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Macroeconomics and the Environment: A Selective Survey

Abstract

Macroeconomics deals with economics at the aggregate level. This could be at a national level or the interaction between nations. Production of output necessarily involves pollution and degrading the environment. Therefore, environmental issues enter inevitably. Some problems that have been highlighted in the literature are surveyed here. It has been argued that a poor country deliberately lowers its environmental standards that enables it to steal jobs from other countries. What is the theoretical underpinning and the evidence for this assertion? The evidence is very weak in support of this. Also, in the fight against climate change, the poorer countries claim exemption from tightening their emissions norms, because of their poverty. Although equity demands this, it could pose serious challenges to fighting climate change – oil producers would pump oil faster, if they foresee it becoming useless. A piecemeal approach is thus infeasible. A more basic question is how to introduce natural resource use in national income accounts to give meaning to the notion of sustainability? National income accounts do not take into account non-market activities. Some progress has been made in the theory and empirical implementation of sustainability by including non-market activities. A lot of work has been done but a lot more still needs to be done here.

JEL-Codes: Q500, F100, F200.

Keywords: macroeconomics and environment, trade and environment, green paradox, genuine saving, comprehensive wealth.

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1. INTRODUCTION

Macroeconomics is a relatively new area of research in economics, not even one hundred years old. Initially macroeconomics was concerned with the short run (i.e. stocks of assets were held constant or ignored). Over time, macroeconomics embraced dynamics and started to take stock-flow interactions more seriously.

Environment economics is even more recent as a sub-discipline. Some attempts at modeling environmental concerns were initiated once it was granted that all economic activity causes some pollution as a by-product. The micro-theoretic concepts of externalities, market failure, and public goods found ready applicability in analyzing these problems. Almost all types of models looked at cases where the damage to the environment was not internalized by the market participants.

In these earlier static models, the terms pollution and environment were used interchangeably. By pollution, they usually meant local pollution (SO_x, NO_x etc.) and not global pollutants (like CO_2) nor degraded land or polluted rivers. More often than not, and it is perfectly acceptable in a static model, pollution was thought of as a flow variable.

About this time, but quite independently of macroeconomic concerns, long-lived environmental problems were also becoming central to the debate. The protection of wild life, the hole in the ozone layer, degradation of land and water, and climate change are some of the big issues that have emerged in the last three decades of the twentieth century. In the mid-1970s the quadrupling of oil prices in the world markets had focused attention on the total available stock of oil before issues of "sustainability" came to dominate the discussion.

An essay on macroeconomics and the environment needs to be selective, since both of the above areas (i.e. the environment and macroeconomics) are really vast. This is particularly true for macroeconomics. Indeed, one can argue that the area of macroeconomics and the environment does not exist except as a collection of individual topics. In determining the choice of topics to be covered, presumption is that macroeconomic models are general equilibrium models. With this in mind, the interface between international trade and the environment is addressed. To keep the discussion manageable, therefore, the partial equilibrium models and also the (very interesting) literature on international environmental agreements are not discussed. The second, topic that will be covered is the recent literature on national income accounts, focusing on the "income" and "wealth" approaches.

A third topic emerges from the second topic of the previous paragraph. Most of the discussion on

national income accounts looks at a planner's, as opposed to a market version of equilibrium. This is true of optimal taxation of fossil fuels in the context of climate change. If there is an attempt to decentralize such a decision-making process, the possibility of a "green paradox" arises. The absence of environmental policies and appropriate property rights will be present throughout the discussion.

Open economy considerations are important both from a macroeconomic and, of course, a trade theoretic point of view. A country produces (and usually exports) goods that it has a comparative advantage in, and imports the rest, from a trading partner whose comparative advantage is different. If we allow unbalanced trade i.e. borrowing and lending, then from a macroeconomic perspective international borrowing (or lending) allows a country to smooth its consumption. How does comparative advantage and consumption smoothing get modified when we take into account environmental considerations?

As a starting point, note that in an open economy the production of a good does not necessarily imply that it is consumed domestically. This carries over to inputs used in production also. This it is very possible that a country's emissions of CO_2 are low (in production) but it consumes CO_2 intensive goods. An implication of this is that in the recent climate negotiations (Kyoto, Paris etc.) the emphasis on emissions from production could be misplaced – some of China's emissions are consumed in the US.

The trade and environment debate has taken place in a framework where the North (developed countries) has higher environmental standards, and the South (developing countries) has lower standards. The concern was that the South would use its lower standards to gain a "competitive advantage" in "environmental-intensive goods". The South, in turn, accuses the North of using environmental concerns as a tool of protection.

In the discussion of this trade and environmental standards literature, one feature that has received some prominence is that property rights tend to be not clearly defined (or could even be non-existent) in the South. The absence of property rights causes "overharvesting" of the resources and increases the exports of these resources. The empirical evidence point to a tightening of property rights lowers environmental exports (e.g. from deforestation).

Initially there was some hope that as the poorer economies prospered, these environmental problems would disappear. In hindsight, this turned out to be a false hope. For local pollutants like SO_x and NO_x (or even sewage), there might actually be turning points – as the economies grow

richer, the population will pay to reduce these emissions, but for CO_2 or plastics[1], there are no natural turning points. Similarly, if the Chinese value tiger body parts for traditional medicine, then as China grows richer, there is the possibility that the tiger population is the world would disappear.[2]

To repeat then, in the policy debates, the environmental "input" played a major role as a possible determinant of trade flows. Could poorer countries export "environment-intensive" products? Is free trade "fair", or can it be manipulated to seek trade advantages? We look at these arguments below. The data does not support this view – environmental costs are never a very big component of total costs, except for minerals and chemicals.

The second area that we will focus on concerns national income accounts. The initial short run macroeconomic models came with a system of national income accounts. These looked at the value-added at market prices in various activities. Where there was no market transaction, these accounts did not have anything to say. Thus, production within a household or pollution caused by emissions fell outside the purview of national accounts. In the last two decades of the twentieth century (and gingerly before that), the concept of income in the presence of depletable stocks of natural resources and the valuation of assets outside the market have received a lot of attention. The implication of this is obvious: not accounting for the environmental input overstates the measured GNP (just as not taking into account home production understates it); or to put it more correctly, it is the depreciation of the "natural capital stocks" that is contributing to the recorded GNP (and thus overstating it). Recent NNP calculations have tried to accurately account for this. In this area, it will be argued below, that while much progress has been made, a lot remains to be done. This is true about the theoretical structure as well as its empirical implementation.

A third area we will focus on is North-South interaction in the context of climate change. We shall focus on the possibility that not all countries participate in curbing their carbon emissions (e.g. by allowing poorer countries more time to prepare for a reduction in their emissions; or even President Trump unilaterally pulling out of the Paris accord!). This could have serious consequences for the fight against climate change. Fossil fuel exporting countries, anticipating a fall in their export

[1] CO2 is public "bad" and it requires a credible international agreement to reduce the emissions--no individual country would want to undertake the costly act of reducing emissions, without being able to capture the benefits. Plastic use is as much a technological issue as a lifestyle one. It offers conveniences (that possibly do not disappear as the society becomes richer), while its recyclability is limited (to date)—in this case exhortation or making its use expensive does not seem to have solved the problem.

[2] As for the discussion on plastics in footnote 1, more policing as well as an appeal to change Chinese preferences could help.

prices, could be tempted to bring their extraction of the fuel forward in time.[3] This literature points to a need for the participation of all countries in curbing carbon emissions. Of course, the global nature of the damage to the environment caused by CO_2 emissions makes individual countries want to free ride.

2. TRADE AND THE ENVIRONMENT

Before turning to a detailed discussion of trade and the environment, how do environmental and natural resources fit into a macroeconomic modeling framework? After a discussion of models of trade and environment, where these are treated somewhat shabbily, the answers that emerge will be reassessed.

