International Trade and Exhaustible Natural Resources: Some Theoretical Aspects

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CERTIFICATE

Certified that this dissertation entitled "**International Trade and Exhaustible Natural Resources: Some Theoretical Aspects**" submitted by **Nivedita Dutta** in partial fulfillment of **Master of Philosophy** is entirely her own work and has not been considered for the award of any other degree either at this or any other university.

We recommend that this dissertation be placed before the examiners for supervision.

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CONTENTS

Introduction

" During the last twenty years since the first Earth Day, in 1970, the world lost nearly two hundred million hectares of tree cover, an area roughly the size of the United States east of the Mississippi River. Deserts expanded by some one hundred and twenty million hectares, claiming more land than is currently planted to crops in China. Thousands of plant and animal species with which we shared the planet in 1970 no longer exist. Over two decades, some 1.6 billion people were added to the world's population ---- more than double that inhabited the planet in 1900. And the world's farmers lost an estimated four hundred and eighty billion tons of topsoil, roughly equivalent to the amount of India's cropland. "[1]

This painful litany of problems cited above has led to a great deal of soul searching in the environmental community. This soul searching has centred largely on the question of why there has been relatively little success resolving these problems, despite the significant increase in environmental awareness over the past two decades.

'Environmental problems' are often associated with resources that are regenerative, but in danger of exhaustion from misuse. Exhaustible resources do not fall into this category, for they are not regenerative, except in geological time. It is important to note that *people* usually do not regard depletion of an exhaustible resource as an environmental issue, except so far as the act of extraction and use in production cause 'environmental effects'. The environmental issue, as usually understood, here pertains not to the fact that the world's supply of fossil fuels and minerals are being reduced, but rather to the fact that such activities have a detrimental effect on the earth's atmosphere.

It is important to note, however, that although exhaustion is a problem in the use of natural resources, it is only a part of the iceberg. Environmental discussions need to be conducted in the face of a clear recognition that, (a) these resources are

Brown et.al. 1991.

often common-property, (b) resolutions of environmental problems usually involve changes in the allocation of property rights, (c) resource use may well be irreversible (for example, it may lead to their exhaustion when in fact this could have been avoided), (d) resource stocks often affect welfare directly, (e) the environmental impact of certain types of activity are cumulative and only become noticeable sometime in the future, and (f) the environmental consequences of economic activity are uncertain. Environmental problems are often treated as externalities in the production process, and once their actual prices (that includes the social costs of environmental damage) are taken into account, environmental use will be sustainable. That is why some economists have emphasised on the property rights issue. Once a country (or an individual) owns a particular environmental good privately, she will take care of its sustainable use. However, in this dissertation, I have ignored the above issues and concentrated on the problem of exhaustibility.

To emphasise the importance of the environmental problems, I have tried to deal in this dissertation about the inter-linkages economic activity has with the environment in the first chapter. It is important to know that environmental effects can be divided into two groups: the effects that economic activity has on the environment through pollution, and the effects it has through resource usage and depletion. Among these two classes, pollution has always been given more attention by the environmentalists as well as the economists, while the natural resources issue have faded more into the background. Hence, in the next chapters, I will try to investigate the issue of natural resources, and how increasing economic activity, particularly trade, affects them.

While looking at the role of trade in the extraction of natural resources, it is important to note that natural resources are valuable because they are scarce in nature. If they were not so, no prudence was required for their use. Any amount of use would have been sustainable, and benefits could be accrued *ad infinitum*. But this is not the case. Natural resources are scarce, be they exhaustible or renewable in nature. Exhaustible resources face further problems, as once they are depleted, they cannot be recreated. Renewable resources on the other hand can regenerate themselves in a given period of time, but once the stock of resources fall below a certain level, this process of regeneration can stop, leading to exhaustion. Thus, any kind of unsustainable use will be harmful for the economy. The concept of resource scarcity, therefore, gathers importance. How would one decide about the optimal rate of extraction of a natural resource? One cannot do so unless one is able to measure the stock of the resource, and hence the level of resource scarcity. Therefore, it is important to know how to measure this resource scarcity. The second chapter deals with this problem. In the last section of this chapter, I shall also try to deal with the effects trade liberalisation (and therefore trade policy) has on the world in reality. The South East Asian countries have undergone trade liberalisation very recently. Therefore, I shall concentrate on this part of the world to find out how such a trade policy has affected the natural resource base of these countries.

It is worthwhile to note, that to study the effect natural resources have on trade theories, it is important to first find out how an optimal depletion rate is arrived at in a closed economy. As we have different market structures like perfect competition, monopoly, imperfect competition and oligopoly, the optimal rates of depletion should be different in different cases. As a real-life example we can cite the case of the

OPEC countries. These OPEC countries extract much more oil than they require domestically, and they export their oil at a monopoly price to obtain all other goods --- be they necessities or luxuries. If these OPEC countries did not enjoy this monopoly power, they would have had to charge lower prices, and thus extract more oil for the same amount of goods that they now enjoy. Thus, once it becomes clear, even in the theoretical context, how the behaviour of firms (or countries) differ under different market structures, and how they affect the optimal rates of extraction in the context of a closed economy, it will be easier to deal with these aspects in the case of an open economy. In the third chapter I have tried to deal with this question. However, as the theoretical analysis in the dissertation will be limited to perfect competition, the discussion of other forms of markets will be outside its scope.

The basic purpose of the fourth chapter is to study the effect that inclusion of natural resources has on static trade models. Will the inclusion of a natural resource, particularly an exhaustible resource make a static model dynamic? If so, will the results of the static trade theories hold once natural resources are included in the analysis? If we take into account the factors of production of the static models, namely capital and labour; capital accumulation and population growth will also feature in the analysis. Can capital accumulation and population growth along with depletion of natural resources be included in a single dynamic trade framework? We will also observe how trade affects the autarkic depletion rate of the exhaustible resource.

The last chapter looks at a simple extension of a dynamic trade model. In the models of the fourth chapter, cost of extraction of the resource was assumed to be costless. In the last chapter, I will try to incorporate costs of extraction in the analysis, and try to observe the differences in results, if any.

Chapter I

Trade, Environment and Natural Resources: A Survey of Theoretical and Empirical Issues

The traditional, classical, and neo-classical theories of trade explain trade in terms of the benefits accruing to all the participants engaging in trade. These benefits arise from the different efficiencies in the production of goods in different countries. Instead of each country producing everything, the countries choose to specialise according to their comparative advantages, and costs are thereby minimised. Trade and specialisation will result in a higher total production and the countries will have a greater joint 'pie' to share. Since trade is beneficial to everyone involved, the obvious conclusion is that trade should be free, and not restricted by any intervention that reduce the realisation of these benefits.

A body of mainstream economic theory (for example, the infant industry argument) had challenged the view free trade is the first-best policy. The argument survived these critiques, albeit with some qualifications. However, today, this view has been challenged again --- now by environmentalists. Environmentalists are sceptical about international trade due to a number of reasons:

- Trade increases specialisation. And if the good in question is pollution intensive, increased specialisation of such a good will lead to increased environmental disruption. On the other hand, if the good is resource intensive, and the resource is scarce, or can be exhausted with overuse, specialisation might lead to unsustainable depletion, and affect the environment adversely.
- Trade increases output and consumption; therefore, waste management problems would increase.
- Certain factors become mobile with trade. Hence, they can move to areas where pollution abatement requirements can be met cheaply. This may induce certain countries in need of international capital to lower their environmental standards in order to attract investment.

- Another aspect of opening up an economy is opening up opportunities of trade in hazardous waste. The countries which import such waste are less capable to process it: also, the exporters are less bothered to minimise the amount of toxins created (as these wastes are not deposited in their own country. This unprocessed waste will increase pollution as well as affect the natural resource base of the importing country.
- Economies, which are exporters of primary products, might resort to excessive use of chemical fertilisers as a means of escalating production. This may pollute the land and water bodies on one hand, and lead to increasing deforestation on the other.
- Trade leads to an increase in transport. This implies an increased use of fuel, and therefore, an increased damage of the environment through pollution. Also, as all fuels are exhaustive resources in nature, increased and unsustainable use of fuel can exhaust its supply.
- Lastly, free trade can increase the dependency of the underdeveloped nations on foreign imports, which might prevent them from adapting sound environmental policies.

Trade economists have been at pains to point out that whilst trade could, in theory, be neutral in its effect on the environment, this would only apply if all environmental costs are incorporated or internalised in the cost of producing traded commodities, in all the countries that produce them. The World Bank, for example, argues that productive enterprises should "pay for environmental services"(World Bank, 1992). But, this is hardly ever the case. This is because policy-makers fear that once such policies are implemented, the domestic country will no longer remain competitive if their environmental standards are higher than their competitors. The question that then arises is that will the gains from trade be positive if its environmental consequences are taken into account? To find the answer to this question we have to look at the present theoretical literature that tries to explain the relationship between trade, environment, sustainable development and growth.

1.1 Trade and Environment: Some Theoretical Perspectives

There exists a vast amount of literature which deals with the effect trade has on environment. Although a majority of the papers deal with policy issues, some deal with the changes that trade can bring in the environment, either by increasing pollution, or by over-utilising natural resources. In this section, I shall give a general overview of the models that deal with the latter aspect.

Markusen (1976) in a paper focuses on the pure trade theory issues that arise when two countries share a resource stock. Today, nations are seeking new sources of energy and raw materials. This leads to a new set of economic problems, as these countries exploit these resources. The problems become international in scope when the resources in question are held as common property among nations. Such disputes are becoming frequent. Trade in common property resources creates interdependence between countries. Markusen, showed that this interdependence consists of two parts: first, foreign use of a resource reduces domestic supply; and second, the quality of that resource will influence foreign willingness to trade in commodities, thereby influencing domestic welfare. This second (and indirect) component of the externality may work in either direction. An increase in resource stock may make the foreigners more willing to trade in commodities, resulting in an increase in domestic welfare, or the opposite may occur.

The purpose of Markusen's paper is to develop a model of two countries in a trading relationship in order to examine the trade theory issues that arise when the two countries share a common property resource. The model assumes that the resource is renewable, i.e. a resource which is depleted in the production process but which renews itself at some natural rate depending upon existing supply. The model assumes the point of view of the domestic economy. It assumes that the government takes responsibility of maximising a social welfare function. One country can not impose its rules on the other country. If the domestic economy has monopoly power in trade, it can influence world commodity prices and hence foreign production and resource use.

Initially the author assumes that to maximise domestic welfare, planners ignore foreign policy responses to domestic efforts to manipulate world prices. The domestic policy makers limit themselves to imposing tariffs and subsidies as their only tool to influence social welfare. The problem therefore is to solve for and interpret a set of necessary conditions, which must be satisfied by an optimal tax structure. Instead of going into the intricacies of the production model that whether a steady-state solution exists or not, the author simply assumes that at least one steady-state does exist when each country is following an optimal programme from its own point of view. He restricts his analysis to examining the characteristics of such a steady-state solution.

The conclusions that are drawn are as follows:

(1) If the domestic economy can influence world commodity prices, it can influence foreign production and foreign resource use.

(2) The maximising conditions confirm that two forms of dependence exist between countries producing from a common property resource: foreign use of the stock reduces domestic supply and the stock available to the foreign country influences its willingness to trade. For small increases in the resource stock, the foreign country will always increase his excess supply of the resource intensive commodity. Ceteris paribus, an increase in the resource stock will have a favourable terms of trade effect on the domestic economy if it imports the resource intensive commodity and an unfavourable effect if it exports that commodity.

Hartwick (1977), building upon Solow (1974), identified the condition for sustaining consumption in a simple economy based on a non-renewable natural resource in a general equilibrium framework. The condition was that investment in physical capital and other forms of reproducible capital must equal the economic depreciation of the resource. The latter, in turn, is given by the Hotelling rent: the product of the product of the quantity of resources extracted and marginal rent. In effect, other forms of capital must offset dimensions in natural capital. Dixit *et.al.* (1980) termed the sum of the values of changes in all forms of capital "net investment". Hence the consumption is sustainable only if net investment is nonnegative.

The models of Solow, Hartwick and Dixit *et.al.* were for closed economies in which prices of resources and other economic variables are determined endogenously. In practice, when one attempts to measure the sustainability of a particular country's economic course, one is inevitably dealing with an economy open to some amount of international trade and exhibiting some degree of price taking behaviour. What has remained unresolved however is the treatment of capital gains rising from the exogenous changes in the prices of natural resources. This is important because the prices of internationally traded natural resources are extremely volatile and can effect the overall development of the economy. Vincent *et.al.* (1996) in a paper has tried to resolve the capital gains issue in a theoretical context. They have found that exogenous price changes affect the amount that a small country exporting natural resource commodities must invest to sustain its consumption level. The difference between Hotelling rent and the discounted sum of future terms-of-trade, give the necessary amount. They have found the latter term to be large in resource-rich countries would need to invest more than previously expected to sustain their consumption levels, if natural resource prices continue their historical decline.

Low and Safadi (1992) examine a situation where a pollution externality affects two countries of different sizes, and where there is no explicit co-operation between the countries. In such a situation, welfare can be improved beyond the non-cooperative solution if the large country is prepared to make an initial binding commitment to which the small country responds (in the face of a credible threat). Strictly speaking, this result depends on the existence of a leader and a follower, and not in the characterisation of the countries as small or large. While this result is superior of non-cooperation, it is not desirable from the welfare standpoint as co-operation. The important point is that in the absence of co-operation, a large country still has an incentive to act unilaterally and derive additional benefits both for itself and for the small country.

López (1993) has tried to look at the effects of trade liberalisation and economic growth on natural resources used as a factor of production. He uses a simple framework, considering the effect of growth on environmental degradation instead of their interaction and considers trade liberalisation in a small open developing country instead of world trade liberalisation as a whole. He found that the effects of economic growth and relative price changes on the environment critically depend on the nature of the resource stock effects (where pollution or resource depletion affects future production) on production and/or whether individual producers internalise such stock effects. It is shown that for resources that have a productive stock feedback effect[1], economic growth and trade liberalisation in a typical developing country decrease degradation in both the short and the long run if individual producers internalise the stock effect. However, the effect of trade liberalisation is dependent on two assumptions, namely, that initially the manufacturing sectors is protected vis-à-vis the primary sector and that the productive stock effects of the resource occur entirely in the primary sector. On the other hand, the effects of economic growth and trade liberalisation on the resource stock are unambiguously negative if individual producers do not internalise the productive stock effects of the resource.

Rauscher (1997), in a general equilibrium framework, examines international trade in final goods in case of perfect competition. In this model, international trade is explained by differences in the environmental resource endowment of different countries. The Ricardo-Viner model and the H-O model are integrated in this paper. That is, in the short run when environmental policies are given, the world is a Ricardo-Viner one (where some factors of production are sector specific), while in the longer term, when environmental policies are adjusted, a modified H-O approach

[1] That is whether the changes in the stock or the environmental factor play a role in output.

(where all the factors are mobile across the sectors of an economy) is used. In a similar fashion, the capital employed in each sector can be treated as given and fixed in the short run and variable in the long run. As in the traditional H-O model, it is assumed here that supply of this factor is inelastic.

The results from the model are as follows:

(1) A country with a high degree of environmental concern tends to export goods that are relatively environmentally friendly in their production and relatively environmentally intensive when consumed.

(2) For a highly regulated country, trade makes it possible to 'export' some of its environmental problems to the other country.

(3) Trade liberalisation may have negative environmental effects if environmental policies that regulate production and consumption are not at their optimal levels. In such cases trade interventions may be used for welfare improvements and the achievement of second best solutions.

North-South Trade Models with Global Environment

The North-South aspects of the linkage between resource exploitation and environmental quality are complicated. Developing countries are major suppliers of raw materials to industrialised countries. If left unregulated, environmental damages associated with the extraction and initial processing of raw materials are borne by the South. A claim could be made that rich countries are practising environmental exploitation of the developing world through an insatiable demand for raw materials. However, the problem is not entirely one sided. Developing countries sometimes, are net importers of foodstuff that can place additional environmental stress on the developed country's agricultural resources. But, calculations of net disadvantages of this sort are of little use. The appropriate policy principle for any country that exports raw materials is to institute whatever environmental safeguards that are justified on the basis of local cost benefit calculations and to price its exports to cover full social costs. This principle may be hard to apply mainly for two reasons. First, local cost benefit analysis is inadequate when damages are regional or global. Second, it is unlikely that long-term damages are properly accounted for in countries with imperfect markets and high immediate consumption needs. In practice it may be difficult to avoid marginal adjustments among suppliers as they place environmental constraints on production, and the problems of inspection and enforcement in developing countries may be severe. Primary responsibility for curbing environmental abuse rests with the producing country. When resource exploitation involves international common property resources such as the oceans, or when waste disposal involves transfrontier pollution, assigning responsibility for controls is more complex. This is because countries that are recipients of damage flows do not have extraterritorial authority to impose control on polluting countries.

The North-South trade models in the literature try to explain the basis for trade between the two economies while trying to explain the environmental effects of trade. One of the most important of such models is the one developed by Chichilinsky (1994). She develops a basis for trade in a very interesting context. Two countries indulge in voluntary trade in the model inspite of identical technologies, endowments and preferences (so that the conventional neo-classical trade theories prescribe a no trade situation) if the property rights a re defined differentially among countries with respect to environmental resources. The results that are derived are as follows:

(1) If the pool from which the environmental resource is extracted is unregulated common property in the South, then the South exhibits apparent comparative advantage in the environmentally intensive good (through ill-defined property rights) even though neither region has any (actual) comparative advantage[2] over the other.

