving averages(ARIMA) models are examined. The choice of a model to forecast a series is based on selected measures of fit (see Appendix 1 for description).

In time series analysis of economic data (such as investment) or environmental data (such as emissions), the forces that generate the series may keep them together so that they would not drift apart. If a series is drifting apart, stationarity of the series can be achieved using various methods. It is essential to establish stationarity if the purpose is to examine true trends in the series and if there is a need to undertake forecasting. Appropriate tests are applied to examine the presence of stationarity and unit-root in the data examined by this study.[20,21,22,23,24,25]

In forecasting future values of a variable, time-series analysis relates the current values with past values, and current and past random disturbances. The unique feature of time-series analysis is that it doesn't begin with any conceptual framework provided say by economic theory. Instead, emphasis is placed on making use of information in the past values of a variable to forecast its future value. The methods of econometric time-series analysis used in this study are presented in Appendix 1.

3. Sources of Data

There are three types of capital assets needed in the economic production process: natural, human and man-made capital assets. The present study examines resources that fall under the category of natural capital assets provided by the environment.

Data on natural resources was obtained from statistics Canada covering 1976 to 1995. Other data related to socioeconomic and environmental variables were gathered form various OECD documents.[26] The study will examine trends in stock, depletion and additions of non-renewable resources, defensive expenditure and relate these trends with selected socioeconomic parameters. The non-renewable resources examined in this study include zinc-lead-silver, uranium, silver, nickel, natural gas, lead, iron, gold, crude oil, copper-zinc-nickel, sulphur, potash, and crude bitumen; and government expenditure on pollution control including sewage collection and disposal. In addition, these variables would be examined vis-à-vis i) other resources such as fish catch, arable land, energy consumption, forest cover, forest harvest, grassland cover and irrigated land, ii) socioeconomic variables such as current account balance, GDP, employment, labour productivity, population, and total factor productivity, and iii) environmental variables such as emissions of CO_2, SO_2, VOCs, and NO_x.

Defensive expenditure in this study includes purchases of solid waste and waste management services; outlays on environmental monitoring; expenditure on machinery, equipment, building and infrastructure required for pollution abatement and control; site reclamation and decommissioning; environmnetal assessment and audits; wild life and habitat proetction; environmental fees, fines and licensees; and administration of environmental projects.

In the literature, in addition to those listed above, environmental damage compensation; expenditure induced by spatial concentration of production activity, such as increasing cost of commuting, housing and recreation costs; increased expenditures induced by increased risks associated with industrial system, such as expenditures against protection from crime, accident, sabotage, etc.; expenditures due to negative side effects of automobile transportation, such as traffic accidents, and increased repairs, and medical expenses; and expenditures arising out of unhealthy consumption and behavioral patterns, and poor working and living conditions, such as drug and alcohol use (both active and passive), and stress, etc. are included under defensive expenditure. The definition of defensive expenditure used in this study is primarily for environmental protection by all levels of government and is intended to serve only as a proxy for the standard definition of this variable.

Natural capital includes other resources as well as amenities provided by the environment. The present study uses selected number of resources and doesn't incorporate other amenities provided by the environment.

4. Results of the Analysis

4.1. Tests for Stationarity (Unit Root)

There are two commonly used tests of unit-root: Augmented Dickey-Fuller (ADF) and Phillips-Perron tests. In the present study the ADF tests were used. Unit root tests using the Augmented Dickey-Fuller test for all resources, but Gold, were found to be non-stationary. After differencing, all variables exhibited stationarity. Therefore, the series were differenced to establish stationarity. Once, stationarity was established, AR, MA and ARMA models were estimated. The model with the smallest value of standard error, Akaike Information Criterion (AIC) and Schwarz-Bayesian Criterion (SBC) was selected to make forecasts for the period 1996 to 2020.