The GDP of any country is assumed to be produced using the available technology with factors of production such as labour, reproducible factors (such as capital) and natural resources. Production thus uses renewable and non-renewable natural resources. Initially, in the literature the stock- flow interactions were not considered at all (until, as mentioned above, the oil price shocks of the 1970s). Among natural resources, the reproducible factors e.g., flora and fauna, grow through natural reproduction, while non-renewable resources (e.g. fossil fuels and metal deposits) do not. Production and/or consumption uses up natural resources, while at the same time changing the characteristics of other life-sustaining elements like air, water etc. The environmental "input" consists of altering these through pollution and the degradation of the renewable resource stock, e.g. land, the habitat of wild-life etc. An analysis of these issues would involve many disciplines beside economics, e.g. ecology, geology etc. The oil price shocks of the mid-1970s led to an animated discussion on the substitution possibilities between natural resources (especially exhaustible resources) and other inputs, and whether the growth process itself was without limit (i.e. whether production was possible when the stock of non-renewable resources was exhausted).

As the concern about climate change (e.g. the hole in the ozone layer) became a topic for discussion, the notion of "sustainable development" or "intergenerational equity" had to be addressed. This tries to come to grips with the dilemma of how to raise current living standards (especially of the poor countries) while, at the same time, ensuring that the environmental consequences are not "too" damaging i.e. it should not affect adversely the availability of the "natural capital" that is left for the future generations.

[3] This would apply to other reasons for bringing forward the time profile of extraction of the fossil fuel e.g. to repay debt, or a civil war. The discussion here refers to the negative consequences of using a well-intentioned policy.

With this background we turn to the first of the questions of this essay: how do international trade and the environment affect each other? Trade here is between the "rich" North and the relatively "poor" South.

2.1 Comparative Advantage and the Environment

Since David Ricardo's Principles of Political Economy was published two centuries ago, economists have used the concept of comparative advantage to explain the pattern of production and trade in the world. In a simplified two-country two-commodity framework this simply boils down to asking: which is the commodity that the country produces at lowest cost (in relative terms)? This, however, does not guarantee that the good will be exported -we require that the lower cost of production is not nullified through stronger domestic preference for these goods.

Before the 1970s, there were two popular theories of international trade viz. the Ricardian theory and the Heckscher-Ohlin theory-the former emphasizes differences in technologies to explain comparative advantage while the latter relies on relative factor abundance. Since the late 1970s a third explanation – the "new" trade theory has emerged. It relies on market structure and increasing returns to explain the pattern of trade.

Note that the models of international trade discussed in the literature tend to static and, hence, trade between countries is always balanced. Thus, issues of comparative advantage can be discussed but not those of competitiveness (or absolute advantage)

In the trade and environment literature, "the" environment is treated as a factor of production. This begs the question of how do we construct an aggregate for the environment. It is a shortcut for a more complicated statement viz. that production pollutes, and hence pollution is an output jointly produced with the final good and a reduction of pollution (for a given level of output) – abatement – is costly. The "true" price of this input is whatever the society thinks it is worth i.e. it depends on social preferences. Taste differences play a crucial role here (unlike in models of comparative advantage, where they were put on a back-burner). Thus, poorer countries may tend to put a lower value on a clean environment and hence are considered to have a large endowment of the environment and hence have a comparative advantage in producing pollution-intensive goods.[4]

[4] Note that here the environment makes an appearance only through the production function. Later on, for example in the climate change models, these variables enter the analysis both as the (flow of) fossil fuel input and through the stock of carbon affecting utility.

This assertion is backed by an appeal to the so-called Environmental Kuznets Curve (EKC).[5] Simon Kuznets had asserted that as countries grow, from low levels of per capita income, initially inequality increases. After a certain point, further development is accompanied by reduced inequality. The EKC seeks to perform a similar exercise for pollution by relating the emission of various pollutants to GNP per capita. It started off as a cross-section exercise but its predictions also have time series implications.

The EKC attracted a lot of attention because of the observation that a lot of pollutants have turning points with respect to income levels per capita—examples of these are sulphur dioxide, oxides of nitrogen, water pollutants, suspended particulate matter (SPM) etc. For instance, Grossman and Krueger (1995) find SPM and SO_2 have a turning point at $ 5000 per capita (1985 US $). On the other hand, carbon emissions and solid waste do not have any turning points at all. Without going too much into the details of the process at work, one may hazard a guess that as society becomes richer some types of pollution may be easily tackled (and policies to tackle these are put into place because firms and individuals in isolation may not have the incentive to correct these "externalities"). But for other pollutants the cost of clean-up may be very high (as for carbon emissions, a global pollutant). But still there is a belief that a country can pollute initially and clean up its act later --- this presumes that environmental pollution has only transient effects. Even SO_x and NO_x could have longer term consequences via the health of the population. Dissipation of pollutants also depends on local conditions --- an oil spill is less of a problem in a choppy Atlantic setting than it is in the placid Mediterranean Sea. Another issue that is not addressed by the EKC is the time frame taken to achieve the increase in GNP per capita. For instance, Japan grew at an average annual rate of 8.07 per cent between 1955 and 1973. This implies that because Japan was a latecomer to the development process it had access to cleaner technologies (compared to the early industrializers like the UK) but it was also compressing into two decades what the UK might have taken a hundred years to achieve.

Grossman and Krueger (1993) had predicted that the North American Free Trade Agreement (that was being negotiated at the time) would, by raising incomes, via the EKC logic, improve the environment in both the US and Mexico. The US, presumably, was way beyond the turning points for the local pollutants; and Mexico was presumed to be at the turning points. Theoretically, the relationship between trade liberalization and lowered emissions is not clear cut. The total effect has been decomposed into three different channels: the technique effect, the composition effect and a scale effect. It is possible that a larger market makes for cleaner techniques of production. Since, freer trade is about specialization, some countries in the agreement would move away from producing the pollution intensive good – the composition effect would differ between economies. Overall the volume of production would rise with freer trade, and, therefore, the scale effect would

[5] See Grossman and Krueger (1993 and 1995) for the original contribution, Andreoni and Levinson (2001) for a theoretical model and Dasgupta et al. (2002), Carson (2010), and Copeland and Taylor (2003) for surveys.

point to a rise in overall pollution.

Copeland and Taylor (2003), look at effects of trade liberalization that Grossman and Krueger (1993) had started off with. Theoretically, in a two good Heckscher-Ohlin type set up, trade liberalization can lead a country with more stringent environmental policy to pollute more if it has a comparative advantage in pollution intensive goods. Similarly, if poorer economies have a comparative advantage in dirty goods, then more closed economies among these should have a cleaner environment (because they have chosen to produce, rather than import, some cleaner good).

Any discussion of North-South trade in an environmental context presumes that the South is better endowed with the environmental "input". It is undoubtedly true that much of the world's bio-diversity is located in the South, as is the stock of mineral deposits. If indeed it is accepted that the South is better endowed in "the" environmental input, it should then export goods that use the environment intensively. While the evidence in favour of this is not unambiguous, this has raised concerns that the South could and does deliberately exploit its environmental resources to gain an unfair advantage in trade.[6]

Northern (labour and environmental) lobbies fear that as environmental standards are raised in the North, mobile factors of production will move to the South where the environmental standards are lax, and they want similar environmental standards to be adopted in the South. The evidence on foreign investment by multinationals does not support this hypothesis of lax environmental standards as a major determinant of capital flows.

It is undoubtedly true that the post-war free trade system ushered in by GATT has benefited the South. Poor countries have used trade as an "engine" of growth. This is however not true for all the developing countries. The Northern protectionist lobbies in the past saw low wages in the South (low labour standards) as the main cause of the loss of industrial jobs in the North. With successive tightening of environmental standards in the North, low environmental standards in the south are also seen as a cause of unemployment in the North. Hence the call for "fair" (as opposed to "free") trade and objection to the South's (low) environmental (and labour) standards. There is a fear that environmental concerns in the North will raise costs of production there causing shift in comparative advantage to the South where standards are relatively lax. Either the South adopts standards similar to the North or face protectionist action in the North. The South views this, quite

[6] Whether polluting techniques are used depends on the price (including subsidies) prevalent. In agriculture, the North uses more chemical fertilizers and sprays per acre than the South. Various economists have argued that a liberalization of world agricultural trade—the Northern agriculture receives subsidies and protection—would, therefore, make Southern incomes rise and as the world moves away from environmentally unfriendly to labour-intensive sustainable methods.

justifiably, as unwarranted protectionism – a form of non-tariff barriers. In this view, certain activities it would be profitable to shut shop in the North and relocate to the South – the "pollution haven". In addition, if FDI moves to locations with lower environmental standards, there could be a competitive lowering of standards in the countries of the South. If the North lowers its environmental standards in response to this, we have the so-called "race to the bottom". Thus in this view, given lower environmental standards, international trade exports jobs and investment abroad only makes this more irreversible.