(2) At the world equilibrium, the two regions trade, and the South exports environmentally intensive goods at a price that is below social cost. The equilibrium is nor Pareto efficient.

(3) Trade makes things worse, in the sense that the overuse of the resource increases as the South moves from autarky to trade.

(4) The South shows apparent gains from trade, even though it has no actual gains from trade. It extracts more environmental resources and it produces and exports more environmentally intensive goods than is Pareto optimal.

Therefore, although trade between the North and the South leads to the equalisation of prices of all traded goods and of all its inputs of production, prices of environmentally intensive goods are below social costs. At a competitive equilibrium, the South uses more environmental resources and produces and exports more environmentally intensive goods than the North, and more than is Pareto optimal. Thus, there is overconsumption by the North of underpriced resource-intensive products imported from the South.

It becomes clear from Chichilinsky's model that inexpensive environmental resources are a main source of environmental overuse. The statement that resources

[2] Actual comparative advantage occurs when the private property supply curves internalises all the externalities that each unit of extraction has on others.

are over-consumed is practically equivalent to the statement that they are underpriced. Environmental overuse does not occur solely because the South itself overconsumes its resources. This occurs because the South exports these resources to a rich international market at prices that are below social costs. This is why the global environmental issue is inextricably connected with North-South trade. The South over-produces, and the North over-consumes; the international market transmits and enlarges the externalities of global commons.

Copeland and Taylor (1994) developed a static model of North-South trade to examine linkage between national income, pollution and international trade. Two countries produce a continuum of goods, each differing in pollution intensity. They have shown that the higher income country chooses stronger environmental protection, and specialises in relatively clean goods. By isolating the scale, composition and technique effects of international trade on pollution, they show that free trade increases world pollution; an increase in the rich North's production possibilities increases pollution, while similar growth in the poor South lowers pollution; and unilateral transfers from North to South reduce world-wide pollution.

Runge (1996) states that growing consumer concerns about environmental quality and pollution in the North are promoting more attention to environmental hazards from imported products. Trade in commodities and services then embody trade in environmental risks and degradation. This paper reviews the environmental factors and consequences of trade and then overviews the policy alternatives available to attend the desired objectives in a number of varying situations.

In this section, we have briefly surveyed the theoretical aspects of the trade and environment literature. However, it is important to know what effect trade has on the environment in reality. In this context, it is very clear that in reality, trade policies can have environmental repercussions, which might or might not be beneficial for the economy as a whole. In the next section I shall try and examine certain broad issues regarding this real-life situation.

1.2 Effects of Trade on Environment: Some Empirical Evidence[3]

The recent emphasis on reform of trade and exchange rate policy as a means to further development has provoked questions concerning the environmental impact of such reforms. At the centre of the debate is whether or not these reforms will lead to a non-optimal rate of depletion of natural resources and increased environmental degradation – i.e., a type of development that is not sustainable.

Virtually no analytical work exists in this area. This is because of two reasons. First, trade liberalisation, devaluation, and accompanying policies such as fiscal and monetary austerity, and other policies would undoubtedly have some impact on the use of natural resources and the extent on environmental degradation. But, this type of impact is not predictable *a priori*. Second, even if one were able to predict that certain trade reforms would increase the export of, say, a natural resource, this would not imply that such a policy will be harmful for the economy. The problems of optimal resource use and optimal rate of degradation depend on the shadow prices and rates of time preference. These are domestic problems and trade policies are only second-best methods to achieve such a domestic objective.

[3] This section mainly looks at the changes that are brought on the environment by trade liberalisation policies and structural adjustment programmes.

Effects of Agricultural Trade Liberalisation on the Environment

Markandya and Richardson (1990) provide a detailed examination of how specific liberalisation policies might be expected to affect the environment. Devaluation should increase the producer price for export goods. To the extent that this causes rise in the output of export crops, it may imply increased land clearing (increased deforestation) or more intensive use of existing lands. It may also imply changes in the use of fertilizers, pesticides and the choice of crop. There may be an increase in the rate of soil erosion or increase in the incentive to invest in land improving equipment or techniques.

They anticipate that removal of tariffs and quantitative restrictions give rise to the same potential impacts as devaluation, across a more limited number of products. This is also the case for increases in the official producer prices of agricultural products. Simultaneous removal of subsidies on agricultural inputs could result in a number of outcomes. For example, removal of pesticide subsidies could imply the use of more traditional methods, which are less environmentally damaging. However, less effective they are, lower would be the productivity. This may induce the farmers to cultivate land more intensively, leading to a different set of problems.

Barret (1990) actually attempts to analyse how farmers' decisions regarding soil conservation will be affected by liberalization policy. He focuses on the following debate. Suppose particular liberalization policies lead to a rise in farm producer prices. Will this lead the farmers to deplete the soil less, because they have financial incentive to invest in conservational farming techniques or equipment? Or will this lead the farmers to 'mining the soil' for a quick return on larger crop yields now? Barret proposes the following maximisation problem for the farmer: choose a soil erosion programme to maximize the present value of a stream of future profits, discounted at market interest rates. He then considers the reactions of the farmer to an unanticipated permanent increase in the price of his crop.

The results that follow are quite startling:

(1) Such a price increase will have no impact on the farmer's choice of optimal soil conservation. This is because the rise in price raises, equally, the benefits to more soil erosion now, and the benefits to adopting more conservation now.

(2) The above result also holds for the impact of the price rise on the length of the fallow period. The only way the price increase will have an impact is through its effect on the farmer's decision to employ non-soil inputs.

Barret concludes that a rise in producer prices could improve, worsen, or have no impact on soil depletion --- which depends on the technical details of the agriculture production function. He also stresses that the concern should not be whether or not policy reforms conserve or do not conserve soil. Rather they should be: to correctly estimate the shadow price of soil use, given that erosion can cause harm downstream; and to incorporate this externality correctly into the farmer's decision process.

Anderson (1992) in a paper tries to look at food, a product group, which has been of concern to the environmentalists, which are subject to extreme price and trade policy distortions. Regarding this product, the main concern of environmentalists has to do with the production externalities. The partial equilibrium framework leads to ambiguous results. Hence the author uses certain empirical studies to find out the outcomes of such a policy change in reality. Surveying several empirical studies[4] he comes to the conclusion that liberalization of agricultural policies would involve a change in the incentive structures that not only raises income substantially in rich and poorer countries, but also is likely to reduce both the damage inflicted on the global environment and the chemical residues in the food produced by the world's farmers.

In another related paper, Anderson (1992) reports on results of a 30-country multi-commodity simulation modelling exercise. He found that a complete removal of trade barriers would maintain global production of agricultural commodities roughly stable, but would redistribute that production from developed to developing countries. Because production would be transferred to the South, furthermore, chemical inputs would be substituted by labour, which would substantially reduce global chemical use in agriculture. Animal production would be shifted from confined systems toward extensive margins, particularly in Latin America, with an increase in range feeding being substituted for cereal-based feeds.

Such adjustments portend a shift of labour from subsistence to commercial production in developing economies. If this occurred, there might be less rural-urban migration, hence relieving urban environmental problems. Land use in export-oriented commercial agriculture would increase, and increased agricultural incomes might thereby induce subsistence farmers to ease marginal lands out of cultivation, thus reducing pressure on tropical forests and other threatened biomes.

These trends, however desirable, would not be necessarily uniform across production units. Price elasticities of agricultural land use estimated by Lopes (1977)

[4] For example, see Anderson and Tyres 1991b, 1992; OECD, 1987,1990a; UNCTAD, 1990; Zietz and Valdes 1990.

for Brazil and Cavallo (1989) for Argentina led Anderson (1992) to conclude that increases in output in developing countries as a result of liberalization would arise primarily in modern commercial establishments at the intensive margin. The threat to tropical forests from liberalization-induced agricultural expansion would thereby be minimized. Yet this rosy view is contested by Lutz (1990), who feels that:

> *"..given the existing population growth and generally the large pool of unemployed and underemployed.... It appears unlikely that a higher labour absorption in the commercial farm sector would noticeably reduce pressure on hill-sides and the frontier."*

Furthermore, based on the data presented by Lopes (1977), larger firms would dramatically expand production, labour and input use, while small firms would, in contrast, barely respond, since socio-institutional forces limit their access to land and capital that would enable them to benefit from price improvements.

However, although recent statistical analyses suggest a fairly unambiguous relationship between factors adjusted with macro-economic adjustments and the environment, the evidence in these terms are not unambiguous. Munasinghe and Cruz (1995) review a number of studies focussed primarily on Africa that found that a shift in cropping patterns toward export crops does not result in increased erosion, nor a reduction in food crop production, and that export promotion may not be the most proximate cause for deforestation, considering the need for land tenure reform to internalise distortions introduced by export crop development. Their review of general macro-economic adjustment studies led these authors to conclude that such policies are generally favourable toward the environment.

Effects of Trade Liberalisation in the Non-agricultural Sector on Environment

Anderson (1992) in a paper examines the product coal, where the pertinent question is whether liberalising world coal markets would rise or lower global emissions of carbon and sulphur and thereby affect global warming and acid rain. Anderson again with the help of a partial equilibrium framework establishes the fact that coal trade liberalisation in a situation where protectionist measures were used and coal prices domestically subsidised, is both financially helpful and ecologically friendly.

With respect to the effects of current environmental regulations in trade patterns, all recent empirical studies indeed similarly suggest that the impact is very low, if present at all. The most comprehensive is Tobey (1991), which focuses on heavy-polluting industrial sectors across 23 countries, including developed, newly industrialised and developing countries. He was not able to find any significant influence of the level of environmental regulation stringency on determining trade flows. The main reasons being that environmental control costs currently amount only to a very low percentage of total costs even in high polluting sectors. Kalt (1988) finds these costs in the range of 2 to 2.9% of total costs in most pollution intensive industries in the United States.

In the sectors of manufacturing that are affected by competition, environmental expenditures are still comparatively low. Environmental cost shares in these sectors are minor in comparison with other determining factor, such as changes in exchange rates, or the large labour cost gap between Eastern and Western Europe. In the sectors of steelworks (4.45%) and chemicals (2.96%) and paper production (3.83%), they are, however, on the brink of reaching significant levels.

A range of empirical studies in this respect points out that the importance of environmental costs is likely to increase in the future as there are fewer opportunities available for inexpensive improvement of environmental quality. A lucid explanation is given in Oates et.al. (1989) which estimates marginal abatement cost curves for controlling a common air pollutant in Baltimore. They find the fact that marginal abatement cost curves are fairly flat over a low range of environmental quality levels, but eventually begin to rise steeply as emissions are increasingly reduced. Moreover, they find that the intersection of current marginal benefits and marginal cost of pollution abatement is located at the base of the steep portion of the marginal cost curve. Increases in the demand for environmental quality, therefore, would cause large increases in the control costs, which could hardly be counterbalanced by technological change, alternative production techniques or input substitutions. In such a situation countries most often no longer seek environmental improvement, since under the current trade regulation such a triggered production cost increase would imply significant negative competitive effects.

Environmental standards may not only change trade flows, but also firm location decisions. Here, in a similar empirical development, the standard presumption is that low environmental standards will create a "pollution haven" is also not supported by most empirical studies so far[5]. But again, some recent empirical studies already quantify the effect in a range that is significant. In a study of industries leaving the United States for Mexico, Sanchez (1990) found that 13% of

[5] See for example, Low and Yeats, 1992, who cannot dismiss the fact that environmental standards have influenced firm location decisions, but regard it as a rather insignificant part of the explanation of industry migration.

maquiladoras[6] considered environmental regulations to be the main factors in their decision to leave the United States.

Little work has been done to assess the impact of liberalization policies on the environment, largely because the links are indirect and the outcomes in many cases ambiguous. Furthermore, trade barriers will be, at best, a second-best means of reducing environmental damage. However, empirical work linking changes in trade and exchange rate policy to the environment would be useful to: pinpoint the environmental damage likely to be aggravated by policy change; perhaps speed up the process of implementing an efficient domestic policy to incorporate this damage into production costs; and illuminate other areas where policy change may be required to effectively reduce damage. Any case for more gradual liberalization of policy would need to be based on estimates of the costs of maintaining barriers versus the benefits of delayed environmental damage.

In a paper by Barbier *et.al.* (1993), the international economic factors that played a major role in forest and species decline are examined, and the crushing debt load carried by many developing countries was labelled as the most important one. Half of the third world external debt and over two-thirds of global deforestation occur in the same 14 developing countries. These nations owe some $800 billion to private and public banks and much of their working capital goes to service this debt. This burden operates a powerful inducement to liquidate forest capital in the need for ready cash. The need for foreign exchange also stimulates the planting of cash crops for export, often grown on converted forestland.

[6] tariff-exempted production in the US-bordering area of Mexico.

Countries with significant debt problems are unable to protect their environment due to lack of funds and accomplished with stagnation, the poorer section of the society is hit hardest. As unemployment increases and incomes decline, these poor people are forced to fall back to subsistence agriculture and the conditions of poverty that lead to forest degradation.

A second important factor that leads to such a high degree of deforestation is the high demand in the industrialised nations for tropical timber and other commodities that are grown in the expense of the forests. Roughly, half of all tropical hardwood timber produced is exported to the developed world. Japan has been a major importer, accounting for nearly one-third of the world trade. Exports of pasture fed beef to North America and plantation grown cassava[7] to Europe are also important influences in tropical forest conversion.

It is felt that welfare obtained from the liberalisation of trade can be enhanced even further if removal of distortions is accompanied by proper environmental policy instruments. Excessive deforestation following a rise in food prices can be reduced through stronger enforcement of forest property rights and a production tax and logging; and therefore allow the economy to benefit from a higher food prices (as food is an inelastic commodity). Thus, there might be more efficient policy instruments than trade policies for preserving natural environment. Trade liberalisation not only never need to be put off for environmental reasons, but its benefits can be enhanced if appropriate environmental instruments are introduced at the time of liberalisation.

[7] cheap and nutritious animal feed.

As we have seen in the above sections, the effects that trade can have on environment are examined both in the context of theory and reality. However, a major part of the literature has focussed itself on dealing with how trade leads to increasing pollution, and how policies that can minimise the extent of degradation of the environment, mainly by reducing pollution. The natural resource aspect of environment has hardly been looked at. Natural resources form a very important part of a country's survival. The food we eat, the water we drink, the energy we use, or the forests that protect our lands and our bio-diversity, all belong to the category of natural resources. Unsustainable use of any of these resources due to increasing economic activity in general, or trade in particular, can lead to severe environmental repercussions. Therefore, in the present, it is important to throw light upon these issues. In this context, I would like to examine how international trade affects the resource base of the world, focussing mainly on exhaustible resources.

Chapter 2

Natural Resources: Type, Classification and Scarcity

The role of natural resources in the functioning of an economic system has received intermittent attention from economists. The classical economists of the nineteenth century were very much concerned with the issue. Both Malthus and Ricardo saw in a country's land the key to many characteristics of its economy. However, in the considerable developments of economic theory that have occurred in the twentieth century, there has been little explicit mention of natural resources. This can be mainly because of the fact that for the first two-thirds of the twentieth century, resource constraints were not important for most industrialised nations. These nations either possessed their own resource supplies in abundance, or felt confident of importing resources in unlimited amounts from other countries. This faith in resource abundance was a result of the fact that they controlled most of these developing countries as a part of their colonial system. Also, developing economies had to export their resources due to scarcity of foreign exchange.

Presently, the focus of economic theory has come on the concept of 'resource depletion' because they are no more unlimited. As a consequence, the issue of 'economic development' has given way to the more important issue of 'sustainable development'. As trade acts as a 'magnifier' of all economic processes, it has become important to find out the effects that trade can have on the environment. Trade is an increasingly important factor in national economies and plays a central role in determining the patterns of economic behaviour between nations. The expanded definition of trade, which now includes issues such as investment and intellectual property, has helped shape the nature of development within and between nations. World trade, which totals over $3.5trillion annually, has played a significant role in determining how, and in what manner, the natural resources of our planet are utilised.

This is not to say that trade patterns are the sole determinant of resource use, since most of the economic activity taking place in this planet is domestic and not international. Nevertheless, as more nations engage in steadily liberalized world trade, the role of trade in determining resource use will expand.

Before touching the issue of how the natural resource base of the world is affected by trade, it is important to find out exactly what one means by the term 'natural resource'. According to Ciriacy-Wantrup (1952), 'the concept "resource" presupposes that a "planning agent" is apprising the usefulness of his environment for the purpose of obtaining a certain end'. Before an element can be classified as a resource, two basic preconditions must be satisfied: first, the knowledge and technical skills must exist to allow its extraction and utilisation; and, second, there must be a demand for the material or services produced. There are many economically important commodities that could be described as natural resources---like, land, oil, ores, precious stones, fish populations, areas of scenic beauty, and so on. These resources can be categorised broadly in two parts: stock or exhaustible resources and flow or renewable resources (see table below).