4.2. Results of Econometric Time-Series Analysis

The results of forecasts of stock, addition and depletion of natural resources are presented in Table 1. The results indicate that depletion of i) zinc-lead-silver, natural gas, silver, lead, crude oil, potash and iron are declining, and ii) uranium, nickel, gold, copper-zinc-nickel, sulphur, and bitumen are increasing. If these forecasts hold true, the major source of energy in Canada, natural gas and crude oil, are expected to decline by 50% and 80% respectively in 2020 compared to 1980 level. The implications of this forecast is significant for two reasons: i) unless suitable substitutes are explored, economic growth that is heavily dependant on these sources of energy might be retarded leading to lower standard of living for current and future generation, and ii) if similar forecasts hold true for other countries, there might be a significant reduction in emission of greenhouse gases, thus leading to less threat for climate change. Other resources such as iron and potash may decline by more than 90%. This may imply that unless measures are put in place to minimize the speed of extraction, these resources may be depleted in a short period of time.

Forecasts of aggregate stock, depletion, addition and expenditure are presented in Table 2. The result indicates that the rate of depletion is greater than addition for most resources. However, total stock of resources will continue to show a modest increase. Despite the fact that total stock might increase by about 20%, depletion of resources may increases by about six times the rate of additions of stock in 2020 compared to 1980. The most significant piece of information from Table 2 is the rate of increase in defensive expenditure. The results indicate that expenditure for environmental protection is expected to increase by nearly 500% in year 2020 compared to the 1980 level. Assuming this forecast holds true, this result implies that a significant portion of than nation's financial resources would have to be directed to minimize environmental impacts of wastes generated by unsustainable extraction of resources than for other productive uses.

4.3. Results of Ratio Analysis

Analysis of ratio was conducted with respect to the following three categories: ratio of i) depletion to stock and addition, ii) addition to depletion, and iii) depletion to stock. The results are presented in Table 3. The ratios are given in percentages to facilitate interpretation. The results indicate that the ratio of addition to depletion has declined for all resources except for uranium, crude oil, sulphur and bitumen. Comparison of data for 1980 with 1995 shows that the most significant decline were those of zinc-lead-silver, silver, lead, gold and copper-zinc-nickel. On the other hand, the ratio of depletion to stock has increased for all resources except for iron and potash. In general, the results in Table 3 show that i) the ratio of depletion to stock and addition has increased for most resources, ii) the ratio of addition to depletion has declined for most sources, and iii) ratio of depletion to stock has increased for most resources.

Analysis of ratios indicated that rate of resource depletion is less than addition or addition is not greater than depletion. Unless appropriate measures are taken to develop suitable substitutes, therefore, these non-renewable resources may be depleted within a few decades. If the rate of depletion continue to exceed addition, the possibility of leaving resources as abundant as this generation enjoyed may not be materialized or realized by the next generation. Thus, the premise upon which sustainable development is based will not be satisfied. Indeed, the future generation may be a recipient of large amount of wastes and increasing debt with little non-renewable resource that may translate into lower standard of living.

One of the principles of sustainability is that, over time, environmental management strategies have to move away from minimizing the impacts of wastes from unsustainable extraction of resources to anticipate and prevent the impacts of current and future consumption of resources on the environment. If results presented in Table 3 hold true in the future, then significant changes in policies have to be made to ensure that i) the rate of extraction and depletion of resources would be comparable with rates of growth in the economy, and ii) conditions would be created to facilitate the adoption of waste minimizing technologies and development of substitutes with potential for minimal releases of waste and pollutants.

4.4. Results of Analysis of Correlation and Indices of Growth

One of the objectives of this study was to examine if trends in socioeconomic and environmental parameters, and extraction of resources not examined in this study (land, forest, etc.,) move parallel with depletion of natural capital. Obviously, growth in the economy is often accompanied by consumption of resources. If growth in selected socioeconomic parameters is comparable to growth in addition and depletion of natural resources or capital, then it may be possible to argue that there is progress toward relatively stable growth in patterns of consumption of resources. In this respect, two descriptive analyses were conducted. Firstly, Spearman's correlation analysis was conducted to identify significant associations between depletion of resources and selected socioeconomic and environmental parameters, and other resources. Secondly, indices of growth for these parameters were examined.