A few channels through which openness (i.e. international trade and investment) is linked to the environment are identified in the literature. First, a country's comparative advantage determines what and how much it will produce. In autarky consumption and production are necessarily equal. And it is presumed that the South will export the environment-intensive good. Over time this comparative advantage may change. Second, trade has implications for the technique of production used – in the simple Heckscher-Ohlin model, incomplete specialization in production implies that the techniques of production are identical across countries. Third, international trade raises incomes, which, in turn, changes the scale of production with consequences for the environment? This is especially true if environmental taxes were not at their "Pigovian" level (i.e. equating the tax with the marginal damage pollution causes) to start off with. And finally, as trade raises incomes, people have a higher willingness to pay for a clean environment – this was the starting point of EKCs.[7]

2.2 Some Evidence

The historical evidence is mixed. For instance, in Korea during the 1960's, and even as late as the early 1990's, environmental policies were almost absent. This led to an industrial structure which was very intensive in energy and materials, although Korea had very little of either. The export share in output in the mid-1980's was about 30 per cent but it generated 30 or 50 per cent of waste (pollutants, solid waste etc.). FDI in Korea was pollution-intensive in the early stages of industrialization. This included heavy investments in petrochemicals, chemicals and metallurgy. It is only later that less polluting electronics etc. were added to the list.[8] Japan similarly had a very poor environmental record in the early post-war years but in recent times Japan has reduced its environment-intensive exports significantly.

[7] As we shall see these predictions about turning points are based on a static view of the world. Carbon emissions, stocks of wildlife or trees etc. require a dynamic analysis. Even the static predictions e.g. of a relation between a country's per capita income and NOx should take into account the fact that "development" is about speeding up the process that could otherwise take decades. How this interacts with the ability of the environment to regenerate itself is a moot point.
[8] See You (1995) for a discussion.

Grossman and Krueger's (1993) felt that NAFTA by raising incomes in Mexico would help improve its environmental quality, since they believed that Mexico was hovering around the turning point(s). Empirical evidence does not support this. PM 10 concentrations around Tijuana (a high income part of Mexico and closely linked to NAFTA) remained unchanged in the period 1997-2007 (NAFTA came into force in 1994). Similarly, air pollution (CO, CO_2, SO_2, NO_x and VOC) in Mexico City continued to deteriorate between 1990 and 2000. These results are at variance with EKC but could be consistent with specialization in dirty products, even if as incomes rose people wanted cleaner air – see Carson (2010) for a selective overview.

Elsewhere, the results are mixed. The theoretical structure gives ambiguous predictions, data consistency is usually a problem, and econometric imponderables are ever present (e.g. a posited non-linear relationship has more stringent data requirements than a linear one)

Researchers have found a favourable effect of trade and FDI taken together on the environment. Among the countries of the South, those with an outward-orientation have cleaner technology than inward-looking import-substituting ones. Market pressure causes rapid obsolescence and import of capital goods leads to the acquisition of the latest technology. The post-war historical experience of Japan, with its dependence on trade and a very fast rate of technical progress also bears this out. But it would be fair to say where FDI and trade involves final goods, openness leads to cleaner production; where trade and FDI is in mining and chemicals, there is no such pressure. For instance, it has been found that between 1973 and 1985, overall FDI by the US chemical and mineral industry increased at a rate faster than overall FDI by the US. Sulphur emissions allowed in the host country, was an important locational choice variable for the US chemical industry.

There are other examples where FKI has not led a cleaner technique being adopted. For instance, one of the biggest environmental disasters involved the US multinational Union Carbide. In 1984, a gas (methyl isocynate) leak, in its plant in Bhopal, India, killed between 2000 and 5000 people and over 80,000 people suffered permanent lung damage. The Union Carbide plant in Bhopal had lower standards than its plant in West Virginia USA, where such an accident was unlikely to occur.

Another example of lax standards was Mitsubishi's chemical plants in Malaysia Radioactive thorium waste was disposed of in plastic bags, a fact that was admitted only under legal pressure. A final example concerns a Norwegian-owned aluminum company that has been accused of causing massive water contamination in Brazil in 2018.

A related point involves products that travelled to the South via FDI in the past. The production of

these is now banned in the North (following damaging empirical evidence), but there is continuing manufacture and sale in the South – the South is completely specialized in the production of these e.g. asbestos and DDT (a pesticide).

Why is the effect of environmental costs not more pronounced in the international trade data? Three reasons have been suggested for this apparent anomaly. First, trade accounts for a relatively small share of world production. Second, a large share of trade involves trade in environmentally clean goods. And finally, even for dirty goods, abatement costs account for a relatively modest share of total costs.

A different kind of capital movement that has become important in recent years is that of financial capital. Think of the Asian financial crisis at the turn of the previous century: if Indonesia viewed this as a temporary shock, it would try to borrow and smooth consumption. If lending is unavailable, then it may seek to find other ways to prevent a sharp drop in its consumption e.g. by cutting down some of its remaining forests that the rest of the world believes play a role in acting as a sink for greenhouse gases (GHGs. This is why the REDD+ mechanism allows a participating country to receive a transfer in exchange for leaving its forests untouched.

2.3 Common Property Resources and Trade

Neoclassical models assume, in the background, the existence of property rights. Who appropriates the factor returns? A large literature has evolved where lack of development is related to economic institutions. What would happen to North-South trade if there were different institutions of property rights– in particular, if the South witnessed a collapse of the common property resource ownership which is replaced by open access? It is often the case the village that had common property resources and witnessed its breakdown as the market system seeks to supplant it. Often rural-urban (or international) migration loosens the sense of community. Property rights previously vested in the community become ill-defined.[i] There are many examples of these – forestry, water bodies, wetlands, mangroves, rivers etc. Players from outside the community may exploit this; often outside influences are the cause of such a breakdown. Open access gives rise to free-riding and hence over-exploitation --- one may extract form the commons without penalty or deterrence. For example, in India sand mining mafias extract sand the thereby affect the bio-diversity of the river. An international example is the consequences of overharvesting of fish stocks by trawlers form the EC on the livelihood of traditional fishermen off the coast of Senegal.

In the South, apart from a breakdown of traditional forms of communal ownership, there is a problem of widespread corruption and weak law enforcement. In this situation, state-owned land

is often treated as a common access regime – forests, game arks, even government-owned financial institutions etc. are examples of these. In such a situation it is not clear that the traditional cure for market failure --- government intervention --- improves things. We then have a trade of government (or policy) failure against market failure.

Chichilinsky (1994) was the first to draw our attention to this. She posed the problem in a very stark from. Suppose there is no difference between the North and the South in terms of physical endowments. The only difference lies in the fact that the North has well-defined property rights and the South has an open access regime. An open access regime, as argued above, leads to an over-harvesting of the environmental resource at the prevalent market prices. Additionally, since the appropriation of returns is a problem, there is no incentive to manage the resource in an optimal way from a dynamic viewpoint – this leads to disappearance of fish stocks, forests etc. the open access regime in the South causes the environmental resource to be over-harvested and the south shows an "apparent" abundance of the environmental input. This apparent abundance may cause footloose capital to move to the South, since the capital to environmental input ratio is low there. Of course, this is tempered by the lack of appropriability of returns in the South. If international capital movement is allowed, capital moves from the capital-rich North to the environment-rich South. This brings the environment-capital ratios together. In an integrated world – i.e., when capital yields the same rate of return everywhere – a tightening of environmental standards causes capital to flow out and FDI may actually increase pollution in the recipient country.

Thus the South being rich in the environmental input and trade causing factor price equalization both flow form the prevalent property rights. Free trade causes the North to import the environment-intensive good from the South, thus exacerbating the overexploitation of resources. These give rise to what Chichilinsky calls "apparent gains from trade." Trade is actually welfare-reducing (competitive equilibrium does not represent the scarcity values to society) but without looking at the cause of factor abundance, it does not appear to be so. Similarly, one can see that if the natural resource were exhaustible, it would be exhausted faster than would be the case if the property rights were sell-defined. In Brander and Taylor (1998), it is shown that in such a set- up, a tariff can improve welfare – it corrects the absence of property rights.