STOCK OR EXHAUSTIBLE RESOURCES			*FLOW OR RENEWABLE RESOURCES*	
Depletable, Nonrecyclable, Energy Resources	*Theoretically Recoverable Resources*	*Recyclable Resources*	*Critical Zone*	*Non-Critical Zone*
Oil, Gas, Coal, Uranium	*All Elemental Minerals*	*Metallic Minerals, Paper, Glass*	*Fish, Soil, Forests, Animals, Water on Aquifers*	*Solar Energy, Water, Air, Tides, Wind, Waves*

A resource is exhaustible if it is possible to find a pattern of use that makes its supply dwindle to zero, i.e. it can not naturally replenish itself. The rate of replenishment for these resources is so low, that it does not offer a potential for augmenting the stock in any reasonable time frame. On the other hand, the essential feature of a renewable resource is that its stock is not fixed and can be increased as well as decreased. It will increase if the stock is allowed to regenerate. An obvious example is a single species of fish or a forest. Nevertheless, there is a maximum stock---no renewable resource can regenerate to levels above the carrying capacity of the ecosystem in which it exists. Thus, left alone, a species can increase in number, but they would not carry on increasing ad infinitum. This potential for increase is important because man can 'cream off' or harvest the increase in the size of the stock and, provided certain conditions are met, the stock will grow again, be harvested, grow again, and so on. Other things being equal (e.g. the conditions within the relevant ecosystem); there is reason to suppose that this process of harvesting can carry on for very long periods. But, it can be seen that the potential for overharvesting a renewable resource is significant: it is quite easy to make a renewable resource disappear. This will obviously happen if the rate of harvest exceeds the rate of natural growth of the resource persistently. It can also happen if the resource population falls below some critical level, perhaps because of overharvesting or for some other reason unconnected with the direct use made of the resource (e.g. habitat destruction). As in the table above, we have divided stock or exhaustible resources in three types: the energy resources, that get consumed by use; the theoretically recoverable resources, that can be recoverable, but only after a very long span of time; and the recyclable resources. The flow or renewable resources is broadly divided into resources having a critical zone and those without any critical zone. As mentioned earlier, the critical zone resources are those renewable resources that can be depleted to exhaustion if the resource stock falls below a certain minimum. If the rate of use exceeds the rate of natural replenishment, after some point, the depletion process may be so far advanced that the natural recovery of the supply flow fails to take place, even when all exploitation has ceased. Non-critical zone resources on the other hand can remain renewable irrespective of human activity, although some can be depleted temporarily by overuse. The assimilative capacity of the environment becomes important at this point. Assimilative capacity can be defined as the capability of the environment to take wastes and to convert them into harmless or ecologically useful products. Once the rates of discharge exceed this breakdown capacity, or if the wastes are non-biodegradable, or degradable only over long time periods, environmental change becomes inevitable.

2.1 Generalised Non-Renewable Resource Scarcity

In order to examine the nature of scarcity of non-renewable (or exhaustible) resources in the world in general, it is necessary to find out the amount of such resources that are still available for mankind. To be able to calculate the total amount of exhaustible resources available in the world as a whole, or in a country in particular, we need to identify the different ways in which the term 'exhaustible resource', and its various subdivisions are used.

(a) Concepts and Definitions

We first need to define what we mean by a *'resource base'* of an economy. This is defined as the total quantity of a substance or property within the geo-system. But, it is quite difficult to calculate the resource base of a particular resource in the world. Although conceptually, it is easy to understand when we measure the stock of an exhaustible resource (for they are static), and it is difficult to measure renewable resources (as by definition, it is a flow concept), in reality, it is difficult to measure either. The resource base for an exhaustible resource, like mineral ore for example, becomes an hypothetical notion because, there is no way of obtaining availability estimates independent of current knowledge and technology. All judgements about possible future discoveries are conditioned by past development trends and will change not only with improvement in survey and extraction technology, but also with altered economic and political circumstances. Hence, instead of trying to calculate the total resource base for any resource, it is more useful to use the notions of *'proven reserves', 'hypothetical resources'* and *'speculative resources'* to calculate future availability of resources.

I shall first define the three concepts, and as we proceed, it will become easy to observe that all these above categories are actually dynamic subsets of the concept of the *'fixed resource base'* (see Fig.1below).

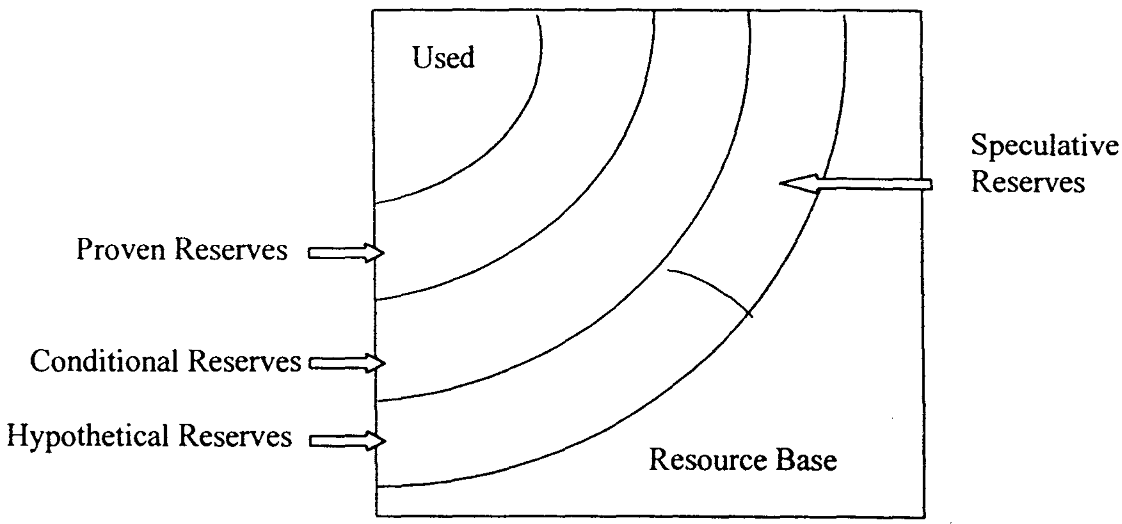

Fig.1. *The Exhaustible/ Stock Resource Base and its Subdivisions*

Proven Reserves

Proven reserves are defined as deposits already discovered and known to be economically extractable under current demand, price, and technological conditions. When proven reserve are used to forecast resource life, the implicit assumption is made that there will be no new discoveries, no technological change, no revision of production objectives, and no price changes. Proven reserve levels, at any point of time, depend on five major and related factors:

(a) The availability of *technological knowledge and skills*.

(b) *Demand levels*; these will in turn depend on a whole range of variables including population numbers, income levels, consumer tastes, government policies, and the relative prices of its substitutes and complements.

(c) *Production and processing costs*; in part these are determined by the physical nature of the deposits and their location, the costs of all factors of production, and the level of taxes imposed by the government. They will also include the costs incurred due to the risk factor to fixed assets from political order or expropriation.

(d) *The price of the resource product*: price will inevitably reflect the level of demand and the supply costs, as well as the pricing policies of producers and by government intervention.

(e) *The availability and price of substitutes*, which include the cost of recycled products.

All of these above-mentioned factors are highly dynamic factors, which can have dramatic effects on proven reserves as they change. A reserve of a particular resource may be available, but only when the technical know-how develops, can these resources be extracted. Demand plays an important role in urging producers to innovate such techniques so that costs and therefore prices can be decreased. If extraction costs become steep with increasing scarcity, a producer might stop extraction what so ever and the reserve will then fall in the category of a used one. The price of the product also plays an important role: if the prices are high enough to not to reduce demand and to increase profits, producers will always be willing to continue extraction. Moreover, low levels of taxes also encourage production, as it would then ensure higher profits. If the political situation in the country is unstable, no producer will like to invest in such a country, as the risk factor regarding losing the fixed assets is very high. And lastly, if cheap substitutes of these resource products are available, no producer will be willing to extract these resources. Hence, to term a certain resource reserve a proven reserve requires the fulfilment of all the above conditions.

Conditional Reserves

Conditional reserves are, like proven reserves, deposits which have already been discovered, but they are not economic to work at present day price levels with currently available extraction and production technologies. This is a dynamic concept, and a conditional reserve can become a proven one depending upon political and market forces, and technological innovation. The changing fortune of copper ore deposits provide a good example of the way in which the division between proven and conditional reserves can vary both over time and space. At the beginning of the century, copper ores with less than ten percent metal content could not be used in most smelters and were therefore, virtually valueless. By the middle of the century, technological changes coupled with major demand increases had allowed deposits with only one percent metal to be defined as proven reserves (Warren, 1973). Today, ores with as little as 0.4 percent copper may be economically exploitable if a combination of key cost or risk reducing factors favours the deposits. In LDCs, political stability is not always certain and cost of infrastructure is higher than the developed countries (due to additional costs). Therefore, the ore grades are much higher, and ores which fall in the category of proven reserves in the developed nations, fall in that of conditional reserves in the case of LDCs.

Hypothetical Reserves

Hypothetical reserves are not known deposits, but are those that we may expect to find in future, in the areas which today have been only partially surveyed and developed. For example, although the North Sea today, produces significant quantities of oil and natural gas, all the potential oil-bearing strata have not yet been test drilled; it is therefore an area in which hypothetical reserves should exist. A common method used to estimate the extent the use of these resources is to extrapolate from past rates of growth in production and proved reserves, or from the past discovery rate per foot of drilling (for oil). But such extrapolations assume that all the variables (political, economic and technical) that have affected past discovery and production rates will continue to operate, which is not always true. As prices and technological innovations are highly unstable variables, estimates can vary very widely depending on the time period over which such projections are made.

Speculative Reserves

Speculative reserves are those deposits which could be found in hitherto unexplored or little-explored areas where reasonably favourable geological conditions are thought to exist. Some attempts had been made to estimate speculative reserves by extrapolating from past discovery patterns in explored areas. But this approach assumes that the currently unexplored areas will be as physically productive and financially rewarding as those developed in the past. A number of commentators have argued that this is extremely unlikely. There is every possibility that the largest, most geologically favourable and accessible structures are tapped already. If this proves to be the case, then the financial returns on capital may fall as the exploration is pushed into more physically and politically difficult areas. The level of investment will fall, and with it the rate of discovery of new reserves.

(b) **Measurement and Nature of Resource Scarcity**

One of the most common questions that one associates with the use of natural resources is ' are we running out of resources?' Clearly, for any non-renewable resource, a positive rate of extraction implies that the physical stock of resource is diminishing in size. However, as we have seen in the previous section, there are major problems in defining what the physical stock should represent. The economic measure of the size of the reserve of the material is not the same as the physical size of the reserves; the term 'economic reserves' is normally used to describe that portion of a deposit which is profitable to extract, given current prices and costs. As the ratio of the price of the resource to its marginal cost of extraction falls, extracting the resource becomes less attractive. Therefore, *economic reserves* are only a subset of the total stock of *proven reserves,* as extraction will only be viable if costs and prices permit: the knowledge of the existence of the reserve is not enough. Costs depend on the state of technology and on cumulative extraction, and change over time. On the other hand, prices change in response to the decisions of extractors over the extraction rates, demand for material and government intervention on prices.

One of the most controversial theoretical and empirical issues concerns the nature and measurement of resource scarcity. Although it is agreed upon that prices should exceed marginal costs of extraction, to reflect the opportunity costs of the resource, no agreement has been reached regarding how the shadow prices should relate to the costs and prices or, how the shadow price path will be like. There are a number of empirical studies that have come up with several measures, but all have certain problems. I shall discuss them one by one.

A frequently cited measure of resource scarcity is the *lifetime of a resource.* This is usually expressed as the economic reserve of the resource divided by its current annual consumption rate, with an allowance for predicted growth in this rate over time. The most immediate problem in using this as a measure is that if we instead divide the reserve base by annual consumption, the figure would be much higher, as this will allow for higher-cost deposits being extracted with a rise in prices. However both the measures have problems. As a resource gets scarcer, its price will, *ceteris paribus*, tend to rise. This will reduce consumption and increase production. These changes will then change the lifetime measure. Also, as prices rise, producers will be encouraged to engage in more exploration, which will increase the reserve base if finds are made. In fact, lifetime measures for many resources have been found to be approximately constant over time, and it has been argued that it says more about firms' attitudes to holding inventories of the resource than about scarcity.

Many economists argue that *unit costs* of extraction can be termed as another indicator of resource scarcity. Ricardo, Mill and Jevons all pointed out that cumulative extraction could result in increasing unit costs. Ricardo considered the use of agricultural land: as demand for food increases production move on to less and less productive land. He assumed that the best quality of land is cultivated first and the state of technology is given. As this shift of production to worse land takes place, costs increase. This creates a scarcity rents on good land, and encourages farmers to use more capital and labour to this land.

A number of studies have been undertaken to test the validity of this argument. It has been found out that, over the period 1870-1957, costs had declined in case of many non-renewable resources, indicating decreasing scarcity[1]. In another study, the same exercise was undertaken for the period 1958-70, which showed that the rate of decline in unit costs had increased over this period[2]. Yet, these results cannot be taken as a proof of decreasing resource scarcity as unfortunately, many problems exist with this unit cost measure. They can be enumerated as follows:

(i) Technological progress has undoubtedly reduced unit costs over this time period, which will also have the effect of increasing the size of economic reserves.

(ii) The unit cost hypothesis relies on the assumption that firms will always deplete the lowest cost deposit first; but to know which deposit is the lowest cost implies a

[1] Barnett and Morse, 1963.

[2] Johnson *et.al*, 1980.

perfect knowledge of the characteristics of all deposits, some of which are not yet even discovered!

(iii) While it was found that unit capital and labour cost were falling, this could be due to substitution of some other input for capital and labour. When a third input, namely energy, was incorporated in the first study mentioned above, it was found that unit costs had actually increased over that period.[3]

(iv) Lastly, unit costs are said to be a poor predictor of future scarcity, as they are based entirely on past experience, and are not forward-looking: technological advances could increase future economic reserves even if, historically, unit costs have risen.

Prices, as in conventional microeconomics, are another indicator of scarcity. Many have argued that the same holds in the case of natural resources. A rising *real price* is said to be a good measure of increasing scarcity. This will be so when prices signal all furrier and current opportunity costs of using up a unit of a non-renewable resource today. For example, in the simple versions of the Hotelling model, the prices of the resource rises at the rate of interest along an optimal depletion time path, until it is equal to the price of its closest substitute. Several empirical studies have looked at price data. It was found by one that for most primary products, real prices had approximately remained constant from 1870-1957.[4] One suggested that the time path of prices must follow a U-shape. This is because an initial decline in prices due to technological progress will be eventually overcome by the tendency for increasing cumulative production to increase costs, and by the desire of the resource extractors to

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[3] Hall *et.al.*, 1986.

[4] Barnett and Morse, 1963.

see rents rising at the rate of real interest. It should be noted here that what empirical measure one chose depended on the type of scarcity one wished to measure.

However, a number of criticisms can be levelled at the use of real prices as scarcity measures. First, the influence of producer cartels on prices of primary products can be great, and yet not reflect scarcity changes. For example, the large oil price increases produced by OPEC in 1974 and 1979 were more to do in voluntary reduction in supply to increase oil revenues than an increase in scarcity. Second, governments intervene in resource markets, imposing price controls that distort price signals. The same was done by the UK government in 1970s and 1980s to keep gas prices high, in order to reduce a loss in sales by the nationalised electricity companies. Third, natural resource prices do not measure social opportunity costs, partly because the owners are not forced to pay for the environmental damages caused by the extraction and processing of these resources. Thus these prices do not measure one element of social opportunity costs, namely the environmental benefits forgone in their production. The last problem that such a measurement face is to select an appropriate deflator for calculating the real price series. Different studies use different deflators and therefore such studies in reality become non-comparable. But, it is not obvious that which deflator will suit the purpose best.

Economic rent is also cited as another measure of scarcity. It was found that in some cases an efficient depletion path involves resource rents rising at the rate of interest. Therefore, if resource rents represent the rate of return on 'holding' a non-renewable resource deposit, then this should be equal at the margin to the return on holding any other kind of asset. Rent can be defined as the difference between price and marginal extraction costs. Rising rents are, therefore, an indicator of scarcity.

However, even this measure faces certain problems. First, not much data is available. Economic rents are not exactly profits, but is the difference between prices and marginal extraction costs. Neither the firms nor the governments are in the habit of collecting such data. Proxy measures are sometimes used; but then the usual criticisms that whether the proxy actually portrays the real values always emerge, as no one can be absolutely certain. Second, the use of rent as a scarcity measure assumes that firms are following optimal depletion plans. Not only this does not hold in reality, but also in order to do so, firms need to be fully informed about extraction costs and future prices, which is impossible. Moreover, interest rate movements will also affect optimal depletion programmes, and changes in rents will pick up these effects.

While rent is possibly the best scarcity indicator from the point of view of theory, it suffers from empirical drawbacks. It is even possible for rent of a resource to decrease when its physical abundance is falling. This is because if an abundant resource can substitute for a resource that is becoming physically scarce, that resource may no longer be viewed as scarce from an economic perspective, thus lowering its rent. Whether this is a 'problem' depends on the importance of the economic or geological perspective to the viewer.

All the empirical studies that have dealt with scarcity measures have come up with different conclusions. This highlight the fact that these conclusions depend critically upon the assumptions made in developing the model, which are sometimes unrealistic. Fisher (1979) states that an ideal measure for scarcity "should summarise the sacrifices, direct or indirect, made to obtain a unit of resource". Economic theory suggests that the best measure for resource scarcity is its shadow price. The implication for empirical work, therefore, is that the functional forms used to estimate cost functions for firms should be flexible enough to identify the true time path of the underlying shadow price.