Correlation analysis between total stock, depletion and addition of natural resources, and defensive expenditure with the other resources (e.g., fish catch, arable land, energy consumption, forest cover, forest harvest, grassland cover and irrigated land), economic factors (e.g., current account balance, GDP, employment, labour productivity, population, and total factor productivity, and environmental variables such as (emissions of CO_2, SO_2, VOCs, and NO_x) was conducted. The results indicate that depletion of natural capital is positively and significantly correlated with most socio-economic variables and emissions of pollutants. Expenditure is also positively and significantly correlated with depletion of resources and most socioeconomic variables. Addition of resources is also positively correlated with some variables but with few statistically significant relations. While correlation doesn't mean causation, these results seem to indicate that the selected socio-economic and environmental variables seem to move parallel with depletion of resources and expenditures to combat the impact of increased wastes and pollution.

Indices for consumption of resources, selected socioeconomic and environmental parameters (see Table 4), and variables examined in this study (e.g., total stock, addition and depletion of resources, and expenditure) were developed using 1980 as a base case (see Table 4). The results show that the amount of fish catch and grassland cover has declined while arable land, energy consumption, forest harvest and irrigated land have increased. This means that more land (increased arable land and reduced grassland) is being brought for productive uses, and that extraction of other resources (energy and forest) have increased. Furthermore, due to over-fishing or increased pollution of the aquatic or marine ecosystem, fish catch has declined. Since most resources and production activities are complementary, increases in extraction of resources could contribute to increases in income that may create the demand for increased extraction of other resources.

Analyses of indices of socioeconomic parameters show that indicators such as GDP, employment, productivity, population and deficit in current account balance are increasing. This trend may imply that extraction of resources move parallel with these key indicators of economic growth. Growth in the economy may create conditions for increased extraction of resources. At the same time, the extraction of these resources may not be properly accounted in the national accounts, thus contributing to increases in deficit in current account balance.

Similarly, analysis of indices of environmental variables (e.g., emissions of pollutants) indicated that compared to 1980, there have been significant increases in emissions of all pollutants except SO_2. These emissions account for a small portion of wastes generated by extraction of resources. If all wastes generated from extraction natural resources are combined with emissions of conventional pollutants, the resulting wastes and/or pollution may increase at a faster rate, thus contributing to increased environmental degradation. If the trend in the releases of wastes or pollutants continue to increase, the ability of Canada to move toward sustainable development could be seriously impaired for two reasons. Firstly, an increasing amount of scarce financial resources would have to be devoted to combat environmental degradation. Secondly, Canada would face an increasing debt (financial and environmental degradation) that would be passed to the next generation.

Similarly, indices were constructed for total stock, addition, depletion and defensive expenditure. Comparison of data for 1995 with 1980 indicates that while depletion, addition and expenditure increased, total stock of resources has declined. The increase in addition of resources was about 20% compared to a 60% increase in depletion. The most significant increase, however, is with respect to defensive expenditure. The data show that defensive expenditure increased by three and half fold in 1995 compared to 1980. This increase is significant considering the fact that Canada is facing an increasing public debt and domestic structural changes to reduce expenditure.

5. Summary and Recommendations

Review of the literature indicated that there is no consensus with respect to the definition of development or sustainable development. Furthermore, the debate over what indicators to choose in a given situation is still unresolved. Nonetheless, analysis of components of sustainable development has to be conducted with a view to provide evidence on whether or not current production and consumption patterns of goods and services provided by the environment are sustainable. In the present study, analysis of natural capital, especially non-renewables, was carried out for Canada.

Progress toward sustainable development can only be attained if and only if extraction of natural resources is sustainable. That is, if the rates with which resources are depleted is at least equated by additions of the same or potential substitute resources. Time-referenced data was utilized to examine trends, forecasts and relationships of depletions with selected socioeconomic and environmental parameters.