There is evidence in favour of this. Consider the imports of logs by Japan. Japan, after an initial burst of depletion of its own natural resources, has been very protective of its own forest cover and has imported logs form Indonesia and Malaysia. In these countries – where property rights are not always well-defined—there has been widespread depletion of tropical forests, with concerns elsewhere in the world about the disappearance of "the global commons". While logging may be a labour-intensive activity, stricter regulation in Japan and the property rights regime in the exporting country are also important in depleting the forest cover.

A sudden rise in the demand for a particular product in its export market puts pressure on the environment where property rights are ill defined. This is especially true of agricultural exports form the South. These give rise to (a) change in eco-systems i.e. loss of bio-diversity, (b) changes in natural endowments e.g. pollution and soil deterioration; and (c) loss of sustainability. Damage could be on-site e.g., land erosion, damage to farmers from pesticides, or it could be off- site e.g., water contamination, acid deposition from ammonia emissions.

Three examples of irreversible change in land use in the South in response to a rise in export demand are given here. Export demand for cassava grew for intensive pig farming in the Netherlands. This was because root crops had their tariffs lowered in the GATT rounds in the 1960s (as opposed to cereals). Thailand and Indonesia responded to the increased demand for cassava. The fragile upland soils of Java and forest lands in the Outer Islands came under mono-cropping of cassava. When the export boom ended, the l and growing cassava was found to be extremely degraded.

Shrimp cultivation in Ecuador (and Honduras) for export to the US and Japan resulted in transforming the mangrove areas into pools for shrimp farming. This resulted in high shrimp yields initially but then yields have fallen sharply due to the destruction of the mangroves.

Palm oil production has increased tremendously in South-east Asia – over eighty percent of the production is in two countries viz. Indonesia and Malaysia. Palm oil is the most commonly used vegetable oil in the world and is used in a variety of products e.g. food, cosmetics, and as biofuel in motor cars etc. Tropical forests and peat lands (carbon-rich swamps) are cleared for palm plantations. This releases carbon that contributes to global warming. The disappearance of forests causes many animal species to be threatened with extinction. The clearing of the land via burning causes a smoke haze to hang over many countries of South-east Asia. Thus the resulting pollution is both local and global in nature. As Indonesia and Malaysia try to curb further clearing of forests, the production is shifting to Africa, where enforcement is even more lax.

3. COMPREHENSIVE WEALTH AND GENUINE SAVINGS

As mentioned in the Introduction, traditional national income accounts leave out non-market activities. Thus even what they measure is probably overstated, since they ignore depreciation of natural capital stocks. Global warming is an example where the effect of industrial activity on the

earth's temperature, sea levels etc. are ignored.

The literature discussed in this section seeks to use national income accounts for natural resources. It is concerned with issues of sustainability. First, the theoretical framework associated with sustainability is exposited. Second, the important distinction between "weak" and "strong" sustainability is discussed. And, finally, some issues in the empirical implementation is highlighted. At the end of each these three heads, some critical comments are offered.

We first turn to the recent literature that attempts to provide a microeconomic basis for a theory (of sustainability) that may provide a basis for national income accounts. It has gone some distance in valuing the contribution of natural capital to production (or equivalently accounting for the depreciation of natural capital). It comes up with a notion of "comprehensive wealth" that includes in addition to man-made capital, measures of natural capital, human capital etc. --- loosely speaking anything that contributes to output. A change in this wealth is true or genuine savings.

In this theoretical literature there are two different approaches with some overlap. The first approach looks at sustainable consumption and harks back to John Hicks. The other, a more recent theory (although based on a conjecture of Paul Samuelson's), looks at income (or wealth) as a welfare measure.[9]

The first approach starts with Hicks's observation "income is the expenditure which if kept constant would yield the same present value as a person's actual future receipts" Hicks (1939), p.189). This notion, which is explicitly dynamic, was formalized by Weitzman (1976), Weitzman showed that the Hamiltonian (or more transparently the current value Hamiltonian of the problem), which can be interpreted as a measure of NNP in the case of a linear utility function, represents a utility level that if maintained for ever would have the same present value as the optimal path. This is what Hicks was alluding to.[10]

3.1 A Formal Model with Reproducible and Natural Capital

Below a formal model is presented that drives these results. Before setting that up, it is useful to

[9] See Dasgupta (2005) for an analysis.

[10] For a vector of consumption goods, we require Divisia index of prices (see Asheim and Wietzman (2001)). The Hartwick Rule discussed later also is based on the Hicksian concept of real income.

give the intuition of this model. It has a central planner who maximizes the discounted sum (integral) of utility of a representative individual from now (period zero) to infinity. This is maximized subject to some initial conditions on the stock of resources (man-made and natural capitals), and the laws of change in these stocks. Usually, a transversality condition is imposed to ensure that accumulation remains (loosely speaking) "bounded". Having obtained the optimal path for consumption and the implied accumulation of stocks of assets, one replaces the optimal vales of the consumption path into the utility functional (functional because it depends on an integral of instantaneous utility function) to derive the "state value functional" (akin to an indirect utility function in static problems). Then, the properties of this maximized functional are used to derive results. After presenting the model and deriving the results, some question that naturally arise are posed.

A social planner maximizes the discounted social utility, over an infinite horizon.[11] In equation (1), u(.) is the instantaneous utility or felicity, **x** is the vector of consumption goods, p>0 is the discount rate and **z** is the vector of state variables (these include, reproducible capital, human capital and natural capital).

$$max_{\{x(t)\}} \int_0^{\infty} u\big(x(t)\big)e^{-\rho t}dt \qquad (1)$$

Subject to:

$$\begin{aligned} & z_i(t) = f_i(z(t), \\ & \dot{z}_i(t) = f_i(\boldsymbol{x}(t), \boldsymbol{z}(t)) \qquad \text{i=1,2,…,n.} \qquad (2) \\ & z_i(0) = \bar{z}_i(0) \end{aligned}$$

u(.) is assumed to be strictly concave and f_i are concave in their respective arguments. The concavity of the f_i's is not innocuous and is discussed below.

In equation (1) we have for simplicity made the instantaneous utility u(.) depend only on consumption (x). In the literature, and quite correctly for environmental issues, it should also depend on the state variables z(t). The discount rate is given by ρ>0.

We set up the usual Hamiltonian with the co state variables μ_i's for the f_i's.

[11] Infinity is a shortcut convenience for a very long horizon. We know the world could end with a bang, but we do not know when!

$$H(t) \equiv u\big(x(t)\big)e^{-\rho t} + \sum_{i=1}^{n} \mu_i(t) e^{-\rho t} f_i\big(x(t), z(t)\big) \quad (3)$$

The first order conditions with respect to the x's are given by:

$$\frac{\partial u\big(x(t)\big)}{\partial x_j} = \sum_{i=1}^{n} \mu_i(t) \left(\frac{\partial f_i\big(x(t), z(t)\big)}{\partial x_j}\right) \quad (4)$$

The co-state variables evolve as:

$$\dot{\mu}_i(t) - \rho\mu_i(t) = -\sum_{k=1}^{n} \mu_k(t) \left(\frac{\partial f_k\big(x(t), z(t)\big)}{\partial z_k}\right) \quad (5)$$

The maximized value of this (the state value functional) is given by:

$$V(z_0) = \int_0^{\infty} u(x(t)e^{-\rho t} dt$$

V has the following properties:

$$\frac{\partial V}{\partial z_i} = \mu_i \quad (6)$$

$$\frac{dV}{dt} = \sum_i \mu_i \dot{z}_i \quad (7)$$

Equation (7) says that welfare (over the infinite horizon)[ii] is increasing over time only if the value (at the shadow prices) of the total investment is positive. This means that if society runs down some capital, it has to be compensated for by accumulating others. This has implications especially for resource-rich economies – they can deplete their stocks of resources but not for current consumption.