In the next section, I shall discuss the problems that are faced by a particular natural resource due to economic development in general, and trade in particular. The broader categories of renewable and non-renewable resources are divided into further sub-categories, and certain deductions are made, owing to their different properties.

2.2 Problems faced by a particular Natural Resource

We can further subdivide the natural resources into six different varieties.[5] The scarcity of a particular resource and the problems faced by it due to increasing economic activity becomes clearer if we look at them in this manner. I shall briefly discuss them one by one.

(a) **Depletable, Nonrecylable, Energy Resources** (e.g. oil, gas, coal, uranium)

Energy is one of our most critical resources. We derive energy from the food we eat. The plant or animal we consume to stay alive depends on the energy of the sun. The materials we use to build our houses and to produce the goods we consume are extracted from the earth's crust, then transformed into finished products with expenditures of energy. Currently, most industrialised nations depend on oil and natural gas for most of their energy needs. But as these resources are depletable resources (i.e. the reserves decrease with each extraction), oil and gas are transition

[5] As in Titenberg, 1992a.

fuels, which should be allocated efficiently. Hence, when deciding how fast to use up a resource, one should realise that the estimates of its availability nay increase or decrease over time in an unpredictable manner. It may increase when some new reserves of resources are discovered. It may decrease when there are unnecessary wastage of resources, as in wars. Trade has contributed to this scarcity by increasing the use of energy. Trade increases transportation, and any transportation requires fuel, i.e. energy: oil, gas or coal. While trade has increased, the use of this energy has also increased, thereby reducing the reserves further. Trade also facilitates increased production, and to produce goods, use of fuel is a must --- thus increasing the use of these natural resources.

Another problem that crops up with these highly essential resources is that as they go on depleting, the countries which have more of these reserves can come together to form a monopoly and they may exploit to effect a considerable transfer of income to themselves. This in turn influences the relative rates of development, diplomatic relations between buyers and sellers, and the political and military standing of the sellers. If one looks at the Organisation of Petroleum Exporting Countries (OPEC), one can get illustrations of all these points; and there seems to be little doubt that similar organisations for other resources will follow in future. Trade only magnifies this concern, by bringing the date nearer, if the rate of extraction of these resources is not sustainable.

(b) **Recyclable Resources** (e.g. minerals, paper, glass, etc.)

In the earliest periods, reliance would generally be exclusively on the origin ore, because it is the cheapest. As more concentrated ores are extracted, the mining industry would turn to the lower-grade ore and foreign sources of higher grade ores.

In the presence of technological progress, the increasing reliance on the lower grade ores would not necessarily precipitate an increase in cost, at least initially. Eventually however, as the sources became increasingly difficult to extract, a point would be reached when the costs of extraction and prices of the origin material would begin to rise. At the same time the costs of disposing of the products would probably rise as the population density became more pronounced, and waste product increased with increasing levels of wealth. Over the last two centuries the world has experienced a large increase in the geographic concentration of people. The attraction of cities and exodus from rural areas led to an increasingly large number of people to live in urban and near-urban environments.

This concentration creates waste disposal problems. Historically when land was plentiful and the waste stream was less hazardous the remnants could be buried in landfills. But as land became scarce, burial became increasingly expensive. In addition, concerns over environmental effects on water supplies and economic effects on the value of surrounding land have made buried waste less acceptable. The using cost of virgin materials and of waste disposal increase the attractiveness of recycling. By recovering and reintroducing materials into the system, recycling provides an alternative to virgin ores and reduces the waste disposal load.

Consumers as well as manufacturers, play a role on both demand and supply side of the market. On the demand side, consumers would find that products depending exclusively on virgin raw materials are subject to higher price than those relying on recycled materials. Consequently, consumers would have a tendency to switch to products made with the cheaper, recycled raw materials, as long as quality is not adversely affected. The powerful incentive is called 'composition of demand' effect.

As long as the consumers bear the cost of disposal, they have the additional incentive to return their used recyclable products to collection centres. By doing so, they avoid disposal costs, while at the same time reap financial rewards by supplying a product someone wants. Although recycling is not cheap, if it is recycled at a marginal cost lower than that of the substitute, the markets will rely more on the recycled resource. As recycling becomes cost competitive, dramatic changes can occur in the manufacturing process. Not only the manufacturers rely heavily on the recycled inputs; they also begin to design their products to facilitate recycling, thereby leading to conservation of these natural resources.

The need for recycling resources is high, as it could augment the current reserves of a depletable but recyclable resource. Recycling and reuse make the useful stock last longer, all other things being equal. Although it is tempting to suggest that depletable recyclable resources could last forever with a hundred percent recycling, this is actually not the case. Some of the mass is always lost during recycling. However, it will increase the time frame of that particular resource; thus helping to reduce the scarcity. In that case, increasing economic activity (for example, through trade) will not deplete such resources that fast, as it would have if only the origin raw materials were used.

(c) **Replenishable but Depletable Resource** (e.g. water)

Water is a very important natural resource of the earth. Although water is mainly affected by pollution and this pollution is transboundary in nature, certain water bodies like closed water bodies (ponds, lakes, closed seas, etc.) and groundwater resources that belong to a particular nation and can be depleted with increased use. Though on global scale, the amount of available water exceeds the demand, at particular times and in particular locations water scarcity is already a serious problem. In a number of areas, the current use of water exceeds replenishable supplies implying that aquifers are being irreversibly drained. In many parts of the world, water scarcity is already a serious problem and unless preventive measures are taken it will get worse. Added to this problem, we also have an increase in pollutants that are discharged in water, thereby reducing fresh water supply even further. Oil spills that occur due to increase in water transportation are also an important source of water pollution.

Historically, policies for controlling water pollution have been concerned with conventional pollutants discharged into surface waters. More recently, concerns have shifted towards toxic pollutants, which apparently are more prevalent than previously believed; towards groundwater, which traditionally was thought to be an invulnerable pristine resource; and towards the oceans which were mistakenly considered immune from most pollution problems because of their vast size. In certain parts of the world, groundwater supplies are being depleted to the potential detriment of future users. Supplies, which for all practical purposes will never be replenished, are being 'mined' to satisfy current needs. Once used, they are gone. Hence there is an increasing need to allocate these resources efficiently.

Early attempts of controlling water pollution failed miserably because of their unrealistic and ambitious nature. This could have been avoided if the methods used were less inflexible and more cost effective. Reforms are possible. Allowing conservers to capture the value of water saved by selling it would stimulate conservation. Creating separate fishing rights that can be sold or allowing environmental groups to acquire and retain instream water rights would provide some incentive to protect streams as fish habitats; and so on. However, the key to a successful environmental and natural resource policy is the ability to enforce them. One recent innovation in enforcement involves giving private citizen groups the power to bring non-complying firms to court. By raising the likelihood that non-complying firms would be brought before the court and assessed penalties for non-compliance, this new system can be expected to increase compliance. Hence as economic activity increases it is important for the world to see that we get the most of the water we are using and we are conserving sufficient amounts for the future.

(d) **Reproducible Private Property Resources** (e.g. agriculture)

The world hunger problem is upon us and it is real. Serious malnutrition is currently being experienced in many parts of the world. The root of the chronic problem is poverty---an inability to afford the rising cost of food. Most authorities seem to agree that an adequate amount of food is currently being produced. The FAO has concluded that developing countries could keep their food production by around 4 percent, which is well in excess of population growth.

As a renewable resource, cereal grains can be produced indefinitely, if managed correctly. Yet, two facets of the world hunger problem have to be taken into account. First, while population growth has slowed down, it has not stopped. Therefore, it is reasonable to expect the demand for food to continue. Second, the primary input for growing food is land, and land is ultimately fixed in supply. Thus, on one hand we have a rising demand, and on the other hand, food being a renewable resource does not negate the problem because it is produced using a fixed factor of production.

Part of the past improvements of agricultural production has come from intensifying the environmental problems caused by agriculture. To summarise them:

(1) Use of land is intensified with a resulting increase in the use of chemicals and fertilizers.

(2) Grasslands and forests have been increasingly converted into farmlands, thereby increasing soil erosion.

(3) Increase in fertilizer use led to contamination of lakes leading to an excessive growth of algae. Aside from aesthetic cost to a body of water choked with plant life, this nutrient excess can deprive other aquatic life forms of the oxygen they need to survive.

(4) Pesticides use also has increased. The use of pesticides leads to a spread of toxicity to species other than the target population. The herbicides and pesticides can contaminate water supplies, rendering them unfit for drinking and for supporting normal population of fish.

(5) Irrigation, a traditional source of productivity growth, is also running into limits. Traditionally important underground sources used to supply water are not being replenished at a rate sufficient to offset the withdrawals, thus exhausting these water supplies. Those that remain are subject to rising levels of salt. Irrigation of soil with naturally occurring salts causes a concentration of the salts near the surface. This salty soil is less productive and in extreme cases kills the crops.

It should be interesting to know that through trade not only the countries with low food producing capacity are affected --- but countries with high food producing capacity are also taxed. This is because the countries with scarce food products import heavily from countries rich in food, thereby urging them to use more of pesticides or other chemical fertilizers to increase their production, thus contaminating both soil and water. While on one hand, trade increases food imports, on the other; it forces the importing country to use trade barriers to reduce import, so that their own production can increase to a level such that it can fulfil its own needs. This results only in further exploitation of water resources and erosion of soil.

(e) **Storable Renewable Resource** (e.g. forests)

Forests represent an example of a storable renewable resource. They provide a variety of products and services. The raw materials for housing and many products made out of wood are extracted from the forests. In many parts of the world, wood is an important fuel. Paper products are derived from wood fibre. Trees cleanse the air by absorbing carbon dioxide and adding oxygen. Forests provide shelter and sanctuary for wildlife and they play an important role in the ecology of watersheds that supply much of our drinking water. Although the combinations that trees make to our life are easy to overlook, even the most rudimentary calculations indicate their significance. In 1980, 31.3 percent of the world land area was covered by forests.[6]

It is not easy to manage these forests. In contrast to cereal grains, which are planted and harvested on an annual scale, forests mature very slowly. The manager must not only decide how to maximise yields on a given amount of land, but also on

[6] OECD, *OECD Environmental Data: Compendium* 1985; p103.

when to harvest and replant. It is necessary to establish a delicate balance among the various possible uses of forests. As harvesting the resource diminishes other values (such as protecting the aesthetic value of forested areas), establishing the proper balance requires some means of comparing the values of potentially conflicting uses in an efficient manner. However, a glance at the forest resources does not inspire confidence that it is it is being managed either efficiently or sustainably. Deforestation is currently proceeding at an unprecedented rate. In 1990, the World Resources Institute reported that 40 to 50 million acres of tropical forests are being destroyed each year as trees are cut for timber and to clear land for agriculture and development.[7] This estimate was 50 percent higher than the previous global estimate prepared by the United Nations Food and Agricultural Organisation in 1980.

Deforestation is a serious problem because it has intensified global warming, has decreased bio-diversity, has caused agricultural productivity to decline, has increased soil erosion and desertification, and has precipitated the decline of traditional cultures of people indigenous to the forests. Instead of being used on a sustainable basis to provide for the needs of subsequent generations as well as current generations, the forests are being 'cashed in'. And trade has contributed a great extent to this mentality. The underdeveloped nations (of Africa and South East Asia) have been lured by the developed nations, mainly Japan and USA, to export timber and tropical hardwood, thus earning a steady flow of foreign exchange to tide over the deficits in their balance of payments. To import essential commodities, these countries have harvested their forests in an unsustainable manner, and are now facing

[7] World Resource Institute and International Institute for Environment and Development, " *World Resource: 1990-91*" (New York: Basic Books, 1990).

the consequences of rapidly increasing soil erosion among other ills. This makes the efficient and sustainable management of forest resources all the more important today. With the help of suitable policies, efficiency and sustainability can be made compatible with profit maximisation. Only then both domestic interests of tropical forest nations, as well as global interests in tropical forests can be taken care of.

(f) **Renewable Common Property Resources** (e.g. fisheries and other species)

Unrestricted access to commercially valuable species generally results in overexploitation. This overexploitation, in turn results in overcapitalisation, depressed income for fishermen, and depleted fish stocks. Even extinction of the species is possible; particularly fisheries characterised by low extraction costs (such as the Pacific-Salmon fishery). On top of it, trade has intensified the exploitation of these common property resources, as the demand for these species have become international and an important source of foreign exchange. However, where extraction costs are higher, extinction is unlikely, even with unrestricted access.

Both the private and public sectors have moved to alleviate the problem associated with past mismanagement of wildlife populations. By reasserting private property rights, Japan and some other countries have stimulated the development of aquaculture. Governments of Canada and the United States have moved to limit overexploitation of the Pacific-salmon. International agreements have been reached to place limits in whaling. It is doubtful that these programmes fully satisfy the efficiency criterion, although it does seem clear that sustainable catches will result.

Creative strategies for sharing the gains from moving to a more efficient level of use could prove to be a significant weapon in the arsenal of techniques designed to protect broad classes of biological resources from overexploitation. An increasing reliance on individual transferable quotas offers the possibility to preserve stocks without jeopardising the incomes of those men and women currently harvesting fish from the sea. The same is done for many other species. Other means like giving stakes to local communities in preserving wild elephants have also prevented some kind of overexploitation.

It would be a folly to ignore barriers to further action, such as the reluctance of individual fishermen to submit to many forms of regulations, the lack of a firm policy governing open ocean waters, and the difficulties of enforcing various approaches. Whether these barriers will fall before the pressing need for effective management, still remains to be seen.

In the above paragraphs, I have discussed how increasing economic activity can affect the exploitation of natural resources. It remains yet to be seen that what are the consequences of such activity in real life. To explore such possibilities, I shall see, in the next section, how trade openness affects the use of these natural resources, and what empirical assertion we can have, by observing particularly the South Eastern Region of Asia.

2.3 Empirical Relevance

Trade openness tends to greatly increase the scale of human use of the environment in two ways. First, it expands the external demand for local depletable resources and, in the case of direct foreign investment, ecological services. Second, it increases the scale of domestic production and income, expanding domestic demand for environmental inputs.

The attitude of most ecologists towards international trade is dominated by the perception of its role as a major carrier of the seeds of systematic disturbances to frontier ecosystems. Excessive logging of tropical timber, trade in ivory, and endangered species, fishing of whales and tuna are some of the familiar issues in this environmental agenda which typically have a distinctive anti-trade bias. Few empirical studies have been undertaken to find out the impact of trade openness on the environment. The conceptual analysis, plus existing empirical studies however show that trade openness both promotes and undermines sustainable development. I would like to focus my attention mainly on the effects that trade openness can have on the use of natural resources. In particular, I would like to look at the South Asian Region to find out the effects if trade openness on its natural resource base, with special reference to India. The South Asian Region comprises of the Indian Subcontinent (Bangladesh, Bhutan, India, the Maldives, Nepal, Pakistan and Sri Lanka), Indonesia, Malayasia, the Philippines, and Thailand.

The South Asian Region is endowed with abundant natural resources, but it is also prone to massive unforeseen dislocations, such as hurricanes and floods, that are both natural and manmade. These factors plus a rapidly increasing population and recent industrialisation, have led to considerable environmental degradation in recent years. Of particular concern is degradation of arable land and exploitation of water resources in this area.

Land use and Deforestation

The South Asian Region constitutes less than one-tenth of total land area of the world but supports around one-fourth of the world's population, leading to intense population pressure on land. The region's land ecosystem has consequently deteriorated over the years, primarily due to changes in land use patterns, deforestation and land degradation.

Long-term patterns of land use have changed dramatically in the recent years. The expansion of cropland, shifting agriculture, encroachment into forests and other natural habitat for development and construction activities and an increased dependence on forest resources are major causes for concern. For example, in Sri Lanka, with tea and coffee plantations replacing rainforest covered hill slopes, there has been a significant loss of forests, with erosion being only one of the resulting problems. Certain mangrove swamps and wetlands have also been cleared for aquaculture firms, which has reduced the natural productivity and cleansing functions of these highly sensitive ecosystems. The Philippines has been described as being in a state of ecological crisis following trade liberalisation. Between the early 1960s and the late 1980s, timber stock declined from 34 percent to 21 percent of total land area, and the capitalised value of soil erosion averaged 242 million pesos per year (in 1972 pesos).

Deforestation is a serious concern in the South Asian Region. Although the region supports about one-twentieth of the total forest area of the world, forest clearing for settlement and development activities, overharvesting of trees and increased dependence on forest resources for domestic use, fuelwood and trade has resulted in the rapid disappearance of forests. Most tropical logging practices severely disrupt the forest's ecological integrity. Typically, commercially valuable species make up a small percentage of the stand. Only 10 to 20 percent of the trees are cut, but another 20 to 30 percent are destroyed or fatally injured and the soil is disturbed enough to impede regeneration even in the long run. Some 4.4 million hectares were logged annually between 1981 and 1985, mostly in South East Asia. By 1985, about half of the productive closed forest in tropical Asia had been logged. Countries such as the Philippines, once a leading exporter, have nearly exhausted their lowland forests. Both the Philippines and Malayasia have totally or partially banned log exports to reduce overharvesting and develop domestic processing facilities in order to capture more of the value of their timber. Nepal, with 4 percent forests cut per year, has one of the highest deforestation of the world and certainly has the highest rates of deforestation in the world and certainly has the highest rates within the Asia/Pacific region as a whole. Sri Lanka is next, its annual rates of deforestation being 3.5 percent. In Thailand, an estimated 50 percent of the country's forest cover was lost between 1961 and 1988 (after trade liberalization). According to Thai environmental organisations, less than 20 percent of the country is forested at present. In Indonesia, tropical rain forests cover almost 40 percent of her land. The annual rate of deforestation is 1.1percent. Although it is low compared to other countries, the fact that Indonesia's share in world trade in tropical timber was 26.7 percent in 1987 and is steadily increasing, makes it no secret that she is heading in the direction of Thailand. The rate of deforestation in India is also very high, with an estimated loss of 47,500 hectares per annum. In Bangladesh, the forested area has declined from 15 percent to 5 percent of the total land area in just twenty years. An important example of linkage between trade and overexploitation of natural resources was the discontinuation of the earlier voluminous exports of timber from Nepal a decade ago because of the unsustainable nature of the large scale logging that was occurring in Nepal.

