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AN ALTERNATIVE ARGUMENT OF GREEN SOLOW MODEL IN DEVELOPING ECONOMY CONTEXT

Santosh K. Sahu
Arjun Shatrunjay

MADRAS SCHOOL OF ECONOMICS
Gandhi Mandapam Road
Chennai 600 025
India

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Santosh K. Sahu
Assistant Professor, Madras School of Economics
santosh@mse.ac.in

and

Arjun Shatrunjay
Madras School of Economics
ee14arjun@mse.ac.in

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MADRAS SCHOOL OF ECONOMICS
Gandhi Mandapam Road
CHENNAI 600 025
India

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Phone: 2230 0304/2230 0307/2235 2157
Fax : 2235 4847/2235 2155
Email : info@mse.ac.in
Website: www.mse.ac.in

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Abstract

The paper attempts to understand the significance of the Green Solow Model, in the context of a developing country such as India. It gives particular importance to the role of population density, in understanding the drawbacks of the Green Solow Model. It further extends the argument to analyse the impacts of the emission regulations on a developing country, by proving relationship between price level on one hand, and abatement costs and emissions on the other. Lastly, interactions between countries, given different price scenarios are studied.

Keywords: Green Solow Model, abatement costs, technology, emission regulations, India

JEL codes: C70, O44, Q52, Q56

INTRODUCTION

Over the years, the debate surrounding concepts of climate change, and of citizen welfare, has reached a crescendo. Indeed, the problem of climate change has even necessitated international interventions from organizations such as the United Nations; numerous protocols held in cities like Montreal and Kyoto, and agreements signed, such as that of the recent one in Paris[1], with the hope of collaborating to fight climate change. Underpinning the arguments around climate change are several theories in economics, such as the Green Solow model; data that validate such theories and the applicability of such theories across different contexts. This paper aims at arguing the Green Solow model in the developing economy context in general and for the Indian economy context in particular, and analyses the repercussions it may have on the COP21 agreements.

Models proposed by Solow (1956) and Swan (1956) primarily aimed to understand the manner in which living standards of economy change over time, as a result of increases in output related to the changing role of capital and labor. The justification for this objective is based on the following assumptions. The first of these assumptions, is that increases in output lead to increases in living standards. Increasing output is driven primarily by increases in consumption, which in turn is built on the assumption of greater material benefit providing greater satisfaction. Secondly, inter-temporal changes in living standards are driven by the desire to maximize satisfaction at lower prices, and in greater quantities. This model, therefore, concludes that it is *this* increase in consumption, and thereby, material benefit, that leads to an improvement in the standard of living. In the midst of all this, lies the problem of scarcity. How does increasing consumption on the one hand, and therefore an increasing need to produce, stack up against a limited

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[1] For details see http://www.cop21paris.org/

supply of resources? Further, how does this scarcity of resources, further exacerbated by an increase in population density, affect environmental health and climate change? These are some questions that the Solow (1956) and Swan (1956) model does not explicitly contend with. In order to better appreciate these questions, the Environment Kuznets Curve Hypothesis (EKC)[2] plays a vital role.

In this way, therefore, the EKC and the Solow and Swan models have a common foundation, and the interrelationships between these two distinct models were studied in the Green Solow Model (Brock and Taylor, 2010). The Green Solow Model was aimed at explaining the empirical behaviour of income, emission and abatement cost. To begin with, the EKC hypothesised that the pollution would eventually come down as incomes increases. What was perplexing, however, was the fact that while the emissions did indeed fall, the abatement cost as a fraction of output largely remained same, after a brief, rapid increase. Similarly, the EKC posits that the emissions rise during an absence of any regulatory policy, and fall immediately upon implementation of a pollution regulation policy. Empirically, however, it is observed that the emission intensities actually begin to decline *before* any active policy is put in place, and precede the peak level in pollutants.