Directly differentiating V and equating to h above, we have H=ρV.[12]

[12] The current-value Hamiltonian on date t has the following property: a utility stream from t to infinity of a constant value equal to the Hamiltonian evaluated on the optimal path at t has the same present value as the utility stream from t to infinity associated with a solution to the problem of maximizing (1) subject to (2):

The definition of net national product (NNP) is given by (to save on notation, in equations (9), (10), (11) and (12) treat x and z as scalars)

We want to analyze the sign of a change in NNP over time and whether it tracks that of V. To see this, differentiate NNP with respect to time:

$$\frac{d(NNP)}{dt} = \dot{x} + \dot{\mu}\dot{z} + \mu\ddot{z} \tag{9}$$

and use H=ρ V to get,

$$\frac{dH}{dt} = \mu\dot{x} + \dot{\mu}\dot{z} + \mu\ddot{z} = \rho.dV/dt \tag{10}$$

$$\frac{d(NNP)}{dt} = \frac{dV}{dt}\left(\frac{\rho}{\mu}\right) - \left(\frac{\dot{\mu}}{\mu}\right)z \tag{11}$$

$$\frac{d(NNP)}{dt} = \dot{z}(\rho - \frac{\dot{\mu}}{\mu}) \tag{12}$$

Or reverting back to the many-good case where consumption, stocks and prices are vectors and consider a small perturbation of the economy's optimal path by changes in the time paths of consumption and of capital stocks, and compute the resulting changes in the Hamiltonian (equation (3)):

$$\Delta H = \sum_{i=1}^{n} \Delta z_i \mu_i (\rho - \frac{\dot{\mu}_i}{\mu_i}) \tag{13}$$

$$\int_t^\infty \left[CVH(t)\left(x^*(\tau)\right)\exp\left(-\rho(\tau - t)\right)\right]d\tau = \int_t^\infty \left[u\left(x^*(\tau)\right)\exp\left(-\rho(\tau - t)\right)\right]d\tau$$

.

Comparing (13) and (7) we see that the sign of the change of the Hamiltonian, could be wrong if the real interest term given by the curly brackets in (13) is negative. Thus NNP (or the Hamiltonian --the NNP is a linearization of the Hamiltonian) has a time derivative along an optimal path that is the same as that of the state valuation functional, provided that the real rate of return in the economy is positive. However, for arbitrary perturbations of the economy the sign of the change in NNP may differ from that of the change in the state valuation functional. Thus, in general NNP is not a satisfactory welfare measure.[13]

3.2 A Wealth Measure

Turning to the wealth (or income) approach to sustainability, we start off with a temporal equilibrium. In such an equilibrium utility maximization implies where $(p_1, p_2, \ldots, p_n)$ is the vector of prices and $(x_1, x_2, \ldots, x_n)$ are the optimal quantities chosen. We then have total expenditure equal to national income. Any bundle that is preferred to the chosen one, must cost more.

$$M(p_1, p_2, \ldots, p_n) = \sum_{i=1}^{n} p_i x_i$$

In a dynamic context we can define Net Wealth analogously as (Heal and Kristrom (2005) refer to this, somewhat misleadingly, as national income). Again we use the intuition that if an allocation of goods is potentially Pareto preferred to a current equilibrium allocation, then national wealth (NW) measured in current prices must be higher in the new allocation.

The definition of NW is ($x(t)\mu(t)$ is the inner product, $\mu(t)$ represents prices):

$$NW(\{\mu(t)\}_{t=0}^{\infty}) = \int_0^{\infty} (x(t).\mu(t)e^{-\rho t})dt \qquad (14)$$

Dasgupta (2009) and Arrow et al (2011) refer to this measure as "comprehensive wealth". Since the right-hand side involves future variables they use the current wealth on the left-hand side to make the concept operational. But for analytical purposes, the right-hand side is important. As against the Hamiltonian (NNP) concept, that we saw gives correct answers only when the real rate of interest is positive, here NW gives correct answers.

[13] See Dasgupta (2009). Asheim (1997) and Asheim and Weitzman (2001) offer a defense of the income concept.

It is readily checked that:

$$\frac{\partial V}{\partial z_i} = \frac{\partial NW}{\partial z_i} = \mu_i$$

and

$$\frac{dV}{dt} = \frac{dW}{dt} = \sum_i \left(\frac{dz_i}{dt}\right).\mu_i \qquad (15)$$

For sustainability, equation (15), makes the important point: the NW criterion agrees with equation (7).

Further, it has been shown (see Heal and Kristrom (2005), sections (9), (10) and (11)) that the NW concept can be applied even when the Hamiltonian approach does not work. The Hamiltonian requires the convergence of the utility functional (equation (1) above). Moreover, for certain problems the transversality condition may not be satisfied (e.g. the Green Golden Rule and Chichilinsky criterion—see Heal and Kristrom (2005) for an elaboration)—even here NW (appropriately defined) gives the correct answers.[14]

Therefore, the value of changes in NW are good indicators of welfare changes for both perturbations about a path and movement along an optimal path. The NNP, on the other hand, delivers the right sign only for changes along a path and provided the real interest rate is positive.
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While NW itself has future variables, the changes it delivers in response to a change in capital stock or the time derivative of NW are all observable (see Dasgupta (2009) and Heal and Kristrom (2005)).

The analysis above is useful as a starting point but nowhere near complete even at a very high level of abstraction. The felicity comes from the consumption basket that consists of many goods (flows) and could have utility from stocks. Considerable emphasis has been placed on the intertemporal aspects of the problem. But an instantaneous or within-period equilibrium is usually modeled without any disaggregation. This is true even when one introduces human capital or health issues. The framework is that of a representative agent. If the emphasis is really the long term, then too much detail within the period could be a distraction. But if we are going to use the theory for an improved national income accounting analysis, then the short term is important. It is not unlike

[14] Heal and Kristrom (2005) distinguish between environmental assets that potentially have infinite lives (they cite Catskills watershed as an example), whereas human-made capital is scrapped frequently. What interest rate should be used to discount the flow of returns from the natural capital is moot. Other examples of assets can easily be thought of, for example wetlands that can be replaced by sewage treatment plants.

economists who claimed to be Keynesians in the short run, but were happy to use the Solow model for long-run issues. Here it must be emphasized that traditional national income accounts, although silent on non-market variables, involve a lot of decentralized data collection on value-added by firms etc. Arrow et al (2011) and other studies, on the other hand, are top-down enterprises.

The concavity of the accumulation equations is problematic. These are highly non-linear and given to chaotic behavior and irreversibilities. Moreover, the future is uncertain, especially on matters relating to climate change and other natural phenomena. The structure above is not equipped to handle this. As Dasgupta (2009.) shows, even with uncertainty represented by a Wiener Process, we need to think outside the box. Fat-tailed distributions would entail precautionary savings, which we know very little about.

The problem is that even at the closed economy level, the equilibrium path may not be decentralizable. Then to use market prices of timber or oil to calculate the return from natural capital may be misleading.

There are then other issues that need to be dealt with urgently. The starting point of environmental economics (and therefore this essay) is that environmental externalities cannot be captured by a simple market-based model. Thus there is no equivalence between a central planning version and a decentralized version. If markets do not signal scarcity through prices, how do agents react? Open access resources tend to be over- extracted (the tragedy of the commons). See Chichilinsky's trade model discussed above for a simple but telling example. The important point to remember in the context of the sustainability or the true savings literature is that the cheaper resource (at market prices) is substituted for the more expensive one. Thus an approach that takes, say, investment in physical capital from the observed data and adds environmental capital does not take into account the substitution that has occurred.

In this context, to treat all members of the population currently alive as homogeneous can give rise to misleading conclusions about the use of natural resources. India and China have (approximately) the same population but India's is younger whereas China's is ageing. This has different social security implications; and different resultant capital accumulation. If the poor have less access to physical capital (they are liquidity constrained, say) and use more natural resources (e.g. of the open access type), then the number of poor in the population should be an important determinant of the use of resources.

En passant note, just as an example, that intergenerational caring in the framework above is probably captured by discounting but at a point in time caring has important implications e.g. is a transfer feasible to prevent deforestation (REDD+)? As the section on the environment and

international trade above, (and on climate change below) suggests technology transfers to poorer countries have positive effects on the preservation of the natural capital stock. Moreover, even in a closed economy, individuals have finite lives. Finite lives with altruism can give rise to an infinitely-lived dynasty set up under some special conditions. We have to have intergenerational caring. In the analysis above, the discount rate captures caring (or the lack of it) for future generations.