Land degradation such as erosion, salinisation, waterlogging and desertification may occur because of unsustainable land use patterns. This includes deforestation, overgrazing of pastures, inappropriate irrigation practices, mining, improper use of nitrogenous fertilizers, intensive cropping, absence of proper organic management, poor drainage and inadequate soil conservation. India has the largest area of degraded land in South Asia, with about 50 percent of its total land area degraded, and 27 percent solely affected by erosion. The recent economic policies (following trade liberalization) which aimed to cut down public spending also have far-reaching environmental effects. In real terms, the 1992 budget reduced allocation for pollution prevention by 35.5 percent, rural sanitation by 46.8 percent, wasteland developments by 23.5 percent and promotion of non-conventional energy sources by 26.3 percent. These cuts may not only undermine environmental management but also reduce income options for the rural poor. Moreover, increased resource demands in the context of environmental management will accelerate resource depletion, directly undermining rural living standards. Among the other South Asian countries, Pakistan and Sri Lanka are also affected in this respect. In Pakistan, 25 percent of unirrigated cultivated land has been degraded into deserts due to soil erosion, while 40 percent of the irrigated land area is affected by salination. In Sri Lanka, 23 percent of irrigated land is also affected by salination.

Although the region supports a high level of diversity among its flora and fauna, the loss of wildlife habitat along with legal and illegal trade in wildlife is also of serious concern. The main causes of lost wildlife habitat are encroachment of rural communities into areas of natural habitat, and pollution. Only in Bhutan does the remaining habitat exceed 50 percent of the original land area. In Sri Lanka and

Maldives, there is also serious concern about the trade in marine species and the degradation of coastal areas. In Philippines, the situation is alarming --- the annual fishing catch per unit of effort decreased by over 40 percent in between early 1960s and late 1980s. The filling up of wetlands and mangrove swamps as well as the mining of coals added up to the losses of the marine wildlife habitat.

Water Resources

The exploitation of water resources has increased significantly in the recent years for domestic, industrial and agricultural purposes. The increasing demand for water has necessitated construction of a number of dams in the South Asian countries, although few have been constructed with environmental safeguards in mind. Consequently there have been many problems of inundation, sedimentation, habitat change and land degradation. Groundwater is also being overexploited. India currently uses around 38 percent of its totally utilisable groundwater resources, with water tables falling dramatically in certain areas. Pakistan has utilised more than a third of her available groundwater. In the Maldives, groundwater assessments fore Male demonstrate that the supply of water for human use has reached a critical point. The depth of the water lens has shrunk from a level of 21 metres in the early 1970s to a mere three metres today.

Wetlands are increasingly subject to pollution and sedimentation, and many areas are already reclaimed. For example, Bangladesh has one of the most biologically diverse and productive wetland environment in the world. While these produce nearly a half million tonnes of fish annually and provide direct employment to 1.2 million people, they are rapidly being converted into agricultural land or shrimp farms, or are facing siltation and destruction through flood control, drainage and irrigation projects. Although Bangladesh is most severely affected by wetland loss in the South Asian Region, Sri Lanka and Pakistan are also rapidly losing their wetlands.

Many of the region's mangrove forests have been destroyed because of land reclamation, the construction of ponds for fish and prawn aquaculture (the latter being one of the most important export item of the area), and felling of trees for fuel. Coral reefs have similarly been destroyed, mainly through the extraction of construction materials, such as coral lime for the production of white cement. This is particularly serious in Maldives. Coral reefs have also been damaged through siltation, oil deposition, and the release of toxic industrial effluents and fishing operations. The destruction of these coastal habitats combined with overfishing has also caused serious depletion in the marine resources of the region.

Ocean-based oil slicks that originate from oil shipping or offshore oil installations appreciably damage the marine environment. The sea route that runs from the Arabian Sea to the foot of India, adjacent to Sri Lanka and across the southern part of Bay of Bengal is prone to oil spills and can dramatically damage the coastal environment of India, Sri Lanka, and the Maldives.

Thus, it can be seen from the above evidence that economic development, and trade in particular, has led to an increasing use of natural resources, even leading certain renewable resources in some countries to the brink of exhaustion. As trade acts as a magnifier, it is important to control unnecessary wastage in resource use. If the development process by itself is not sustainable, then trade will only speed up the process. It is therefore necessary to exhibit some kind of caution while extracting natural resources, especially in the case of exhaustible resources.

Chapter 3

Exploitation of Natural Resources: The Hotelling Rule

In the previous chapter we have observed that how non-renewable (or stock or exhaustible) resources are affected by economic activity, particularly by trade. We have observed scarcity of resources in general, and the effect of development on particular type of resources. We have also seen how adversely the natural resource base of some countries had been affected by mindless resource extraction. I shall now digress a little and see how the theoretical models of exhaustible resource supply and market equilibrium try to explain this behaviour.

For all exhaustible resources, there is a typical sequence of activities, each governed by economic considerations. For example, in case of minerals, in the preliminary period of exploration, a broad geological area is examined, and later specific tracts are marked. Once deposits are discovered, extraction begins. The resource, once extracted, is then transported to some location for further processing and then to final users. Some resources might be recycled for further rounds of processing and consumption.

The timing and magnitude of each process is governed by human decisions, typically by economic forces. But the amount and quality of the deposit discovered and ultimately extracted are constrained by the natural endowment. Thus the basic patterns of exhaustible resource use are governed by the interplay of economic forces and natural constraints.

The combination of processes can be very complex. Yet, economic models of exhaustible resources concentrate only on the rate of extraction of the resource and the resultant change in the quality of the resource stock. This kind of abstraction, on one hand allows insight about the economic forces, while on the other present an obscure image of a complex set of processes.

Exhaustible resource theory typically addresses several broad classes of questions:

- How much of the resource should ultimately be extracted?
- What would be the timing of extraction of with competitive markets?
- Can we expect overuse, underuse, or correct use under competitive conditions and other market structures?
- How do we incorporate costs of extraction and exploration in these models? Will the optimal solution become non-optimal if these costs are incorporated?

A sequence of models in the next sections try to explain these phenomenon. Section 3.1 presents models, which examine the implication of market structure upon the market price, the rate of extraction and the time of resource exhaustion. This analysis concentrates on the perfectly competitive markets.[1] Section 3.2 considers the impact of cost functions on the path of resource extraction, and therefore, how production technology impinges upon the economics of resource extraction and provides certain concluding thoughts.

3.1 Market Structure and the Exploitation of Non- Renewable Resources

The feature that distinguishes markets for exhaustible resources from markets of other resources is that a non-renewable stock is being discovered, produced, traded

[1] Several other forms of market structures, namely monopoly, oligopoly and imperfect competition affect extraction rates and time of resource exhaustion. In reality, markets for exhaustible resources hardly show features of perfect competition. The oil markets, for example, are mostly in an oligopolistic form, where the sellers usually form a cartel. However, in the consequent analysis, I have ignored the details of the different market structures as I have dealt only with perfectly competitive markets in the following chapters.

and consumed. Hence, the characterisation of this stock or resource base and the factors determining the rate and extent of exploration and exploitation are fundamental to modelling exhaustible resource markets.

In the beginning, however, it is necessary to explain the characteristics of a non-renewable resource as defined in theoretical models. A resource can be termed non-renewable if

(i) its stock decreases over time whenever the resource is being used,

(ii) the stock never increases over time,

(iii)the rate of stock decrease is a monotonically increasing function of rate of resource use, and

(iv)no use is possible without a positive stock.

Now, three key issues should be considered in the economics of non-renewable natural resources:

(i) The rate at which a rational firm exploits the resource;

(ii) The price path of the resource and how it changes over time; and

(iii)The life cycle of the resource --- how quickly it is economically exhausted.

If the extraction rate under a competitive market is socially optimal then it is imperative to study how this rate differs under alternative market structures. The following strong assumptions are made to derive the results.

(i) A firm has perfect foresight of its own production plan and the plans of all other firms.

(ii) The industry demand curve is known, thus all future prices are known.

{(i) and (ii) imply that firms have rational expectations.}

(iii)There is a price level at which demand for natural resources is zero owing to the presence of a 'backstop technology' which offers a perfect substitute for the natural resource, but at a higher cost. The backstop technology might take the form of a high cost invention or an alternative source of the natural resource, which is virtually limitless in quantity, but is more costly to extract.

Extraction from a Single Competitive Industry: The Pure Royalty Case

The distinguishing feature of an exhaustible resource is that it is used up when used as an input in production and at the same time, its undisturbed rate of growth is nil. In short, the inter-temporal sum of services provided by a given stock of exhaustible resource is finite. The integral of services provided by a given initial stock of such a resource is bounded.

The above definition of an exhaustible resource is in terms of the service that it is capable of providing over time. However, this is not the same as the *value* of the service that it is capable of providing over time. To distinguish between the two, let t denote time and S_0 be the given initial stock of exhaustible resource at $t=0$. Let R_t denote the rate of extraction at time t. Taking time as a continuous variable, the stock of resources at t $(t>0)$ is then given by

$$S_t = S_0 - \int_0^t R_\tau \, d\tau \qquad \text{----------(1)}$$

Feasibility implies that $S_t > 0$ for $t>0$. Consequently,

$$\int_0^\infty R_t \, dt \le S_0 \qquad \text{----------(2)}$$

This is the sense in which the 'sum' of possible services provided by the exhaustible resource is finite. If the proposed extraction rate R_t is a continuous function of time, then we can differentiate equation (1) and obtain an equivalent statement concerning the relationship between the stock of such a resource and its rate of utilisation:

$$\dot{S}_t = -R_t \qquad S_0 \, given; \;\; R_t, S_t \geq 0 \quad \text{----------(3)}$$

Now, from equation (2),

$$\lim_{t \to \infty} R_t = 0 \, .$$

Feasibility dictates that the flow of services obtainable from an exhaustible resource must necessarily decline to zero in the long run. This explains why the fact that certain resources are exhaustible has been the cause of much concern over the recent years.

In this section, I shall try to analyse the competitive price of an exhaustible resource in a partial equilibrium framework. We shall assume that time is discretely measured in equal intervals of length θ, and there are no costs of extraction. Supposing that the numeraire is an asset, the rate of return on which during the interval $(t, t+\theta)$ is δ (>0). Let p_t be the competitive spot price per unit of resource at t. Now, if an individual who owns p_t units of the numeraire asset at t, holds on to this, he is assured $(1+\delta\theta)$ p_t of the numeraire at $(t+\theta)$. Alternatively, he can purchase a unit of the resource stock at t and sell it at $(t+\theta)$. In this case, he will receive $p_{t+\theta}$ units of the numeraire at time $(t+\theta)$. Under competitive conditions, he will be indifferent between these options. We shall assume that at t the individual knows the spot price $p_{t+\theta}$ that will prevail at $(t+\theta)$. This assumption implies that a complete set of forward markets exist. Then the arbitrage condition can be described as:

$$p_{t+\theta} = (1+\delta\theta)\, p_t \qquad \text{----------- (4)}$$

Now, rearranging equation (4) and taking the limit as $\theta \to 0$, we obtain the movement of the spot price of an exhaustible resource as

$$\frac{\dot{p}_t}{p_t} = \delta_t \qquad \text{----------(5)}$$

The above equation can be termed as the fundamental principle of exhaustible resources. This principle was formulated by Hotelling (1931) and hence is known as the Hotelling rule. The only way that a given unextracted stock of resource yields a return to its owner is by appreciating in value. Under competitive conditions, therefore, the rate of capital gains enjoyed by the resource must equal to the rate of return earned in holding any other asset. This is precisely what the above equation states. An important feature can also be noted. The value of δ_t can vary over time, or can be a constant. Even if it is a constant, as long as it is not zero, the spot price of the exhaustible resource can not remain constant overtime.

The above arbitrage equation is defined as a condition describing the stock equilibrium in the market for assets. It is however, necessary to define the arbitrage equation as a condition of flow equilibrium for the market for the exhaustible resource. Extraction costs are still assumed to be nil. Let p_t^R denote the spot price of a unit flow of resource at t and let p_t continue to denote the price of a unit stock at t. then the spot value of his asset at t is $p_t\, S_t$. Under competitive conditions, this must be equal to the maximum present value calculated at t, that he can earn by extracting the resource over time. If it were greater, no one would wish to extract. If it were less, no one would hold on to the stock at all. Let R_τ $(\tau > t)$ denote an extraction policy and assume that the return to holding the numeraire i.e. δ_t, is a constant δ. Given the price paths p_t^R and p_t the owner will wish to select that time profile of extraction R_t that will maximise his present value of profits. It follows then that

$$p_t S_t = \max_{R_\tau} \int_t^\infty p_t^R R_\tau e^{\{-\delta(\tau - t)\}} dt \qquad \text{----------(6)}$$

subject to the condition

$$\int_0^\infty R_\tau dt = S_t \qquad \text{----------(7)}$$

Let R_t^* $(\tau > t)$ be the solution to the maximisation problem (6). Then differentiating both sides equation (6) with respect to t we shall get

$$\dot{p}_t S_t + p_t \dot{S}_t = \delta\, p_t S_t - p_t^R R_t^* \qquad \text{----------(8)}$$

From equation (7) we have

$$\dot{S}_t = -R_t^*$$

Using this in equation (7), we get

$$(\dot{p}_t - \delta\, p_t) = (p_t - p_t^R)\frac{R_t^*}{S_t} \qquad \text{---------(9)}$$

But under competitive conditions the stock price must equal the flow price. This is because, with no extraction costs, a unit of oil below the ground will be the same as a unit sold in the market. Thus, $p_t = p_t^R$. Substituting the value at equation (8) we again get the Hotelling rule, that is ---

$$\frac{\dot{p}_t}{p_t} = \delta_t$$

With the price of the resource rising at a compound rate δ, the value of the stock (and therefore, the maximum present value of sales) is independent of the actual extraction policy; so long the entire stock is exhausted over the future. In other words, R_t^* is not uniquely given. Given that

$$\frac{\dot{p}_t}{p_t} = \delta_t$$

we have on integration

$$p_t = p_t e^{r(t-t)} = p_t^R e^{r(t-t)}$$

Using the above result in the R.H.S. of equation (6) we have

$$p_t S_t = p_t \int_t^{\infty} \dot{R}_\tau d\tau$$

Thus, if the price of the resource rises at a compound rate δ, owners of the resource stock will be indifferent at the margin between extracting (and selling the resource flow) and holding at each instant. However, an important observation should be noted in the following analysis. With extraction costs assumed away, the entire value of the stock of the resource is composed of the flow of services it can provide. This is why the competitive value of a pool of oil or a deposit of coal is often referred to in the literature as its *royalty* value.

In a centralised set-up, when the planner maximises the present value of consumer surplus over the life of the resource subject to the constraint that the rate of depletion should be equal to the competitiveness of the resource in every period, we again get the Hotelling rule as the solution of the problem. The social planner chooses the same extraction path as the competitive industry, so long as the individual rate of time preference equals to the social rate of time preference.

3.2 Production Technology and Extraction Costs

A careful consideration of the nature of cost functions is important in studies of natural resource extraction as the production process, which is largely determined by the form of geological structures, is often quite different from manufacturing or agricultural production. The foundation of most models of supply is a characterisation of the production technology, either directly, by way of a production function or indirectly, in the form of a cost function. In competitive markets of *renewable* resources, cost functions embody the empirically recoverable structure of the production technology. In case of exhaustible resources, some additional assumptions about the production technology are required.

Exhaustible resource supply consists of two interlocking processes: exploration for new reserves, and the extraction of known reserves. In some modelling situations, it is convenient to focus on only one component of this activity, holding the rest in the background. However, a model of exploration requires a characterisation of the exploitation of the deposits that may be discovered. Cost functions are accordingly tailored to the scope of the analysis: some model the costs of extraction of a known and non-renewable stock, others focus on exploration, while still others are modelling exploration and extraction jointly.

In this section, however, we only consider the impact on the extraction path of non-linear cost functions as opposed to zero or constant marginal cost of extraction analysed earlier of two forms: first, as a function of extraction costs and second, as a function of cumulative resource depletion.