The findings of this study indicated that i) the rate with which resources are depleted is greater than the rate of addition for many resources, ii) the rate of depletion for some resources is declining which may imply that the stock of resources is being increasingly eroded and that there is not enough resources to extract, and iii) the defensive expenditure is increasing at a much faster rate. If current trends in the consumption of resources is maintained, the future generation would be left with less natural resources, large amount of waste and/or emissions, and increasing amount of debt since significant share of the national revenue would be directed towards the protection of the environment and health of the present generation.

The federal government should implement policies to influence the rate with which minerals or natural resources are explored and extracted. Furthermore, spending for research and development to develop potential substitutes for non-renewable resources has to be increased. Economic instruments such as taxes on natural capital may help reduce or eliminate the unsustainable extraction of natural resources. The tax may be passed on to consumers in the price of products and would send the proper signals about the relative sustainability cost of each product, moving consumption toward a more sustainable product mix. Finally, the proper accounting of these depletions in the national account should also be used an early warning system about potential environmental disaster due to increases in wastes and loss of life supporting system.

Without a concerted effort by government, industry and the public with respect to minimizing the rate of depletion of natural capital, Canada may not meet the basic principles of sustainable development. That is, the future generation could be left with fewer resources, increased wastes, degraded environment and huge financial burden or debt. Thus, the future generation may not enjoy the same standard of living as that enjoyed by the present generation. In the final analysis, it is possible to argue that with out a firm commitment by all stakeholders to act jointly to influence current patterns of resource use, the ability of Canada to move toward sustainable environment and development may be questionable.

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Table 1. Actual and Forecasts of Depletion of Resources (in Millions of dollars)

Resources	Year								
	1980	1985	1990	1995	2000	2005	2010	2015	2020
Zinc-lead-silver	325	114	443	216	197	188	180	173	165
Uranium	6739	10441	9721	10238	12598	14174	15947	17942	20187
Silver	1070	1197	1381	1245	1054	1010	967	926	887
Nickel	185	170	195	172	205	224	245	268	292
Natural Gas	3735	5309	3117	2337	2625	2371	2140	1933	1745
Lead	252	268	233	204	205	186	168	152	138
Iron	245	135	77	91	40	27	19	13	9
Gold	147	-19	319	414	552	698	843	989	1135
Crude Oil	4805	9281	4835	3459	2329	1807	1401	1087	843
Copper-zinc-nickel	2084	634	1821	1954	1453	1634	1837	2065	2321
Sulphur	5870	5259	5222	6935	6394	6706	7034	7378	7739
Potash	107	30	26	52	22	17	13	10	8
Crude bitumen	10300	15400	22700	28200	45982	67559	99261	145840	214276

Table 2. Actual and forecast of Expenditure (‘000 of dollars), Stock, Depletion and Addition of Natural Capital (in millions of dollars)

YEAR	Expenditure	Stock	Depletion	Addition
1980	1597055	1257703	35862	80179
1985	2400028	1005190	48218	58693
1990	3859504	1107142	50090	63717
1995	5205810	1126319	55519	93104
2000	5963181	1211779	65390	60031
2005	7041426	1278810	73467	64101
2010	8119670	1349549	81544	67757
2015	9197914	1424201	89621	71092
2020	10276158	1502983	97698	74170

Table 3. Trends in the Absolute value of the Ratio of Depletion to Stock and Additions, ratio of Additions to Depletions, and ratio of Depletion to Stock (***expressed in percentages***)