International trade issues discussed above (and in the next section below) is important. For instance, in a closed economy if natural resource prices rise over time, there is no problem. The rise in price will be offset by domestic consumption later. But in an open economy model the welfare calculus is complicated: now the capital gains of resource-owners come at the expense of a foreign consumer. A sovereign wealth fund of the type set up by Norway, allows that country to smooth consumption by selling its oil (presumably when the world price is high) and living off the fund when the oil runs out. Consumption smoothing is also defined to be sustainable but is it sustainable in the sense that we are using it here? These issues will be discussed again when the empirical evidence (i.e. putting this theory to actual real-world data) is discussed.

3.3 Weak and Strong Sustainability

An important question, mentioned in the Introduction, asked in the fossil fuel literature of the 1970s was: Is oil necessary for production? Equivalently is production sustainable without oil? We can generalize this about other natural capitals. To answer this question, note that in the Cobb-Douglas production function, so beloved of macroeconomists, all inputs are necessary. This is also true of a constant elasticity of substitution (CES) production function, with elasticity of substitution less than unity. That is, for production to be possible without an input, we require in a CES production function the elasticity of substitution be greater than unity (see Solow (1974); Dasgupta and Heal (1979)).

This requirement has come to the center-stage in the recent discussion on the notions of "weak" and "strong" sustainability. Sustainability is per capita utility being non-declining from now to infinity. Services from four types of capital are used in production viz. produced or manufactured, natural, social or organizational, and human. The discussion of the previous paragraph suggests that as long as other forms of capital substitute for the exhaustible natural capital, one can have sustainable development. This is made more precise in the celebrated Hartwick Rule (Hartwick (1977)) that says that the proceeds (i.e. rents) from depletion of the stock of the natural capital should be invested in man-made capital so as to leave the overall level of society's capital stock

(corresponding to the four types of capital) unchanged.[15] To be more precise, this "weak sustainability" (why weak will become clear in a moment) notion requires that the change of capital should not be negative – that is "genuine savings" should be non-negative. Note that this emphasizes the non-decreasing requirement for the total stock of capital (that is for all the four types above). It does not have any special role for natural capital and all forms of capital are taken to be substitutes.[16]

Going back to the four types of capital listed above, it is clear that except for natural capital, the others are man-made. While some of these can take a long time to accumulate, they are analytically different from natural capital. Ekins et al (2003) list four functions of natural capital: (1) regulation of essential ecological processes and life support systems (2) production functions i.e. harvesting from natural ecosystems (3) habitat functions i.e. provision by natural ecosystems for refuge and reproduction; and (4) information functions e.g. aesthetic and recreational.

It is the life support aspect of natural capital that cannot be substituted by any of the other three categories of capital. Weak substitutability assumes very optimistic and continuing ability to replace natural capital with man-made capital; it may be possible, in a more limited way, to substitute the habitat and aesthetic functions. But the life support system is unique to nature. Strong sustainability would have us leave certain critical capital untouched i.e. that which is not substitutable by man-made capital. Fossil fuel extraction can be replaced by solar power, another form of natural capital. But it may not be possible to do so for all natural capital. Some "core" has to be left unmolested. The identification of this subset creates a lot of disagreement even among subscribers to this idea. What is the critical subset of natural capital that has to be "ring- fenced"?

The main reason (there are others) for this lack of unanimity is that there is a lot of uncertainty about the interaction of natural capital with our economy. We do not know enough about e.g. non-linearities in natural processes or future use from preserving biodiversity in a forest. Remember that we are talking of an infinite horizon here and surely uncertainty on such a scale calls for caution in taking irreversible decisions.

The criticism of the theoretical literature was that it was too aggregative, as if the decentralized structure of the economy does not matter. Or in other words, macroeconomics was missing from [iii]the environmental model. In the literature on weak versus strong sustainability, those who argue for weak sustainability are almost willing to disregard the environmental and ecological considerations to make their structures operational. It is as if macroeconomic imperatives trump environmental ones.

[15] With a constant population growth rate, per capita wealth is a good measure of sustainability.
[16] According to the World Bank (2006) (discussed later), weak sustainability is apparently not disturbed if a country uses its natural resource sale to pay off its national (financial) debt.

3.4 Applying the Theory to the Data

The World Bank (2006) lays out in detail the methodology for performing this exercise. The starting point of the analysis is to extend the definition of wealth to include natural capital and what they call intangible capital which includes raw labour, human capital, social capital as well as the nature of institutions.[17] Genuine saving is the change in the value of this extended definition of wealth.

World market prices are used to value stocks of capital (including the non-produced natural capital). This implies that issues arising from open access, and over-exploitation that result from this, are ignored. Market prices less local costs multiplied by the relevant country stocks of natural assets generate the rents associated with each stock. The stock of exhaustible resources at any date (i.e. from past discoveries) can either be left in situ or depleted. For (weak) sustainability, rents from these should be reinvested in other forms of capital so as not to run down the stock of capital.[18]

In looking at the country-wise capital figures, it is found (as one would expect) that as development occurs, the share of intangible capital in wealth rises while the share of natural capital falls. But, on a per capita basis, the share of natural capital is higher in richer countries than in poorer ones. Natural resources play two roles in development. First, in the poorest countries (where land constitutes over 70 percent of natural wealth) it is the basis of subsistence. Second, it constitutes a source of development finance. Open access leads to overharvesting of natural capital, making the genuine savings rates in the poorest economies negative.[19]

Similarly, Arrow et al (2011, p.30) say of their study: ”We advance the theory of growth accounting by providing a consistent framework that incorporates population growth, technological change, human capital, and environmental quality”. Two additional innovations are the treatment of health as a kind of capital and the incorporation of the effects of expected capital gains in natural resource stocks arising from the fixity of their supply in the face of continued demand.

We face significant challenges in applying the theory empirically. Despite the significant uncertainties, we are able to arrive at empirical estimates that, in our view, provide meaningful

[17] Data problems preclude the calculation of certain forms of capital, for example fish stocks, or an explicit value of services provided by ecosystems.

[18] “These rents can be an important source of development finance, and countries like Botswana and Malaysia have successfully leveraged natural resources in this way … . There are no sustainable diamond mines, but there are sustainable diamond-mining countries” (World Bank, 2006, p. 7).

[19] Among the middle-income group, resource-rich countries tend to have low genuine savings rates—the so-called curse of resources.

insights as to the extent to which various countries have achieved sustainability. Even before accounting for improvements in health, our results show that the United States, China, India, and Brazil are currently meeting the sustainability criterion, though Brazil meets the requirement by a narrow margin."

While these exercised, unlike the traditional national income accounts, try to come to grips with the other of forms of capital, we are still some way away from a satisfactory integration of natural capital into national income accounts. Take for instance the issue of negative genuine savings. In a market economy, consumption depends on current and expected future variables. If there is optimism in an oil-producing economy that oil prices will rise in the future, then there will be a consumption boom today, causing genuine savings to be negative (see van der Ploeg (2010a) for an example.[20] Applying the theory from the derivation of optimal shadow prices to the market economy with expectations of the future unspecified is opening a can of worms.

4 North--South Interaction and Climate Change

The issue of climate change has been center-stage in environmental negotiations. Climate change is caused by anthropogenic activity and fossil fuel use is the main, though not the sole, cause. A ton of carbon burnt anywhere in the world contributes equally to global warming. In that sense it is a global public "bad". In devising policies to counter this, countries try to free-ride—because no matter who bears the cost, everyone benefits. In addition, it is the stock of carbon in the atmosphere, rather than the flow of these that causes the problem. Put differently, the sum of all carbon put in the atmosphere since industrial activity started less the natural regeneration of the atmosphere, is the cause of climate change and not the current addition to this stock. This gives rise to an equity issue--the relatively poor countries such as China and India did not contribute to the build-up of these greenhouse gases but have to be part of the solution by limiting their additions to the stock of carbon in the atmosphere (because they cannot hope to replicate the development path of the North --- the environmental consequences would be catastrophic).

Fossil fuels constitute an essential part of production (and consumption) in modern societies. But their use has to be reduced drastically if the world is to have a fair chance of surviving. Climate change will raise the mean temperature on the earth by 1.5 degrees Celsius even if action to limit fossil fuel use is taken now. It will impact among other things, rainfall and the sea level, and cause widespread disruptions (drying up of glacier-fed rivers etc.). The problem with fighting climate change is that the main beneficiaries will be the future (as yet unborn) generations. Thus sacrifices

[20] In the Ramsey model, when, for example, Ricardian equivalence is analyzed, rationality of expectations is assumed.

have to be made now for the (possibly distant) future.