In the first case, costs are a function both of the quantity extracted and of the remaining stock. The marginal cost is increasing in terms of the quantity extracted and the cost decreases as a function of resource stock remaining. Thus,

$$c = c(x,q) \qquad \text{where } c_q > 0,\ c_{qq} > 0,\ c_x < 0.$$

In a competitive industry the problem of the representative firm is to maximise

$$\max_q \int_0^t \{pq - c(x,q)\}e^{-rt}dt$$

$$\text{s.t.} \quad x(0) = x_0, \quad \dot{x} = -q$$

From the Current Value Hamiltonian,

$$H(q,\mu,t) = pq - c(q,x) - \mu q$$

the first-order conditions are

$$p(t) - c(q) - \mu = 0$$

$$\dot{\mu} = r\mu + c_x$$

where

μ = marginal value or shadow price of the stock, other symbols remaining the same.

The second condition demonstrates that the stock has a value in terms of making extraction cheaper.

The modified version of the Hotelling rule will be

$$\frac{\frac{d}{dt}(p - c_q)}{p - c_q} - \frac{c_x}{p - c_q} = r$$

The problem with this approach is that the aggregation of the optimal extraction path over N firms requires the strong assumption that all the firms have identical costs and stocks. In empirical studies it is generally assumed that a representative firm faces a given price and the resource market ensures that the resource rent equilibrates across firms. They then choose a single satisfactory cost function, which can be estimated from data for either a single firm or aggregate industry data.

The cost of extracting a heterogeneous reserve with exploration

Here we make the assumption of a homogeneous reserve and model a joint exploration extraction process as done by Pindyck (1978). He assumed that the marginal and average extraction cost function $c_1(x)$ is a function of proven reserves but is constant in q. As reserves are depleted, marginal extraction cost increases.

Also the discovery cost function $c_2(w)$ is convex in the exploration effort w. The discovery production function $\omega(w, Y)$ determines the rate of discovery of new reserve y, which is decreasing in cumulative discoveries Y. Discovering reserves has two effects: it delays exhaustion and reduces extraction costs.

The prediction of the Pindyck model is that the price path might be U-shaped. Initially the price decreases, as discoveries are cheaper in the early life of the resource and marginal cost falls. With time marginal cost increase, as discoveries become more expensive, thus increasing the price.

Solow and Wan (1976) developed an alternative model where there are constant returns to scale and constant unit extraction costs, but extraction costs increase with cumulative extraction. They define the deposit-cost profile $F(c,t)$ as the fraction of resource reserve at time t with unit extraction costs less than c, and $F(c,0)=F(0)$. They show that it is optimal to extract from the lowest-cost deposit first, the 'cheapest-first' rule. Let $c(x)$ be the minimum cost of extracting a unit from the remaining deposits. Then total cost is $c(x)q$.

$c(x)$ is given by,

$$c(x) = F^{-1}(1 - \frac{x}{x_0}),$$

where $(1 - \frac{x}{x_0})$ is the proportion of the initial deposit remaining.

The unit extraction cost function does not allow for the possibility of exploration and discovery of new deposits. Swierzbinski and Mendelsohn (1989) extended Solow and Wan's aggregation procedure to an industry where new deposits are discounted by a random search.

They assumed constant returns to scale in both extraction and exploration and that the individual firms are risk neutral. By paying a constant search or exploration cost d, a prospector identifies the location of a unit of resource in a particular field and learn the cost of extracting it. The cost of exploration in other fields is unknown.

The resource is separated into two stocks --- x is the located reserve and s is the unlocated reserve. It is optimal for a profit maximising prospector to explore fields with the lowest extraction cost first. The exploration cost function *d(s)* is the minimum cost of identifying a unit of resource in the remaining unexplored field. Let *y* be the discovery rate, which is a decision variable. Then it follows,

As cumulative discovery increases, so does the cost of discovering an additional unit, i.e. $d'(s)<0$. As in the no-discovery case, owners extract first from identified exports with lowest extraction costs. Thus extraction exhausts reserves and newly discovered deposits with extraction costs less than *c(x,s)* first. The function $c(\bullet)$ decreasing in both *x* and *s*.

The cumulative extraction is

$$x_0 + s_0 - x - s = (x_0 + s_0 - s)F\{c(x,s)\}$$

i.e., the proportion of the total stock, which includes cumulative discoveries $(s_0 - s)$ with a cost less than *c(x,s)*. This implies

$$c(x,s) = F^{-1}\{1 - \frac{x}{(x_0 + s_0 - s)}\} \ .$$

We already know that the optimal extraction schedule of the competitive industry will coincide with the social planner's welfare maximising extraction schedule. From this maximisation they have derived a modified version of Hotelling's rule ---

$$\dot{p} = r\{p - c(x,s)\}$$

They also came to the conclusion that, over the life of the resource, the price is strictly increasing. This is in contrast to the conclusion from Pindyck's model where the price path is U-shaped.

Farzin (1992) presents a more general model of natural resource extraction. The cost function is given as $c(q,x,z)$ where x is cumulative extraction upon time t. This differs from the usual version of the state variable as the resource stock remaining and avoids to the need to know the initial stock x_0. The variable z represents an index of the state of technology. He assumes that

$$c_q > 0, \; c_x > 0, \; c_z < 0, \; c_{qq} > 0, \; c_{xq} = c_{qx} > 0, \; c_{qz} < 0.$$

This form of the model differs from earlier models insofar as the initial stock is not fixed and there is no need to explicitly assume a backstop price.

The firm's maximisation problem is

$$\max_q \int_0^\infty e^{-rt}\{pq - c(q,x,z)\}dt$$

$$\text{s.t.} \quad \dot{x} = q, \quad x(0) = 0.$$

Let μ be the shadow price of the resource. In equilibrium the shadow price increases at the discount rate less the percentage ratio of the discounted current incremental cost c_x to the present value of all future increments in incremental costs.

$$\frac{\dot{\mu}}{\mu} = r - \frac{c_x}{\int_t^\infty e^{-rt}\{pq - c(q,x,z)\}dt}$$

They also found out that the time path of shadow price could be increasing or decreasing monotonically, remain constant or change non-monotonically but will converge to a constant shadow price. The scarcity rent may take a number of different time paths.

Thus, in this chapter we have reviewed a considerable amount of literature on the problem of exhaustible resource extraction in a closed economy. We have found out that the particular market structure in the resource market plays a crucial role in determining the optimal depletion path. As the more realistic structures of cartelisation and oligopolistic markets suffer from inherent problems of dynamic efficiency and stability, it becomes clear why such market structures are not introduced in an international trade model with an exhaustible natural resource. Except for a few models, which deal with oil cartels, not much progress has been done in this regard.

The second aspect of exhaustible natural resource extraction that we have highlighted is the importance of variable extraction costs and exploration effort. Again, the insights from closed economy modelling have not been used extensively in open economy modelling.

In the next chapter we will try and see how the open economy models address the optimal resource depletion problem. We will see that most of those models are based on a competitive setting and the results might dramatically change if we can model different market structures, extraction and exploration costs and demand and supply uncertainties.

Chapter 4

Models of Trade with Exhaustible Resource

One of the distinguishing features of exhaustible resources is the uneven distribution of their stocks among nations. Due to this fact, international trade plays a crucial role in the transfer of these resources from resource-rich to resource-poor economies. Despite the voluminous literature on exhaustible resources, the number of studies that investigate the dynamic properties of resource extraction in the framework of international trade is rather modest. The studies that have been undertaken can be divided in two groups:

(i)Models that have examined, under different specifications, the long run behaviour of resource economies engaged in international trade: an analysis of the optimal extraction path and the pattern of trade for a small open economy (Kemp and Long, 1979, 1980). In these models the exhaustible natural resource is used as a factor of production to produce certain final goods which are exported. Terms of trade in these models is assumed to be constant. Thus the commodity price ratio is always given. These models try to find out whether the results of the static trade models will hold once a dynamic factor of production, namely a natural resource, is incorporated into the analysis.

(ii) Models that try to examine the optimal growth possibilities open to those economies that are dependent on natural resources in building their stocks of domestic capital (Dasgupta, Eastwood and Heal, 1978). Resources by themselves can be exported. The terms of trade are treated as endogenous. However, the analysis is always simplified by an either explicit or implicit assumption that the resource-importing country (or countries) owns no resource. These models also account both for capital accumulation and resource depletion as well as technical change and foreign borrowing.

To understand how an exhaustible natural resource is incorporated in theoretical models with trade, it is necessary to discuss both classes of models. I have picked up a few models in both classes to show their nature and analysed each of them in detail.

4.1 Dynamic Trade Models: The Effect of an exhaustible Resource on Static Trade Theory

In this section, I shall discuss those models that examine the effect an exhaustible natural resource has on static trade theories as a factor of production. Do the results of the static Heckscher-Ohlin, Stolper-Samuelson or Rybczynski models hold? Kemp and Long (1979,1980) have dealt with these issues and found affirmative results. The results from the Harris (1981) also come out to be the same. However, it is important to note that not only these models do not allow for capital accumulation or foreign borrowing and lending, they also predict complete specialisation of production. This is in sharp contrast to the general feature of incomplete specialisation present in the static trade models without a natural resource.

In the standard theory of international trade, two primary (non-produced) factors, say labour and land, are combined through a no-joint-products technology to produce two final goods. Each of the primary factors is inexhaustible, yielding its services in a steady flow over time.

Kemp and Long (1979), in this paper have introduced an exhaustible resource as a factor of production, and have tried to observe whether the standard theorems, like Rybczynski theorem or the factor price equalisation theorem, hold. The Rybczynski theorem states that if the endowment of one of the factors of production increases, the endowment of the other being constant, the output of the good using the accumulating factor intensively will increase and the output of the other good will decrease in absolute terms, provided that the commodity and factor prices are kept constant. They are able to show that a dynamic version of the Rybczynski theorem can be formulated which gives results as definite and unambiguous as its static, steady-state counterpart.

Taking the two goods produced by means of labour and an exhaustible resource as factor of production, they assume that first good X_1, is relatively labour-intensive and the second good X_2 ,relatively resource intensive. The output of the ith commodity is given by a concave, constant returns production function:

$$X_i = F^i(L_i\ ,\ E_i), \qquad i = 1,2.$$

where, X_i is the output, L_i is the labour and E_i the raw material input. It is assumed that E_i is costlessly extracted from the resource stock. Assuming a linear utility function and a constant rate of time preference, the small country tries to maximise the total revenue

$$\max \int_0^{\infty} e^{-\delta t}\left[\sum P_i\{L_i(t), E_i(t)\}\right]dt$$

subject to

$$\sum L_i(t) \le L(t) \equiv \overline{L}$$
$$\dot{R}(t) = -\sum E_i(t) = -E(t)$$
$$R(t) \ge 0$$
$$R(0) = \overline{R}, \quad L_i(t) \ge 0, \quad E_i(t) \ge 0.$$

where, $\overline{P}_i$ is the given constant price of the ith commodity,

δ is the positive and constant rate of time preference,

R(t) is the resource stock outstanding at time *t*, and

$\overline{R}$ is the initial resource stock

Thus from the above definition it becomes clear that terms of trade is treated as an exogenous variable.

The authors with the help of the above framework find out that a competitive economy will always specialize in the production of the commodity which is intensive in the factor abundantly available in that economy.They also find that there exists a lower bound of initial resource stock, below which the resource intensive commodity is never produced. If the initial resource stock lies above that value, the production is initially concentrated in the second industry and later after a finite 'switch point'(as the resource get exhausted) in the first industry.Thus if the relatively resource intensive good is ever produced, it will be produced during an initial finite interval of time, the interval followed by a second interval (perhaps infinite) during which only the other commodity will be produced.

From the optimal trajectory it is observed that the raw material input is higher for all *t* until the resource is exhausted. Therefore, the initial interval will be longer, and the output of the relatively resource intensive good greater at each moment, the larger the initial resource stock. Finally, the real price of the resource will be lower and the real rental of the other factor will be higher, the larger the resource stock. That is, an addition to the resource stock forces up real wages and pushes down the real price of the resource. They showed that this result also holds in the presence of extraction costs.

In a sequel to their first paper, **Kemp and Long (1980)** have tried to observe whether the introduction of an exhaustible resource as a factor of production changes the results of a dynamic version of the Heckscher-Ohlin theorem. The static H-O theorem states that under assumptions like a production function exhibiting a constant returns to scale, no-joint production and homothetic preferences, in a 2X2X2 framework, each country will export the commodity which is relatively intensive in its use of the other factor with which the country is relatively well endowed. In the case of a dynamic model, however, the query should not be simply whether a country will export a particular commodity, without mentioning time.

They set up a model where two tradeable goods are produced by means of internationally immobile labour and a non-tradeable exhaustible resource. There is no international borrowing or lending. They assumed that the labour endowment is the same in both countries but they differ in terms of initial holdings of the resource. Given the rate of extraction and the commodity price ratio (price of the resource intensive good in terms of the labour intensive good), the outputs of the two goods are determined.

The terms of trade are therefore exogenously given. Given the perfectly-foreseen equilibrium price-path, each country then solves a problem of the type

$$\max_{(C_1, C_2, E)} \int e^{-\delta t} U\left(C_1, C_2\right) dt$$

subject to

$$C_1 + PC_2 \leq X_1(P,E) + PX_2(P,E) \equiv Y(P,E)$$

$$\dot{R} = -E$$

$$R \geq 0$$

$$R(0) = \overline{R}$$

where, $C_i(t)$ is the consumption of the ith commodity at time t, and

$R(t)$ is the amount of resource outstanding at time t.

Maximising utility by solving a dynamic optimisation problem, they found that at no point of time can the same rate of extraction prevail in both countries. In such a situation, the two countries must produce the same quantities of both goods and since the preferences are homothetic and same everywhere, there will be no basis for trade. But the initial assumption of different resource endowment predicts a basis for trade and contradicts the result that same rate of extraction will prevail in both countries.

If preferences are the same and homothetic in both countries and if we have perfect foresight, then that country which is initially relatively well endowed with the exhaustible resource will always export the commodity which is relatively intensive in its use of the resource, as the rate of extraction is always larger in the relatively resource rich country. This is a straightforward generalisation of the standard Heckscher-Ohlin results in the context of exhaustible resource as a factor of production.

The purpose of the third paper, by **Harris (1981)**, is to extend the two-product/ two-factor static trade model in a dynamic context where one of the factors is a depletable resource. The author is concerned with the pattern of production over time and the classical comparative dynamic questions related to changes in terms of trade and factor endowments. The paper also tries to investigate in what form, if any, the Stolper-Samuelson and Rybczynski theorems hold under the analytical structure of the model.

A two sector, two factor, small, open economy, inter-temporal trade model is examined in which one of the factors is an exhaustible resource. This model also, does not allow for capital accumulation, as in the spirit of Kemp and Long (1979, 1980). Financial capital is assumed to be perfectly mobile, and thus the world interest rate is taken as exogenous. The two goods are produced with the help of capital and the exhaustible natural resource with a constant return to scale production function. This is in contrast with the production technology of the earlier Kemp and Long models.

For a given flow of resource, the production sector will maximise the value of national production (which is the market value of the two goods produced) subject to the production constraint, the availability constraint and the feasibility constraint. The results of the dynamic optimisation problem can be stated as follows. It was found that over the interval $[0, t^*]$ only the resource intensive sector produces, and resource depletion rate continuously declines. At t^* the economy switches instantaneously from producing the resource intensive good to the other good and for all $t>t^*$ only the capital intensive good is produced. Thus for any configuration of factor endowments the economy will never diversify in the production of both goods.

The intuition behind the inter-temporal specialisation result is the observation that in this model at any instant of time the asset price of the resource is fixed and hence factor prices are given. The ratio of endowment flows, however, is an endogenous variable to the economy as a whole and adjusts to clear the factor markets at the given factor prices. Given a positive interest rate, the ratio of factor prices rises continuously over time to ensure asset market equilibrium. In the two sector model, this implies factor prices will never be consistent with diversified production in both sectors, except at that instant at which factor prices equal the static factor prices consistent with production in both sectors. Thus what drives inter-temporal specialisation is the Hotelling asset market equilibrium condition together with competition in both product and factor markets, forcing price equal to unit cost. An immediate corollary of this result is that factor price equalisation in the sense that factor prices are equal at each date, will not occur unless countries have both identical technologies and endowments. Thus, non-specialisation, which is the key to many of the results in the static model, will not hold.

The author then undertakes some comparative dynamic exercises and obtains a number of results. In this model, the comparative dynamic counterpart of the static Stolper-Samuelson theorem holds, i.e. an increase in the price of the resource intensive good gives rise to an increase in the real resource price at any date. The real reward to capital unambiguously falls in the time interval where the capital intensive good is produced. In the interval where the resource intensive good is produced, the effect on real reward of capital depends on the production function of the resource intensive good. Another interesting result was that an increase in the price of the resource intensive good leads to a decrease at each moment in time in the level of production of whichever good is being produced. The economy, however, spends a longer period of time producing the resource intensive good.

It was also found out that an increase in the endowment of the stock of the depletable resource causes

a) a decrease in resource rent for all t,

b) an increase in the time of depletion (provided depletion occurs in finite time),

c) an increase in the length of the period over which the resource intensive good is produced, and

d) an increase in the rate of extraction and level of production for all $t \neq t^*$.

Thus, the Samuelson-Rybczynski result holds true in a modified sense. This result is similar to that derived by Kemp and Long (1979), mentioned earlier in this chapter. An increase in the stock of the resources leads to a higher level of production in the resource intensive industry, and to a longer period of specialized production in the resource sector. However it is also true that the less resource intensive sector expands for all $t > t^*$.