In order to explain these discrepancies, Brock and Taylor (2010) argue by making changes to the Solow (1956) model. They begin by assuming the pollution to be proportional to the output produced, and then factoring in the abatement of the pollution. Consequently, the balanced growth path includes the growth rate of emissions, after factoring in the growth in abatement efforts, apart from the growth rate of population and the depreciation rate. They then use a Cobb-Douglas production model to model the data at hand. Most of the empirical

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[2] The Environment Kuznets Curve (EKC) Hypothesis attempted to explain the relationship between indicators of environmental degradation (primarily emissions), and the income of a country, across a span of time.

findings are published in the context of developed economies such as the USA and developing economy studies are scanty. Thus, it is only imperative to test the validity of the Green Solow model in the Indian context. The reminder of this paper is as follows. An introduction is first provided, that outlines, among other things, the history of the climate change debate, and the elucidation of the Green Solow model. Having done this, a literature review is then put forth, followed by the analysis. The conclusion and the inferences are presented in the next section.

RELATED LITERATURE

The motivation for this study follows Brown et al., (2014), where they argue that "*growth is a consequence of what we call the Malthusian-Darwinian Dynamic*". They essentially look at growth from two perspectives - that proposed by Malthus, on the one hand, and the other being that proposed by Darwin. They argue that the manner by which growth manifests itself is, firstly, driven by an increase in demand as a result of population growth. In other words, output grows with population until restricted by environmental limits, as was proposed by Malthus. On the other hand, they argue, population tends to adapt to changing environmental conditions, as propounded by Darwin, as a result of which the environmental limits can be pushed back, and there is possibly more room for growth. They further argue that cultural evolution, which comprises of changes in social organization and human behaviour, can potentially push back the environmental limits.

One aspect of this cultural evolution, that could perhaps be representative of a change in the interactions between different members of a society, is that of technology development. Greater demand, and ever greater curiosity, combined with the motive for profit, often incentivizes the development of technology. Consequently, there is an overall increase in not just the output (in order to cater to the ever increasing demand) but also that of wastes, emitted as a part of the production process. While there certainly is a possibility of pushing back the environmental limits in order to favour growth, it cannot be done endlessly, and there exist limits to the extent of push-back that can be done. Eventually, therefore, it appears that the Malthusian prediction certainly wins over. However, the Darwinian argument can still play a role, as it can be argued that the very change, the cultural evolution that is arguably causing this mess, can hold the key to solving the problem too. Indeed, it may very well be that this cultural evolution can manage to negotiate the need to grow more output, and the need to stay within the environmental limits. Technology, again, is one instrument that comes into play here. It can potentially help maximize output, while ensuring that the environmental limits are not breached.

A particular example of this is in the case of the emissions. While there are environmental limits to the amount of emissions that can be released, there is an ever growing desire for economic growth. However, as growth increases, the development of technology can potentially help reduce emissions, thereby catering to the dual need to pursue growth, while remaining confined within the environmental limits. It becomes necessary, therefore, to study the relationship between growth driven by increase in population on one hand, and emissions on the other. One of the well-known theories that attempt to address this issue is that of the Green Solow model. Brock and Taylor (2010) published their findings which aimed at reconciling contradictions between the economic theory and empirical evidence.

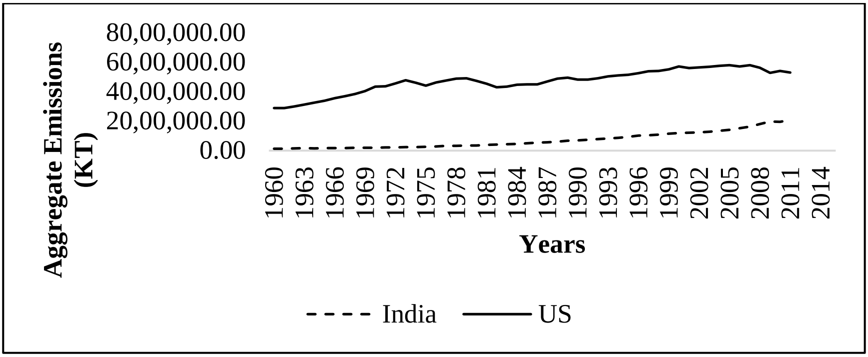
As has been mentioned earlier, the Green Solow model attempts to reconcile the fact that emissions intensities fall before the fall in aggregate emissions, and the fact that abatement cost as a fraction of output remained largely the same, despite the fall in emissions, seemed perplexing to the authors, who modified the Solow growth model of 1956. This model has been validated by Chen in 2015 for the European Union. However, there are certain limitations with the Green Solow Model in the context of a developing country perspective. For one, it does not clearly illustrate the role of technology in the production process, and neither does it show its effect on the aggregate emissions of a country. Similarly, it does not show the welfare impacts of adding regulations in order to control the emission flow. While it does consider population growth, it does not exactly give it the amount of importance it ought to be given, choosing instead to give far more importance to the growth rate of the economy. It really is not as detailed a study into the production processes in an economy, as it ought to be, as the reabsorption of wastes into the production processes is rarely ever considered. It does not differentiate the different forms of technology, and the differentiated stages of their development.