Resources	Type of ratio	Year			
		1980	1985	1990	1995
Zinc-lead-silver	Ratio of Depletion to Stock and Additions	2.45	4.26	6.20	7.64
	Ratio of Addition to Depletion	259.91	40.68	161.73	39.71
	Ratio of Depletion to Stock	2.62	4.19	5.63	7.88
Uranium	Ratio of Depletion to Stock and Additions	1.50	3.82	3.19	2.07
	Ratio of Addition to Depletion	256.14	128.73	573.20	1897.23
	Ratio of Depletion to Stock	1.44	4.02	3.90	3.41
Silver	Ratio of Depletion to Stock and Additions	3.07	3.91	6.43	6.13
	Ratio of Addition to Depletion	257.01	9.86	210.72	94.14
	Ratio of Depletion to Stock	3.33	3.89	5.66	6.50
Nickel	Ratio of Depletion to Stock and Additions	2.25	2.36	3.26	2.87
	Ratio of Addition to Depletion	483.66	2.94	74.87	389.37
	Ratio of Depletion to Stock	2.53	2.35	3.18	3.23
Natural Gas	Ratio of Depletion to Stock and Additions	3.44	3.97	5.22	7.69
	Ratio of Addition to Depletion	150.36	61.69	107.73	100.55
	Ratio of Depletion to Stock	3.63	4.07	5.54	8.33
Lead	Ratio of Depletion to Stock and Additions	2.54	3.06	3.97	5.28
	Ratio of Addition to Depletion	356.36	152.33	360.15	1.57
	Ratio of Depletion to Stock	2.80	2.92	3.47	5.29
Iron	Ratio of Depletion to Stock and Additions	0.88	0.86	0.77	0.79
	Ratio of Addition to Depletion	100.00	227.96	100.00	100.00
	Ratio of Depletion to Stock	0.89	0.88	0.78	0.80
Gold	Ratio of Depletion to Stock and Additions	3.95	0.91	8.32	6.84
	Ratio of Addition to Depletion	953.17	1411.98	23.96	137.56
	Ratio of Depletion to Stock	6.34	1.05	8.48	7.55
Crude Oil	Ratio of Depletion to Stock and Additions	8.44	8.06	10.14	11.94
	Ratio of Addition to Depletion	41.87	119.61	22.49	114.61
	Ratio of Depletion to Stock	8.75	8.92	10.38	13.84
Copper-zinc-nickel	Ratio of Depletion to Stock and Additions	3.05	3.17	4.69	4.63
	Ratio of Addition to Depletion	278.40	17.71	33.63	102.48
	Ratio of Depletion to Stock	3.33	3.15	4.62	4.86
Sulphur	Ratio of Depletion to Stock and Additions	5.85	5.86	5.05	7.23
	Ratio of Addition to Depletion	101.75	18.24	78.45	24.42
	Ratio of Depletion to Stock	5.52	5.92	5.25	7.36
Potash	Ratio of Depletion to Stock and Additions	0.55	0.51	0.17	0.20
	Ratio of Addition to Depletion	100.00	100.00	100.00	100.00
	Ratio of Depletion to Stock	0.55	0.51	0.17	0.20
Crude bitumen	Ratio of Depletion to Stock and Additions	2.99	4.29	4.15	4.68
	Ratio of Addition to Depletion	86.41	194.81	19.82	131.91
	Ratio of Depletion to Stock	2.92	4.68	4.19	4.99
Total Stock	Ratio of Depletion to Stock and Additions	2.88	4.53	4.28	4.05
	Ratio of Addition to Depletion	32.26	121.73	127.21	439.66
	Ratio of Depletion to Stock	2.85	4.80	4.52	4.93

Table 4. Trends in Selected Resources, Economic Parameters and Pollutants (in %) 1980=100

	Category	1980	1985	1990	1995
Other Resources	Fish catch	100	108	121	62
	Arable Land	100	119	108	107
	Energy Consumption	100	106	105	117
	Forest Cover	100	100	100	100
	Forest harvest	100	108	104	104
	Grassland Cover	100	84	87	88
	Irrigated land	100	126	120	119
Economic Parameters	Deficit in Current account balance	100	150	1412	1183
	Gross Domestic product	100	132	215	213
	Employment	100	100	105	101
	Labour productivity	100	119	112	119
	Population	100	105	113	120
	Total factor productivity	100	102	104	102
Pollution	CO_2	100	93	99	108
	SO_2	100	80	72	62
	VOCs	100	132	135	129
	NO_x	100	101	102	102
Natural Capital plus others	Stock	100	80	88	90
	Depletion	100	134	140	155
	Addition	100	73	79	116
	Expenditure	100	150	242	326

Appendix 1.