4.2 Dynamic Optimisation Models: Resource Export and Capital Accumulation

The aim of this group of models is to find out the optimal rates of extraction that will allow open economies to export resources in return to foreign capital. The question that arises is that whether these economies will use the resource domestically or export them in return of capital. It has been observed in this group of models that the country which own the resource, begin extracting till the resource is exhausted in finite time, and then a switch will occur where the other good will be produced and resource will no more be exported. Dasgupta, Eastwood and Heal (1978) and Cecen (1991) have addressed more or less the same issue, where the former addressed the capital accumulation aspect, the latter tried to show the effect of constant or variable resource price on the extraction paths. Yang (1995) also addresses the same issue in a different framework, in which he includes a 'backstop' technology on one hand and the relative resource and capital scarcity on the other.

The paper by **Dasgupta, Eastwood and Heal (1978)** tries to throw light upon the rate of depletion of an exhaustible resource in a resource-rich open economy, and the extent to which the resource should be exported rather than used domestically. There is often a choice between using a natural resource as an input in a domestic industry or exporting it. In this paper, the authors try to analyse the optimum policy mix for an economy faced with such a range of options.

The production possibilities open to the economy are given by

$$Y_t = F(K_t, R_t, t)$$

where, K_t: stock of domestic capital at time t,

R_t: rate of utilisation of the exhaustible resource in domestic production at time t.

This particular resource is also exported --- E_t is the rate of export at time t, while $P(E_t)$ is the export price. The stock remaining at time, S_t satisfies

$$S_t = S_0 - \int_0^t (R_\tau + E_\tau) d\tau$$

$$or, \quad \dot{S}_t = -(R_t + E_t)$$

Let W_t be the economy's total capital and C_t be the rate of consumption at time t. Therefore, $(W_t - C_t)$ can be defined as the stock of foreign investment earning an exogenous rate of return, say r. The basic accounting identity of the system will be

$$\dot{W}_t = F(K_t, R_t, t) + r(W_t - K_t) + P(E_t)E_t - C_t$$

The overall-planning problem faced by the economy is

$$\max \int_0^t U(C_t)e^{-\delta t}dt$$

subject to

$$\dot{S}_t = -(R_t + E_t)$$

$$\dot{W}_t = F(K_t, R_t, t) + r(W_t - K_t) + P(E_t)E_t - C_t$$

where δ, the rate of time preference, is positive.

The authors have specified the Hamiltonian in such a way, that the shadow prices of total wealth W and resource stock S are λ and μ respectively.

To pursue the analysis for definite results, the authors have made three assumptions on the various functional relationships:

(a) They assumed a constant relative risk aversion (CRRA) utility function for which the elasticity of marginal utility, η, is constant.

(b) The demand function of exports of resource, E, is negatively sloped and is not defined for a negative E.

(c) The production function is of a Cobb-Douglas nature with decreasing returns to scale. This assumption is made on the ground that this model omits the importance of other factors of production like labour and land.

Under two alternative parametric conditions the following scenarios emerge:

for $\beta < (1-\alpha)r$, $dR/dt < 0$

and for $\beta > (1-\alpha)r$, $dR/dt > 0$

where, α and β are parameters of the production function.

The latter case does not hold as a positive dR/dt implies infinite resource consumption for the country, and hence continually increasing resource imports. This case is unappealing as the demand function is not defined for a negative value of E. Therefore, the authors have concentrated on the first case, and have shown that K0, R_0, and E_0 --- the initial values of K, R, and E respectively are independent of δ and η and their paths, K_t, R_t, and E_t (and therefore, optimum rate of extraction, $R_t + E_t$) are independent of δ and η. This independence result is similar to the standard result in static trade theory, to the effect that an open economy's optimum production point is independent of its preferences and determined entirely by world prices.

The authors have also tried to incorporate uncertainty in future demand conditions in their model. The above mentioned results were obtained under the assumption that future demand conditions on export markets are known with certainty. However, it might be possible that new technologies or resource discoveries bring a sharp change in demand conditions in the future. The authors tried to model this phenomenon by assuming that there will be some date $t=T$, where this sharp change in demand will take place. Although this time T is not known with certainty, it is assumed that it will act as a random variable with a known probability density function. Assuming that the export demand function changes from *P(E)* to *P*(E)* where *P*(E)<P (E)*,for all *E*, the authors find that the result that the optimal rate of extraction and exports would be independent of preferences, do not hold except in a special case. The special case states that the ratio of the shadow prices of S and W after the switch in demand remains the same as before (i.e. λ/μ). Thus, the random event should leave the relative shadow prices of the two types of wealth unchanged for the independence result to hold.

Cecen (1991) in this paper analyses the optimal growth of a small economy that extracts exhaustible resources both for domestic production and export purposes and tries to develop a model that can address the capital accumulation and resource extraction policies in this case.

This model differs from the above model (Dasgupta, Eastwood and Heal,1978) in the sense that it takes labour into account as an input. The author then moves in a similar fashion to formulate the model so that the problem of allocating the resource optimally between domestic production and export can be solved. The dynamic efficiency condition takes the form that the returns of the two assets (capital and exhaustible resource) should be equal along the optimal path, net of depreciation.

The author then demonstrated that when the endogenously given relative resource price is constant over time, opening up of trade results in resource extraction for export purposes, but this will come to an end in finite time. After the economy stops extracting the resource, its optimal growth will be determined simultaneously by the elasticity of substitution between capital and resource input and the dynamic behaviour of the marginal product of the resource, as depicted by Dasgupta and Heal (1974). On the other hand, if the resource price has an exponential trend, he showed that resource extraction would continue forever to support domestic production and the export sector, as the resource is asymptotically depleted.

Yang (1995) examined a dynamic trade problem of a resource-secarce and capital short open economy [1]. In this economy, exhaustible resources are traded for foreign capital. Typically, developing countries operate such type of economy. The purpose of this paper is to examine the optimal trade bahaviour of an economy that trades scarce resources for much neded capital. Unlike previous research on the topic, this paper allows for endogenous export revenue. Such an approach brings the model in the paper much closer to economic reality. The long run trend of the optimal trade of resources is also probed here. The author goes on to formulate an optimal growth model, where the optimal path of consumption, capital accumulation, and the rate of depletion of the exhaustible resource are derived.

Exhausible resources, notably crude oil, are indispensible factor inputs in most production processes. Due to the uneven distribution of resource deposits, and the concentration of production and consumption in the world, there are large-scale flows of exhaustible resources in international trade. Therefore, it is natural to extend the optimal growth model with exhaustible resources into an open economic framework.

Literature in the trade of exhaustible resource has focussed primarily on the case of a small open economy with abundant deposits of exhaustible resources and negligible modern industry (for example, the OPEC countries). The depletion capacity

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[1]An economy is resource scarce, according to the author, if percapita consumptiom of the resource is lower than the world average level. It is capital-short if capital-labour ratio is lower than world average level. He gives China and India as examples of resource-scarce, capital-short open economies.

of exhaustible resources far exceeds domestic demand in these countries. They are the major suppliers of the vital energy resources for the advanced countries. They trade resources with capital rich countries for almost everything from consumer goods to capital goods. These countries face the following portfolio choice : to store the resources either in the form of undepleted deposits or in the form of foreign currency and financial assets. The author has tried to incorporate this portfoilo choice in the present model and has obtained an efficiency condition for the portfolio choice of the small open economy. He found that a necessary condition for the optimality of economic growth in a market economy is the satisfaction of the arbitrage condition that the rate of return to the foreign investment (from resource export income) equals the domestic marginal product of capital, equals the change of the domestic marginal product of resources and equals the social rate of time preference. In a perfectly competitive environment, markets reach equilibria when this condition is satisfied. In a planned economy, however, the social planners will choose the rates of extraction, level of investment and the export volume of resources in such a manner that the above condition holds.

Although most developing countries need capital to boost economic growth and they export primary goods in exchange for modern technology, many developing countries simply do not possess vital energy resources. For resource-scarce developing countries, resource imports and technology imports compete with each other in the social planner's development scheme. Therefore, the planner's problems in such economies is totally different. These countries exports its exhaustible, scarce energy resources in exchange for capital. The author tries to formulate the comparative advantage of such a trade pattern.

The assumptions that are outlined for building this model differ from earlier models in two aspects :

a) It is assumed that domestic capital and foreign capital are not perfect substitutes.

b) A 'backstop'technology exists as the substitute to the exhaustible resources at higher cost internationally.

It was found that the sole incentive for trading resurces in this model is the difference between gains from returns to foreign and domestic capital. Once such a difference is smoothed out over time, the planner will be indifferent to the trading or not trading. In addition, it was found that if the economy is insulated from the rest of the world to some extent, the domestic marginal product of exhaustible resources is not necessarily equal to the international price of the resources. Man-made distortions are likely to widen the wedge between the two.

It was also found that a competitive economy with a higher cost of 'backstop'technology will terminate the export of exhaustible resources within finite time horizon along its optimal growth path. This is because if an economy incurs a higher a cost to acquire 'backstop'technology (which is the case for all developing countries since such technology in invented by the developed countries), the domestic ceiling price of exhaustible resources will exceed the international price ceiling as the resources are depleted. The efficiency condition in this case will cease to hold and no trade situation will be optimal.

In a centrally planned economy, almost all prices of any goods are embodied in implicit taxes or subsidies since the prices are manipulated by the government. The author examines a case where he assumes that only the price of exhaustible resources is set lower than its marginal cost. Then he goes on to analyse such a distortion's impact on the behaviour of resource trading. As the resource price is set lower than the domestic market clearing price and the international price of exhaustible resources, such a low price will induce faster depletion of resources and leave fewer resources for the future generations.

Therefore, he finds that a manipulated low price for the exhaustible resources encourages both exports and domestic demand. If the 'bottle-neck'[2] situation exists concerning exhaustible resources, the subsidy to domestic consumption of the resources will exacerbate the situation by widening the gap between domestic supply and demand and by promoting the export of the resources. Subsidising domestic consumption of resources will not shorten the time horizon of exports, but is more likely to prolong it. As a result, more exhaustible resources than necessary will be exploited in a policy regime that subsidises domestic consumption of resources.

4.3 Integration of the Two Groups of Models

In the above sections we have found that the two groups of models follow two different modelling techniques. The question that then arises is that can these two groups of models be integrated? Can we incorporate the important features of both groups into a single model and derive the necessary results? Djacic (1981) made an attempt to answer the above question. He has tried to re-evaluate theorems of the Heckscher-Ohlin and Stolper-Samuelson type under the assumption that one of the factors of production is an exhaustible. It has been assumed that each country is

[2]The author interprets the term 'bottle-neck' as the following : if the whole planning process can be treated as a large scale linear programming problem, the 'bottle-neck' are those constraint sets with highest shadow prices.

endowed with an exhaustible and an inexhaustible factor of production (an exhaustible natural resource and labour in this case). An attempt is made to incorporate the dynamic nature of an exhaustible resource in the otherwise static Hechscher-Ohlin factor proportions model of comparative advantage. The focus of the paper is to examine the role of both initial factor endowments and the rates of time preference in determining how the pattern of trade between the two countries evolves over time.

Three important characteristics of this model can be noted:

a) Terms of trade is endogenous in this model.

b) Resource is treated as a factor of production as well as a final product that can be exported and imported.

c) Both countries, the resource exporting one and the resource importing one, owns resources.

This paper introduces an exhaustible resource into a closed economy model in the beginning. In this closed economy, there is a given supply of labour (L), and a stock of exhaustible resource (S_o) at time $t=0$. A single consumption good is produced by competitive firms that use labour and resource as inputs. The real wage is assumed to be perfectly flexible and labour fully employed. The resource stock is controlled by infinitely lived owners, who behave competitively and have perfect information on all of the economy's relevant parameters. It is assumed that the elasticity of derived demand for the resource is a constant greater than unity; and the production function for the single consumption good produced in the economy is of the Cobb-Douglas form. The marginal physical product of the resource therefore gives the relative price of the resource in terms of the consumer good at each instant. The rate of time preference, which is constant, is denoted by δ and is assumed equal to the real rate of interest at which residents are able to borrow or lend units of the consumption good to one another. It has been assumed that resource extraction is costless; and therefore, by Hotelling's (1931) arbitrage principle, implied that along an equilibrium path price must rise at a proportional rate equal to the pure rate of time preference. This condition is satisfied when the resource owners are indifferent between supplying the resource at different points of time. Since the resource is essential for the production of the consumption good, some of the resource should be supplied at each instant, the arbitrage principle will hold. The author also assumes that this resource can not be stored once it is extracted. Therefore, the rate of resource utilisation will always equal to the rate of extraction. The author then solves for the price path and the corresponding rate of resource extraction (which is the same as that of resource utilisation) at each point of time. From the initial resource stock, which will be asymptotically exhausted over the infinite time horizon, the initial rate of resource extraction is derived. It is found that the rate of resource extraction and resource utilisation is proportional to the remaining stock of resources, the rate of time preference and the elasticity of demand for the resource. It was also found that the initial relative price is directly related to the economy's labour supply (and hence, the demand for the resource) and is inversely related to the rate of resource extraction.

This paper assumes that under autarky there is another foreign economy, which is identical to the above-mentioned closed or `home' country, except for the rates of time preference and factor endowments. The values of its initial rate of resource extraction, its initial relative price of the resource in terms of the consumption good, its price path and its extraction or resource utilisation path, therefore, could be obtained in the same manner as that of the `home' country. Comparing the autarky prices at time $t=0$, it was found that the domestic price will be greater, lesser, or equal to the foreign price as according as $L/S_0\delta$ is greater, lesser, or equal to $L^*/S_0^*\delta^*$ (where the asterisk denotes the foreign country). The author defines $L/S_0\delta$ and $L^*/S_0^*\delta^*$ as initial domestic and foreign effective labour to resource endowment ratios. It is observed the relative price of resource is greater in the economy, which is effectively more labour abundant. This model is different from the Heckscher-Ohlin model in the sense that the absolute endowment ratios neither determine the pattern of trade between the two countries, nor the relative scarcity of factors in the two countries. Therefore, a country may be relatively resource poor in absolute terms, yet effectively resource abundant if its residents have a higher rate of time preference than those of the other country.

Assuming that the foreign country is effectively resource abundant relative to the home country at $t=0$, which implies that the initial relative price in the domestic country is greater than that of the foreign country in autarky, the question that then arises that whether the home country should import resource in exchange for the consumption good. Here, the rate of time preference plays a very crucial role. Unless $\delta^* > \delta$, the foreign country will be unwilling to extract its resources in the beginning. If only the resource and the consumption good are traded upon opening up of trade, the economy with a higher rate of time preference will be the one to export resource, while the other economy specialises in the production of its consumption good, leaving its own resource stock intact. At a certain point of time $t=T$, the more impatient economy will have completely exhausted its resource stock. This gives rise to a certain reversal in the pattern of trade an specialisation as the less impatient country begins to extract the resource, using part of the flow domestically and exporting the rest. The other economy, having depleted its resource stock, has no choice but to specialise in the production (and export) of the consumer good. Thus, the direction of trade is solely determined by rates of time preference, independent of the relative factor endowments. Therefore merely comparing relative prices under autarky will not give a correct insight in the direction and pattern of trade.

The author explains this result using the arbitrage principle of Hotelling. If $\pi(t)$ is the relative price of resource in terms of the consumption good under free trade, domestic suppliers are indifferent in supplying resources at any point of time as long as it grows at the rate of time preference . In case of the foreign country, the same holds, if the foreign relative price under free trade $\{\pi(t)\}$ grows at the rate δ^*. Now, say, $\delta > \delta^*$. Since the resource is indispensable for production, someone must be willing to supply it along an equilibrium path. If the rate of growth of relative price is greater than both δ and δ^*, such a growth rate will not be consistent with the equilibrium as no one will be willing to supply the resource. However if the rate of growth of the relative price is at least equal to the domestic rate of time preference, but greater than δ^*, then the home country will be willing to supply the resource at each point of time, although foreign owners will prefer to postpone extraction into the future. With increasing extraction, at some $t=T$, the domestic country will exhaust its own stock of resource. Only at the point where the rate of growth of relative price of the resource be equal to δ^*, will a continuous supply of resource take place, as it would induce the foreign owners to extract. Simultaneous extraction of resource in both countries will occur only in the borderline case where the rate of growth of relative price be equal to both δ and δ^* .

An interesting point to note is that although the relatively impatient economy is the first to export the resource, regardless of whether it is resource abundant or resource poor, the time at which the shift in the pattern of trade takes place, will be directly related to the ratio of its own resource endowment to that of the less impatient country. Higher the ratio, longer will be the time of exhaustion of the resource in the more impatient economy, and later will be the shift in the pattern of trade.

Thus, we observe that the author has been able to integrate the salient features of both groups in his model. He is also able to explain the switch-point with the help of different time preferences for different countries. In the otherwise static Heckscher-Ohlin model, he has included a dynamic factor of production, namely an exhaustible resource, and is able to show how relative 'effective' factor abundance (which incorporated time preference) is able to predict the pattern of trade. One thing to note in this model is that the author has incorporated changes in demand in the Heckscher-Ohlin theory to find out the pattern of trade.

However, the same result can be obtained from the supply side. If we keep same rates of time preference in both countries, and introduce differences in extraction costs across countries in the same framework, similar results can be obtained. In Djacic's model, extraction is assumed to be costless. In reality it is not so. I have tried to show in the next chapter how a difference in extraction costs between the two countries lead to a similar dynamic pattern of trade and resource depletion.