At the world level, to tackle global warming the cost of using fossil fuel must be raised to equal its benefit i.e. the externalities should be internalized. Hence their price should equal the social cost of carbon, which is the present value of all current and future marginal damages from burning one ton of carbon by those alive at the current moment. There are different ways of achieving this e.g. by a (global) tax on carbon or via an emissions market (see van der Ploeg and Withagen (2012a, 2012b, 2015).

Taxing carbon would switch demand away from it. This would help fight climate change in many ways. Within fossil fuels, the relatively cleaner (less carbon content) fuels would be used. Only the more cost-effective oil and gas fields would be used, by making the rest economically unviable. Renewable energy sources would be preferred over fossil fuels and technical progress would be "directed" towards clean technologies. For a given use of fossil fuels sequestration would be encouraged.

The problem with these prescriptions is that there is no global government that is setting an optimal tax. In a world with many governments and different endowments, different taxes have different incidences. In a universal setting, the incidence does not matter. At least in a simple framework, equilibrium price and quantity of the taxed good in question change by the same amount, no matter whether the tax is on purchase or sale of the good. But things are very different in a multi-region setting. Whether the oil producers keep the revenue, or the consumers do, or, indeed, the most equitable solution will have every individual alive receiving an equal lump-sum transfer, will have very different implications for welfare--see Whalley and Wigle (1991). Thus, we have to live with the prospect of different countries having different rates of taxation—free-riding, no doubt, contributes to this.

Thus, we need to ask ourselves whether there is a solution to the following two questions: (1) What can be done to prevent a tipping point for global warming from being reached? Tax fossil fuel use? Subsidize “cleaner” fuels? Or try and capture the carbon emissions before they add to the stock in the atmosphere?; and (2) Who should bear most of the burden of the clean-up? The richer industrialized countries (because it is the stock of pollution that matters), since the poorer countries did not cause the problem? If so, how are countries such as India and China going to participate in this? Will they be given access to cleaner technology developed by the private sector in the North?

4.1 Green Paradox

There is by now a sizeable literature that cautions against a piecemeal approach to tackling climate change. Of course, it is well known, that if there are many distortions, a tax or a subsidy that targets

one such distortion could be welfare-reducing. Examples of this are immiserizing growth—growth proves welfare-reducing when it "amplifies" a pre-existing distortion-- and trade or environment policy reform—where proportionate reductions or increases are called for. The example given below is important because in the policy domain it has some attraction. Given that the stock of carbon is the cause of the problem, maybe the poorer countries should be given some time to come on board the global platform to fight climate change. Thus, suppose the rich countries (called the North here) reduce their emissions, while the poorer countries (the South) are exempted from doing so (much like the structure of the Kyoto Protocol). Does this yield at least move the world in the right direction in alleviating the climate change problem? The answer is ambiguous. If the fossil fuel in question is like coal, which we can assume is priced at its marginal cost of production, then the South (Annexure 2) will increase its demand for coal and "occupy" some of the space "vacated" by the North (Annexure 1) but overall use of coal will be reduced. This is the normal reaction in a market, where following the (exogenous) decrease in the supply of a good, a rise in its price will elicit supplies from other producers--in this case the good in question uses a dirty input viz. coal.[21] The carbon leakage is less than one hundred percent, and world emissions go down.[22]

But, on the other hand, if the fossil fuel is like oil or natural gas which are priced above marginal cost, then the fossil fuel suppliers have every incentive to reduce the price of the fuel, as long as marginal cost is still covered. This could yield what has come to be referred as a "green paradox"[23]: after the North reduces its use of the fossil fuel, the price of the fuel falls and ensures that the entire stock of fuel is pumped out of the ground. The carbon leakage is one hundred percent. It may also (depending on the timing of the implementation of the policy) bring the time profile of extraction forward in time, when from a climate change perspective, given the total emissions, a postponement of extraction of fossil fuels is desirable.

When the fossil fuel is priced above its marginal cost of extraction, the Hotelling Rule requires the surplus from extracting the fossil fuel to grow over time at "the" rate of interest.[24] The price of the fossil fuel rises over time, with constant or rising stock-dependent marginal extraction costs. This is because the fossil fuel is like a "durable asset" and, via arbitrage, the return from it should equal that on any other asset. In other words, if the surplus is expected to rise slowly (compared to the

[21] Because the price of the final good has risen, less coal will be used. This assumes the technology is the same in the North and the South.

[22] The empirical evidence based on CGE models (see, e.g., Burniaux and Martins, 2000) estimates carbon leakages to be about 20% at most.

[23] The term was coined by Sinn (2008).

[24] We are concerned with what in the literature is called a "weak green paradox." The distinction is that "a weak Green Paradox occurs if fossil fuel is extracted more quickly and thus global warming accelerates in the short run in anticipation of a gradual tightening of climate policy (e.g., steeply rising carbon taxes in the coming decades or much cheaper renewables). A strong Green Paradox occurs if the present value of the costs of global warming in terms of reduced output, which is the converse of green welfare, falls in anticipation of a gradual tightening of climate policy" (van der Ploeg and Withagen, 2015, p 289).

interest rate) or even fall, then fossil fuel producers should pump it out in the current period.

The price of fossil fuel (that initially exceeds marginal cost) would collapse following a decline in its demand as the world tries to grapple with global warming. Think of this as the decision by governments to e.g. subsidize a "clean fuel" (say wind, solar etc.). The fall in the price of fossil fuels[25] may well result in an increase in emissions (certainly in some periods and in those economies where the clean fuel is not subsidized). To see this, note that with the price of the fossil fuel set above marginal cost, then it would be increasing at the rate of interest (a la Hotelling). Suppose the exhaustion of the fuel stock was to occur at date T. Now suppose the oil producers expect that at T'<T, oil would be replaced by a clean fuel. If the marginal cost of extraction is zero (thus all revenue is rent), then the oil-producers would pump out all the oil by T'. Assuming the interest rate remains unchanged, this means a lower price on all dates between now at T'[26]. Thus oil demand would be stimulated during this period (in the economies where the clean fuel subsidy is not in operation).

The problem of tackling global warming (i.e. the aggregate effects) has two dimensions. The first is the level of emissions. These have to reduce drastically because the initial stock in the atmosphere is very large. The second is the timing: given a level, postponing emissions is better i.e. emission cuts have to be front-loaded. The green paradox may violate both of these. It leaves the overall level of fossil fuel unchanged and may (but not necessarily so) bring higher emissions forward in time. This possibility implies that the South, which would be the spring-board of carbon leakage-cum-green paradox, has to be roped in to be part of the climate agreement. Moreover, the analysis points towards the use of quantitative restrictions of emissions in the absence of (possibly) time-varying taxes.

There is by now a large literature that deals with these issues. A number of papers have looked at the logical consistency of the green paradox in partial equilibrium settings. The outcome is mixed.[27] In a general equilibrium setting, there are papers by van der Ploeg and Withagen (2012, 2015). Eichner and Pethig (2011) and, van der Ploeg (2016) looked at the possibility of a green paradox in an open economy setting.

The closed economy models, while very illuminating, still leave a lot to be desired. The poorer economy is not a replica of a rich economy in the past, both existing in autarky. In the real world, the rich and the poor trade with one another, and climate change negotiations typically focus on the competitive advantage that may accrue to those economies that are allowed to pursue lax

[25] We use oil and fossil fuel interchangeably.
[26] In general equilibrium, the interest rate would not remain unchanged.
[27] See Chakravorty, Magne, Leach, and Moreaux (2011) for an argument that suggests the green paradox may kill off the introduction of the electric car.

environmental policies.

Here the sketch of a model is outlined to give a flavor of the argument in the simplest dynamic framework viz. a two-period model.

4.2 A Model

There are two countries (or blocs) (we do not model oil exporters explicitly--we just assume that their behaviour as suppliers of fossil fuel is captured by the Hotelling Rule). Gross output uses capital, the fossil fuel and other (inelastically supplied) inputs. In the first period, the capital stock is inherited from history, while for the second period it is chosen optimally. Since the horizon is two periods, there is no investment in period two.

The two fossil fuel importing countries are called N and S (for the North and the South respectively). N is assumed to impose fossil fuel taxes in either or both of the two periods, while the South does not do so. We look at the macroeconomic implications of this unilateral climate policy.