In order to trace these weak links, an effort has been made in this study, to represent (1) the cyclical processes of an economy, (2) the role of waste in the economic system, and (3) the potential welfare impacts on emission regulations. Further a simple game is constructed that seeks inspiration from (Bagchi et al., 2014). Similar to Bagchi et al. 2014, we construct a game after deriving different optima for different players, and then analysing the model based on hypothetical values considering the role of technology.

THE GREEN SOLOW MODEL AND THE INDIAN CONTEXT

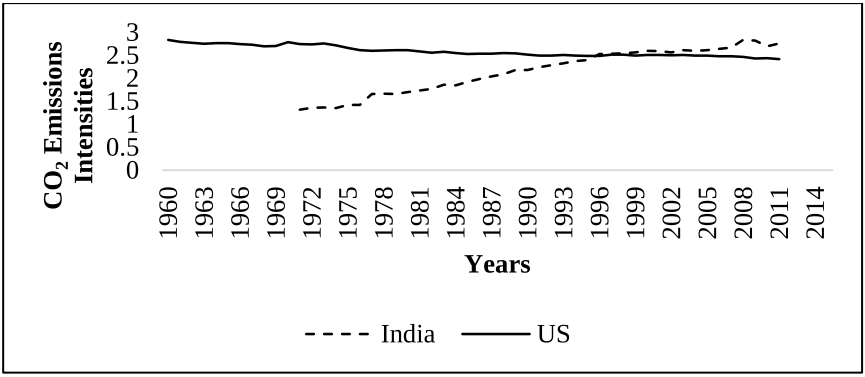
We begin first by considering the evidence. In the case of overall aggregate emissions, India shows a steady rise in the emissions of Carbon Dioxide (CO_2). It is nowhere near the emissions of the US, which, as Figure 1 illustrates, does not follow such a steady trend, but which nevertheless seem to validate the EKC hypothesis. The emissions intensity data, in Figure 2, shows an extremely gradual decline in the case of the US. In India's case, however, the emission intensity increases dramatically, and shows no sign of decreasing.

Figure 1: Trends in the Aggregate Emissions of the US and India



Source: WDI, The World Bank.

Figure 2: Trends in the CO_2 Emission Intensities of the US and India

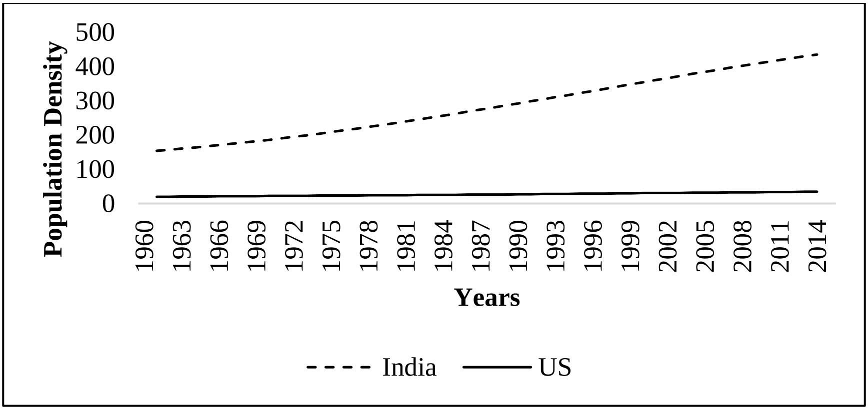


Source: WDI, The World Bank.