Chapter 5

A Model of Trade with Exhaustible Resource and Cost of Extraction

In this chapter, I have introduced an exhaustible resource into a closed economy model. The resource is used as an input along with an inexhaustible factor, in the production of a single consumption good. The equilibrium time paths of the resource depletion rate and the relative prices of resources in terms of the consumption good are then analysed. The model is then opened to international trade in the markets for the exhaustible resource and the consumption good, but assumes away the possibility of international lending and borrowing. A foreign economy, which may differ from the home country in its endowment of the two factors of production and costs of extraction of the resource, is introduced. Finally, the role of these asymmetries in the determination of the direction of trade, the pattern of specialisation and the volume of trade are examined within a dynamic framework.

The assumptions of the model are as follows:

(i)We consider a closed economy with a given supply of labour and a stock of an exhaustible resource at time $t=0$.

(ii)A single consumption good is produced by competitive firms that use labour and an exhaustible resource as inputs.

(iii)The real wage is assumed to be perfectly flexible and labour is fully employed.

(iv)The resource stock is controlled by infinitely lived owners who behave competitively and have perfect information on all of the economy's relevant parameters. They are assumed to be rational in the sense that they use this information to formulate expectations regarding the future course of the resource price.

(v) The elasticity of derived demand for the resource is a constant greater than unity.

(vi) The production function for Q, the single consumption good produced in the economy, is Cobb-Douglas, i.e.

$$Q(t) = L^{\alpha} X(t)^{1-\alpha}, \qquad 0 < \alpha < 1 \text{ -------(1)}$$

where

L : fixed supply of labour

$X(t)$: flow of resources used by competitive firms in the production of consumption good at time t

Profit maximisation requires that q(t), the relative price of the resource in terms of the consumption good, must be equal at each instant to the marginal physical product of the resource; i.e.

$$q(t) = \frac{\partial Q(t)}{\partial X(t)} = (1-\alpha)\left[L/X(t)\right]^{\alpha} \text{ ---------(2)}$$

The constant rate of time preference in our economy is denoted by δ and is assumed equal to the real rate of interest at which residents are able to borrow or lend units of the consumption good to one another. However, some costs are incurred for extraction of resources.

It is simplest to regard extraction costs as 'transport' costs involved in moving the resource from the source to the market. This alone suggests that the effect of extraction costs is to drive a wedge between price of the unextracted resource and price of the extracted resource, where the latter price is higher. It is then evident that under competitive conditions the difference between these two prices is the marginal cost of extraction. Let $p(t)$ denote the competitive spot price of the unextracted resource, where $q(t)$ mentioned above is actually the competitive spot price of the extracted resource. Then,

$$q(t) = p(t) + \frac{\partial C}{\partial X(t)} \text{---------} (3)$$

And it is $q(t)$ that determines the volume of the resource flow that clears the market.

We shall now consider the arbitrage condition in this setup. Under competitive conditions, the rate of return (δ) on holding the marginal unit of the stock consists of two components:

i) the capital gains that the stock enjoys

ii) the reduction in extraction costs due to the fact that this marginal unit has been stored and not extracted.

The arbitrage condition states the equality of these two rates of return at each instant. Thus, supposing time to be measured in discrete units, consider an individual who owns $p(t)$ units of the numeraire asset at t. If he holds on to this he is assured $(1+\theta r)p(t)$ units of the good at $(t+\theta)$.

Alternatively, he can purchase a unit of the unextracted resource stock at t and sell it at $(t+\theta)$. The maximum he will receive at $(t+\theta)$ is not only $p(t+\theta)$ but an additional $(\Delta c)\theta$ units of the good. Δc denotes the reduction in the extraction cost during $(t, t+\theta)$ due to the fact that an additional unit of the resource has remained unextracted during the interval. Under competitive conditions the producer will be indifferent between these two options.

Consequently,

$$p(t+\theta) + (\Delta c)\theta = (1+\theta r)p(t)$$

Rearranging these terms and letting $\theta \to 0$, then yields

$$\frac{\dot{p}(t)}{p(t)} - \frac{\partial C / \partial S(t)}{P(t)} = \delta \quad \text{--------}(4)$$

To simplify the above condition (in order to analyze the competitive price with extraction costs) we assume that the average cost of extraction, is a constant b (>0).

$$\frac{\dot{p}(t)}{p(t)} = \delta \quad \text{--------}(5)$$

From the above equation therefore we get

$$p(t) = p(0)e^{\delta t}$$

And from equation (3),

$$q(t) = p(t) + b \quad \text{----------------}(6)$$

But equation (5) and (6) implies,

$$q(t) = p(0)e^{\delta t} + b \quad \text{--------}(7)$$

Now, it is important to solve for $p(t)$ and the corresponding rate of extraction at each point of time. From equation (2) and (7), we have

$$p(0)e^{\delta t} + b = (1-\alpha)\left[\frac{L}{X(t)}\right]^{\alpha}$$

$$or, \qquad X(t) = \frac{(1-\alpha)^{1/\alpha} L}{\left[p(0)e^{\delta t} + b\right]^{1/\alpha}}$$

Now as α is a constant, let $(1-\alpha)^{1/\alpha}$ be k. Thus we have,

$$X(t) = \frac{kL}{\left[p(0)e^{\delta t} + b\right]^{1/\alpha}} \qquad \text{--------(8)}$$

Since the initial resource stock S_0, will be asymptotically exhausted over the infinite time horizon, we have

$$S_0 = \int_0^{\infty} X(t)dt \qquad \text{.........................} \qquad (9)$$

$$= \int_0^{\infty} \frac{kL}{(b + p(0)e^{\delta t})^{\frac{1}{\alpha}}} dt$$

$$= kL \int_0^{\infty} (b + p(0)e^{\delta t})^{-\frac{1}{\alpha}} dt$$

Integrating the above equation we get

$$S_0 \cong \frac{\alpha\beta kL}{\delta} [b + p(0)]^{-\frac{1}{\alpha}} \qquad \text{..................................(10)}$$

where β is a constant greater than 1.

The integration involves an infinite series where the terms are progressively smaller. We have assumed that the series sums up to a constant greater than one since the first term of the series is one. This assumption is only for mathematical convenience to get definite results about the initial values of the resource stock, the resource price and the extraction rate. As we shall see this will facilitate a direct comparison of the two trading countries.

From equation (10) we get,

$$p(0) = \left(\frac{S_0\delta}{\alpha\beta kL}\right)^{-\alpha} - b = \left(\frac{\alpha\beta kL}{S_0\delta}\right)^{\alpha} - b \qquad \text{.......................(11)}$$

$$q(t) = b + \left[\left(\frac{\alpha\beta kL}{S_0\delta} \right)^{\alpha} - b \right] e^{\delta t} \quad \text{......................(12)}$$

And

$$X(t) = \frac{kL}{\left[b + \left\{ \left(\frac{\alpha\beta kL}{S_0\delta} \right)^{\alpha} - b \right\} e^{\delta t} \right]^{1/\alpha}} \quad \text{..........................(13)}$$

Now, we are in a position to analyse a trading situation with a foreign country, which exhibits similar characteristics as that of the domestic country. Then,

$$p'(t) = \left\{ \left(\frac{\alpha\beta' kL'}{S'_0} \right) \alpha - b' \right\} e^{\delta t} \quad \text{---------(14)}$$

and,

$$q'(t) = b + \left\{ \left(\frac{\alpha\beta' kL'}{S'_0} \right) \alpha - b' \right\} e^{\delta t} \quad \text{--------(15)}$$

The only exceptions are in the cost of extraction of the resource and the endowment ratios. It is assumed that there are different deposits of the resource in the countries, the difference being in the extraction costs. We assume that $b' > b$. This can be explained by supposing that the deposit in the foreign country is less accessible; or some geological difference makes extraction cheaper at the home country deposit.

Now, an interesting point to note that under competitive conditions, these two deposits will not be extracted simultaneously in the presence of trade, over any interval of time. For suppose they were, then owners of the two deposits will be indifferent between storing and extracting over this interval. Consequently,

$$\frac{\dot{p}(t)}{p(t)} = \frac{\dot{p}'(t)}{p'(t)} = \delta$$

Also, as the two deposits contain identical products:

$$q(t) = q'(t)$$

Now equation (13) and (14) are inconsistent with each other. Therefore the two deposits will not be mined simultaneously, but instead will be extracted sequentially. Given $\delta > 0$, the higher cost deposits will be extracted later. So long as stocks of both deposits are positive, equation (13) will hold in order that the asset market clears. For an initial period *(T)*, the deposit in the foreign country will be found unprofitable to extract. That is

$$q^*(t) = q(t) = b + p(t) < b' + p'(t) \qquad \text{for } 0 \leq t < T$$

During this period, the owners of the deposit of the home country will undercut the price of the second one. The owners of the foreign country, therefore, will store and import resources from the domestic country to produce the consumer goods; while the producers of the domestic country will export resources and import consumer goods. The owners of resource in the foreign country will not extract, as the market price of the extracted resource does not cover the higher cost of extraction. Meanwhile *q(t)* grows continuously (from 13 and 15) and the extraction rate falls (follows from the assumption of a downward sloping demand curve). At *T*, the home country exhausts its deposits and there is a switch to the foreign country's deposit. Thus at $t \geq T$

$$q^{*}(t) = q'(t) = b' + p'(t)$$

The foreign country will now extract its resources while the domestic country will now import these resources and produce and export the consumer good. Thus, due to a difference in the cost of extraction, we observe that a drastic reversal in pattern of trade will take place.

An important thing to note would be that if the costs of extraction in this model were taken as zero and differences in time preferences are incorporated, this model will be exactly similar to Djajic's model mentioned in the previous chapter. Hence, the basic differences in these two models are those in cost.

In this model, in the absence of international lending and borrowing, the possibility of incomplete specialisation, and therefore simultaneous extraction of the resources in both countries do not arise unless $q(t) = q'(t)$. However, it has been shown in the model that above result will be inconsistent with free trade. Hence, there will be complete specialisation of extraction will export resources in the initial phase.

In this model, it is assumed that marginal costs (and therefore average costs) of extraction are constants. This is hardly true in reality. As observed in the third chapter, they can be a function both of the quantity extracted and of the remaining stock. Then, the marginal cost will increase in terms of the quantity extracted and the cost will decrease as a function of total stock remaining. In some analysis exploration costs are also included. The total stock of resources are then divided into proven and hypothetical ones, and it is optimal for a profit maximising prospector to explore fields with lowest extraction cost first. As cumulative discovery increases, so does the cost of discovering an additional unit, and so will the costs extraction. An alternative approach to discussing exhaustible resources is to postulate an infinite resource base, but with unit costs of extraction increasing indefinitely with cumulative extraction. In the long run, therefore, it follows that the rates of extraction will be tending to zero. However, in this analysis, it does not follow immediately that the integral of resource utilisation is bounded above. Dasgupta and Heal (1979), in a discussion had remarked that such a form of analysis will only complicate matters and be possibly less intuitive.

To conclude, therefore, we observe that similar results regarding pattern of trade could be obtained from this extension. However, even this extended model predicts complete specialisation in production as one of its results. It is necessary to formulate a model in such a manner so that the general result of static trade theory, namely incomplete specialisation can be obtained. As mentioned above, not only are marginal costs functions of rates of extraction and remaining resource stock, costs of exploration can also be incorporated in the analysis. It can be expected that some fruitful research and definite results can be obtained from that direction with will further enlighten the working of dynamic trade models that incorporate natural resource in their analysis.

Conclusion

While addressing the issue of trade and natural resources it should be kept in mind that trade, by itself, cannot cause any harm to the environment. Therefore, we can agree to the views of the classical economists that trade is beneficial to all. However, if the resource exploitation or use is unsustainable, trade tends to magnify the effect, thereby worsening the situation further. To quote,

> *"None of the aspects of sustainable development is intrinsically linked to international trade. A failure to place a value on environmental resources would undermine sustainable development even in a completely closed economy. Trade is seen, rather, as a 'magnifier'. If the policies necessary for sustainable development are in place, trade promotes development that is sustainable."*[1]

The first chapter demonstrates the importance of the inter-linkages of trade and the environment. The inter-linkages between trade and the pollution, and trade and natural resources should be addressed as two different set of issues. This is because not only the style of theoretical modeling is different in these two cases, the issues addressed by these two groups are also different. While the former refers to the problems that increasing levels of pollution can cause to the economy, the latter refers to the extraction and depletion of a natural resource in a particular area. Pollution is transboundary in nature: activities of one country can affect another through pollution. On the other hand, natural resources in a single country, if depleted, can not effect the natural resource base of another country except in a very indirect manner. If trade exists between these two countries, then the country which has depleted its own resource stock might wish to import resources from the other country, leading to a

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[1] *International Trade, 1990-91*, GATT 1992, p.25.

faster depletion of its resources than it had been originally intended. In the second chapter, I have gone in details to show the various classifications of natural resources. It is an interesting fact that when natural resources are used in theoretical models, they are at the most classified into two types: renewable and exhaustible. These two groups are then treated as homogeneous bodies; as if fishes and forests exhibit same properties, and so do minerals and natural gas. But, in reality it is not so. Hence there is a need to incorporate the various characteristics of natural resources in the theoretical analysis, to make it more genuine.

I have, in the next section discussed at length the importance of natural resource scarcity and its measures. However, none of the measures of resource scarcity are able to explain or measure actual scarcity. Proxy variables that are able to truly portray the characteristics of natural resource scarcity and hence, their measurement, are difficult to measure empirically as data is either scarce or unavailable. On the other hand , those variables with easily available data are unable to give a correct value or measure of scarcity and therefore, are less theoretically feasible.

In the third section, I have looked at the effects of trade liberalisation on the natural resource base of the South East Asian Region, which showed some startling results. Trade liberalisation has encouraged export of timber in many of the countries, particularly in Thailand and Indonesia. To solve their balance-of-payment problems and to gain scarce foreign exchange there has been severe deforestation in these countries. Land erosion have taken place, while shrimp culture in many others (like India) have destroyed mangrove forests. Disappearance of these mangrove forests with increasing sea traffic have also affected marine life. These activities have definitely contributed a fair share in global warming and extinction of species, plant as well as animal.

In the third chapter, we deal with the optimal rates of extraction with different market structures in the closed economic context. We have observed that under the ideal situation of perfect competition, the Hotelling rule determines the rates of extraction. The Hotelling rule states that with a fixed, exhaustible resource stock and zero extraction costs, a firm will be indifferent between extracting in the current period and in future, if the price rises at the discount rate (i.e. the rate of time preference). When costs of extraction an those of exploration was incorporated into the analysis, a modified version of the Hotelling rule still prevailed.

In the fourth chapter, I have tried to study those groups of models, which throw light on how exhaustible resource affects trade models. Models that deal with exhaustible resources were divided into two groups. The first group tried to include an exhaustible resource as a factor of production and found that the Heckscher-Ohlin, Stolper-Samuelson and Rybczynsky results hold with minor modifications. These models predict a complete specialisation of production. The important features of these models are that although they are dynamic in nature, terms of trade are treated as endogenous and resources could only be used for production purposes. Both countries --- the resource-abundant as well as the resource-scarce one own resource; but resource is immobile across countries.

The second group of models tries to find out the optimal extraction paths of an open economy. This open economy has to decide whether it would export its resources in return of capital, or use it domestically. It was found that the dynamic pattern of trade, even by including resources in the analysis, would be independent of preferences as in case of static trade models. It was also found that when resources will be extracted and exported, this will occur only for a finite period, and then a switch will take place: i.e. patterns of trade will be reversed after a finite period of time. In these models, although terms of trade are treated as endogenous and resource trade do take place, one important departure is the assumption that the resource importing country (or countries) owns (or own) no resource.

In the last section of this chapter, I have shown a model that has tried to include the salient features of both groups. Three characteristics of such a model can be enumerated:

(a) terms of trade are treated as endogenous;

(b) both countries own resources – i.e. there exists a resource-rich country and a resource poor one; and

(c) resources are used as a factor of production as well as a final product that can be exported as well as imported.

This model shows how the relative 'effective' factor abundance (that includes rates of time preference) determines the pattern of trade. The 'switch' in the pattern of trade occurs when the more impatient economy (i.e. the economy with a higher level of time preference) will exhaust its level of resources in the initial period and then the less impatient economy will begin extracting and exporting its resources.

This model, however, had assumed extraction to be costless. Although this assumption is a fairly common one in natural resource models, it is nonetheless unrealistic. A detailed discussion in the last section of chapter three highlights the importance of costs of extraction in natural resource models. In this context, in the fifth chapter, I have tried to show that similar results, as those predicted in the above model, can be obtained by including a difference in costs across countries, while assuming rates of time preference in both countries to be the same. It was found that the country with higher extraction costs will not extract resources in the beginning as its resource prices will be higher than the country with lower extraction costs. Therefore, the country with lower extraction costs will first extract its resources and export them, exhaust them after a finite period of time, and finally import resources for its own domestic needs. Thus, a similar reversal in the pattern of trade can be predicted.

An important feature of all these models (in chapter four and five) is that all of them exhibit complete specialisation of production after trade. An important feature of static trade models, namely incomplete specialisation, could not be obtained in these models. Also in the extended model (in the fifth chapter), costs of extraction are taken as constants. It is necessary to find out how these dynamic trade models behave with the presence of variable costs, which can be functions of rates of extraction, remaining stock of resources, costs of exploration, or all of them. In the concluding note, therefore, one can only expect that these areas will be explored.

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