2.1.1. Autoregressive (AR) Processes

Time series models assume that the future values of a variable depend on it's past values plus random disturbances. An autoregressive model is based on the principle that past values and past and current disturbances determine current values of a variable. Let an autoregressive process of order p be represented by, AR(p), then the equation is given by:

$$Y_t=\phi_1 Y_{t-1} + \phi_2 Y_{t-2} + ... + \phi_q Y_{t-p} + \delta + \varepsilon_t \quad (1)$$

Where δ is an intercept parameter that relates to the mean of Y_t , ϕ_i's are unknown autoregressive parameters, ε_t is uncorrelated random error with zero mean and constant variance of σ^2_ε .

One of the problems in constructing the AR models is identifying the order of the underlying process. To identify the order of an AR process partial autocorrelation function is utilized. The sample and partial autocorrelation functions can be represented by Yule-walker equations that relate correlations in time t to past correlations. The Yule-Walker equations or autocorrelation functions are given:

$$\rho_1= \phi_1 + \phi_2 \rho_1 + ...+ \phi_p \rho_{p-1}$$

. .

$$\rho_p= \phi_1 \rho_{p-1} + ...+ \phi_p \quad (2)$$

Solving the Yule-Walker equations for p will give us values of $\phi_1 ...\phi_p$.

Solving equation 2 also requires knowledge of p. The partial autocorrelation function(PAF) could be derived by solving equation 2 for successive values of p. The PAF enables us to determine the order of the AR process. For example, if the order of a process is k then the PAF value should be close to zero for lags greater than k.

2.1.2. Moving Average (MA) Processes

Let's assume that change in the current values of a variable from year to year behave as a series of uncorrelated random variables with zero mean and constant variance. Let the series be Yt. Then,

$$Y_t= y_t-y_{t-1} =\varepsilon_t \text{ for } t=1....T \quad (3)$$

Where ε_t is a random component.

The random component reflects new or unexpected issues, such as new information, unanticipated regulation affecting economic activity, unexpected wide spread use of new technology, etc. However, the full impact of any unexpected event may not be completely absorbed by current values of the variable. Thus, next year the value of the variable may be:

$$Y_{t+1}= \varepsilon_{t+1} +\theta\, \varepsilon_t \quad (4)$$

Where ε_{t+1} is the effect of new information in year t+1 and $\theta\, \varepsilon_t$ reflect the impact from year t . The representation given by equation (4) is a moving average process where the value of a variable in year t+1 is a weighted average of current and a past random variable.

In moving average process of order q, each observation Y_t, is generated by a weighted average of random disturbances going back q periods. Let's denote moving average process of order q by MA(q) and the equation becomes:

$$Y_t=\mu+\varepsilon_t -\theta_1\varepsilon_{t-1} - \theta_2\varepsilon_{t-2} -\theta_3\varepsilon_{t-3} \ldots\ldots\ldots\ldots \ldots\ldots - \theta_q\varepsilon_{t-q} \qquad (5)$$

Where the parameters θ_1 to θ_q may be positive or negative. The disturbance terms are assumed to be independently and identically distributed across time ($\varepsilon \sim IID(0, \sigma_\varepsilon^{\,2})$).

The order of the MA series can be identified using the autocorrelation function, which enables us to determine at which lag the autocorrelation no longer differs from zero. For a moving average process of order q, the sample autocorrelation function should be close to zero for lags greater than q. The sample autocorrelation function is given by:

$$r_k= \sum_{t=1}^{t-k}(Y_t-Y^*)(Y_{t+k} -Y^*)/\sum_{t=1}^{t}(Y_t-Y^*)^2 \qquad (6)$$

Where Y* is the mean of the sample series.