The representative consumers in the two blocs maximize the discounted sums of utility subject to the intertemporal budget constraints. We assume that the utility functions are identical and homothetic.[28]

$$\text{Max } U(x^1, x^2) \text{ subject to } \quad Y^1(\bar{K}^1, q^1 + \tau^1) + \frac{Y^2((\bar{K}^1 + I^1), q^2 + \tau^2)}{1+r} - (\bar{K}^1 + I^1) \qquad (16)$$

$$\text{Max } U(x^{*1}, x^{*2}) \text{ subject to } \quad Y^{*1}(\bar{K}^{*1}, q^1) + \frac{Y^{*2}(\bar{K}^{*1} + I^{*1}, q^2)}{1+r} - (\bar{K}^{*1} + I^{*1}) \qquad (17)$$

In equations (16) and (17), U(.) is the utility function, Y^t is the domestic value added in period t (t=1,2), K is the capital stock, q is the price of fossil fuel, I is the investment, and r is the interest rate. Similarly, for the foreign country. We have assumed that capital does not depreciate. As mentioned above, there is no investment in period 2.

The GDP function is the value added by a domestic economy and is the gross value added less the

[28] This is for ease of manipulation. Nothing of substance hinges on this.

value of imports of fossil fuel. It is captured by a function (for t-1,2):

$$Y^t(K^t, q^t + \tau^t) \equiv argmax_{R^t}(F(K^t, R^t) - (q^t + \tau^t)R^t)$$

where F(.) is a production function that is strictly concave in K and R (we have suppressed the other specific factors). From the property of the GDP function, we have (for t=1,2):

$$R^t = Y_q^t$$

The fossil fuel market has two features. First, we assume that the price is above the marginal cost of production in both periods. The optimal extraction of the fossil fuel is then dictated by the Hotelling Rule. This is given in equation (18) where we assume that the marginal cost of extraction is constant, and we set it equal to zero (a constant non-zero marginal cost can easily be incorporated without changing the results).

$$q^2 = (1 + r)q^1 \tag{18}$$

Equation (18) says that the present discounted value of a unit of the fossil fuel extracted in period two must be equal to surplus today for there to be extraction in both periods.

Second, since we assume the q_t's (t=1, 2) are positive, while the marginal cost of extraction is zero, the fossil fuel stock will be exhausted over the two periods. Thus, we have:

$$\bar{R} = R^1 + R^2 + +R^{*1} + R^{*2} = -\left\{Y_q^1 + Y_q^2 + Y_q^{*1} + Y_q^{*2}\right\} \tag{19}$$

There is an international capital market that allows each bloc to borrow or lend, subject to its inter temporal budget constraint. The interest rate (in general equilibrium, with other endogenous variables) equalizes the borrowing and lending. The total saving in period one is the world's capital stock in period two. Thus, the existence of the world capital market allows for consumption - smoothing and investment. A model without such a market, there is a separation of the saving and investment decisions--see Sen (2016) for a similar model but without international borrowing and lending.

$$Y_K^2(K^1 + I^1, q^2 + \tau^2) = (1 + r) \tag{20}$$

$$Y_K^{*2}(K^{*1} + I^{*1}, q^2) = (1 + r) \tag{21}$$

$$x^2 + x^{*2} = Y^2(K^1 + I^1, q^2 + \tau^2) + Y^{*2}(K^{*1} + I^{*1}, q^2) \tag{22}$$

4.3 Unilateral policies

In period 2, N decides to impose a tax on fossil-fuel use (in our aggregative set-up it would be equivalent to subsidizing a clean fuel that is a perfect substitute for fossil fuels in generating energy). We do not model any strategic interaction between N and S. The reason that S is allowed not to join N in imposing a tax on fossil fuel is that either it is expected to join in soon of its own accord or there is an explicit recognition of a differentiated responsibility.

Relative to the initial equilibrium, in period two there will be an excess supply of the fossil fuel, since N's demand will fall. At a given interest rate, the price of oil will fall in both periods (from equation (18) given r, they move together). In period 1, both N and S use more of the fossil fuel, whereas in period 2, S will do so. N anticipates a fall in period 2 income and has an increase in period 1 income. To try and smooth consumption, its saving will go up. It would want to lend more to S, because its investment will fall. The latter happens because the marginal product of capital falls if capital and fossil fuel are Edgeworth-complementary (in simple language, the productivity of capital is lower due to the fact that the tax on the fossil fuel implies there is less oil for capital to work with). S will see a rise in its incomes in both periods. The marginal product of capital tends to rise for S—there is more oil for it in the second period compared with the original situation. Whether S saves to add to its income in period 2 or brings some potential increase in come from period 2 to period 1 (remember N wants to lend) is uncertain. The final effect on the interest rate is ambiguous and depends on the intertemporal elasticity of consumption and the substitutability in production between capital and the fossil fuel. But the process at work is clear: period 1 sees a glut in fossil fuel use, while its overall use is the same (this is true by our assumption that the total use of the fossil stock must be exhausted in the two periods—equation (19)). But the time profile of extraction has been brought forward. If the cost of fossil fuel extraction were not constant, more oil could be left in situ, thus tempering the green paradox outcome possibility.

An obvious implication of this is that the South must be brought on board and the lead time for the policy implementation has to be eliminated. Another implication is that possibly quantitative targets of fossil fuel use are better than using taxes.

The purpose of this section was to point out that calculation of the optimal tax from a world economy perspective is woefully inadequate to address the global warming problem. There are no

short-cuts to bypass a world agreement. We are then back at our starting point. An equitable scheme would be where every country gets a carbon quota proportional to its population. As Whalley and Wigle (1992) pointed out, this will cause welfare losses to the rich countries (who use most of the fossil fuel before the proposed reform) and be welcomed by the poorer countries.

It must be mentioned that the Hotelling Rule employed here is the simplest one--if there is a cost of extraction, then the marginal cost is constant. If this marginal cost is rising, a tax may cause fossil fuel producers to leave some of it in the earth's crust.[29] Of course, there are sunk costs of exploration, fixed costs of rigs etc. that would need to be considered in a more realistic set-up. But the simple point made in this section would survive these complications.

5. Summing Up and Some Further Readings

The interface between macroeconomics and the economics of environment is evolving. Macroeconomics is an area where there is much disagreement among practitioners; and although the models there are dynamic, there is still an overwhelming interest in the short- to medium-run horizon. Of course, this is not entirely accurate e.g. growth theory looks at long-run issues. Environment and resource economics, on the other hand, are concerned with medium- to long-run (and very long-run) problems. The two areas overlap all the time, but not enough to constitute a solid sub-discipline that can be surveyed as a unified whole. In this essay, I have chosen to concentrate on three major issues that are at the intersection of macroeconomics and the environment. All three have solid theoretical foundations and generate policy prescriptions. And they address issues that will be around for quite a while.

In the first quarter of the 21st century the earlier enthusiasm for free trade is waning. As protectionism increases so will the importance of environmental standards as a justification. Similarly, as FDI is discouraged what are the ramifications for the environment? Our discussion above helps in answering some of these questions.

National income accounts will have to take the role of natural and other capital stocks seriously. The discussion on this points to a future where more disaggregated, bottom-up analysis is carried out. Market imperfections will be woven into the analysis.[30]

Finally, the pressing problem of climate change will require more serious co-operation. Knee-jerk, piecemeal approaches will not work. The green paradox literature points to a Damocles' sword hanging over the negotiators.

[29] If the fossil fuel is a homogenous product but there are fields with different marginal costs of extraction, then it requires extraction of the fossil fuel in a sequence—first exhaust all low-cost fields, then move to the next low-cost one, and so forth.
[30] See Hallegatte, Heal, Fay, and Treguer (2012) for a comprehensive discussion on how to look at growth theory with environment-tinted glasses.

Further Readings

On trade and environment see Copeland and Taylor (2003). They are trade theorists and this is a careful and detailed work from a trade theoretic perspective. On the relationship between growth and pollution that generates and EKC see Brock and Taylor (2010).. In this context also see Andreoni and Levinson (2001).

On the theory of sustainability and its applications see Hamilton and Hartwick (2014). For a later study along the lines of World Bank (2006), see World Bank (2011).

A paper that brings Chichinsky type lack of property rights to bear on genuine savings see van der Ploeg (2010b).

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