2.1.3. Autoregressive Moving Average (ARMA) Processes

An ARMA model exhibits both MA and AR processes. A process with MA(q) and AR(p) denoted as ARMA(p,q) is given by:

$$Y_t=\phi_1 Y_{t-1} + \phi_2 Y_{t-2} + \ldots\ldots + \phi_q Y_{t-p} + \delta + \varepsilon_t -\theta_1\varepsilon_{t-1} - \theta_2\varepsilon_{t-2} -\theta_3\varepsilon_{t-3} \ldots\ldots - \theta_q\varepsilon_{t-q} \qquad (7)$$

2.1.4. Integrated Series

The above procedures regarding estimation using AR, MA and ARMA processes assume that the series is stationary. The only concern is to identify the order of the process for the purpose of forecasting future values of a variable. However, non-stationary series are ubiquitous. In many cases a series could exhibit a monotonically upward or downward movement. Thus, the assumption of a constant mean upon which the above time-series models were based will be violated. The variance of a series may also become non-constant or infinite. These kinds of non-stationary series could be transformed such as by differencing so that the series could be made stationary. The number of times a series is differenced to be stationary indicates the order of integration. If a series Y_t is stationary after differencing d times, then it is said to be integrated of order d.[20]

Y_t is said to be nonstationary of order d if :

$$W_t=\Delta^d Y_t \qquad (8)$$

Where W_t is stationary series and Δ denotes differencing.

Summing the series W_t d times will give:

$$Y_t= \Sigma^d W_t \qquad (9)$$

The values of a variable Y_t can be represented as:

$$Y_t = Y_0 + W_1 +W_2 +W_3 \ldots\ldots W_t \qquad (10)$$

where Y_0 is the original undifferenced series, $W_t=\Delta Y_t$

2.1.5. Autoregressive Integrated Moving Average (ARIMA) Processes

ARIMA is a model that incorporates both autoregressive and moving average processes. If $W_t = \Delta^d Y_t$, and W_t is an ARMA(p,q) process, then Y_t is an integrated autoregressive moving average process of order (p,d,q). ARIMA(p,d,q) can be written, using a backward shift operator, as:

$$\phi(B)\Delta^d Y_t = \delta + \theta(B)\varepsilon_t \quad (11)$$

With $\phi(B)=1-\phi_1 B-\phi_2 B^2 - \ldots\ldots\ldots\ldots - \phi_p B^p$

$$\theta(B)=1-\theta_1 B-\theta_2 B^2 - \ldots\ldots\ldots\ldots - \theta_p B^p \quad (12)$$

$\phi(B)$ is called the autoregressive operator and $\theta(B)$ the moving average operator.

There are several estimating and forecasting techniques of time-series variables. Many of these techniques are fitted to a data on the assumption that the model is an adequate approximation to the true generating mechanisms and then forecasts are made using the model. Among most models used to forecast time series data, the ARIMA has been found to be superior.[20]

2.1.6. Testing for Stationarity (Unit-Root)

Estimation of AR, MA and ARMA processes apply only to stationary time series. If the data is non-stationary, it implies that it contains an integrated component and that it should be differenced either before or during estimation process. A series is called weakly stationary if it has finite mean, a finite variance and covariances, all of which are independent of time. Let's consider an AR(1) process:

$$\Delta Y_t = \mu + \rho Y_{t-1} + \varepsilon_t \quad (13)$$

where μ and ρ are parameters and the ε_t 's are assumed to be independently and identically distributed

with zero mean and equal variance. If $|\rho|$ is between -1 and 1, the series is stationary. If $|\rho|=1$ the equation defines a random walk with drift and Y is then non-stationary. The variance of a series with a unit root

becomes infinite. If $|\rho| > 1$ then the series is explosive. Thus, the null hypothesis for testing

non-stationarity is that $|\rho|=1$. The null hypothesis is,
H_0: $\rho=1$

The test of this hypothesis is called a unit root test. If a series is represented by:

$$\Delta Y_t = \mu + \Upsilon Y_{t-1} + \varepsilon_t \quad (14)$$

where $\Upsilon=\rho-1$. Thus, the null hypothesis is H_0: $\Upsilon=0$. Rejection of the hypothesis implies stationarity.

2.1.7. Measures of Model Fitness

To ensure accuracy of the forecast, the models have to be screened using various measures of fitness. In the present study, Akaike Information Criterion (AIC) and Schwarz-Bayesian Criterion (SBC) will be used in addition to standard errors. A model with minimum values of these measures is hypothesized to be the best candidate for use in forecasting.[22,24]