Thus, the manner in which the US data behaves is significantly different from the data illustrating the Indian context. Aggregate emissions in India's case are not falling, and are in fact, on a steady rise. They do not show any signs of falling. Similarly, the emission intensity data also illustrates a rise. The Green Solow model was formulated to explain the behaviour of the US data. As the trends in the US and the Indian cases are dramatically different, the Green Solow model does not hold true for the Indian case. The very contradictions inherent in the empirical evidence that the Green Solow Model tried to reconcile, are not necessarily the contradictions found in the Indian case. Indeed, the Indian case is perhaps far more complex than the US equivalent. There really is no fall in emissions, for instance, despite the implementation of policy and a slow growth in the output. Why might this be?

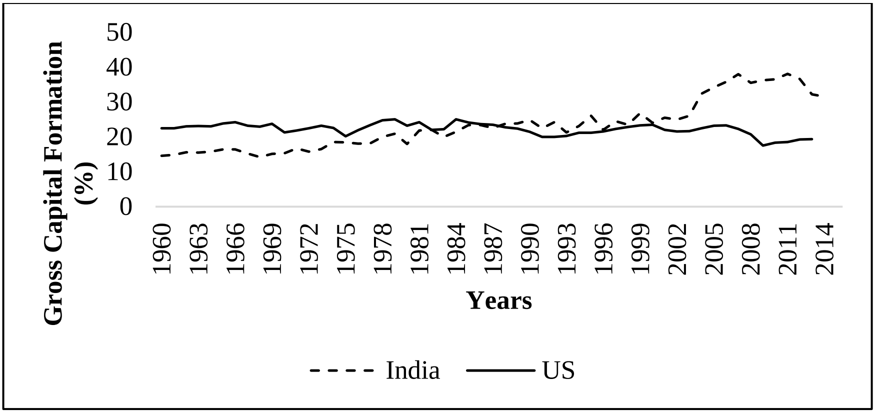
There are several reasons each of which is deeply linked with every other reason. Let us first consider population density. The trend in the population density is illustrated in Figure 3. As is very evident, it is this population density that is causing a real structural difference to the Indian economy. Not only has population density in India always been higher than that of the United States, its rise has clearly been more dramatic and at a much faster rate than in the case of the United States. The impact of this is seen in the trends in the Gross Capital Formation (as a percentage of Gross Domestic Product: GDP), as is illustrated in Figure 4.

Figure 3: Trends in the Population Densities of the US and India



Source: WDI, The World Bank.

Figure 4: Trends in Gross Capital Formation as Percentage of GDP of the US and India



Source: WDI, The World Bank.

Despite the rapid fluctuations in the data behaviour, a trend can most certainly be observed. In the Indian case, an upward trend in the Gross Capital Formation is observed, as against the case in the United States, where there has been, by and large, a rather flat trend in the Gross Capital Formation. Indeed, it seems rather contradictory, that in a country with so high a population density as India, the amount of capital per unit GDP has risen. The reason for this is likely that the aggregate demand is so high, simply by virtue of having an enormous population that production techniques are turning to more capital intensive techniques, as they offer greater efficiency and economies of scale.

As a result of this structural shift in the production, from being primarily labour driven, to being more capital driven, the emissions generated during the production process have increased. Thus, while in the case of the United States there certainly exists a possibility of reducing emissions without a significant welfare loss, in the Indian case, that is not true. Thus, it might appear that there is a very good chance of the Indian emissions not falling in the future, with the emission rise driven primarily by a rising population. This, however, need not necessarily be true, as the improvements in the trade of technology and technical knowledge (through such instruments as Intellectual Property Rights) might offset any further increase in future emissions. Whether they bring down the emissions remains to be seen.

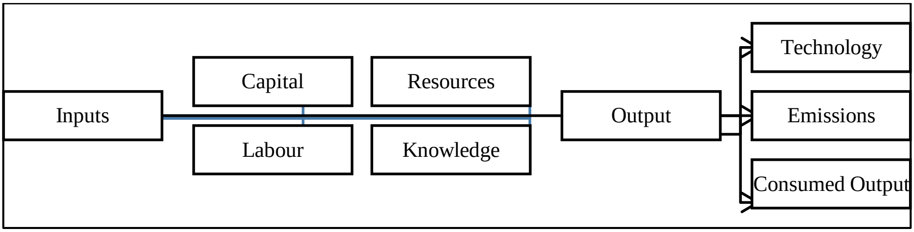
The objective of this study is to understand the manner by which emission waste, output and technology interact as a part of the production process. This is done by deriving a model which analyses the flow of wastes in the context of the production process, after factoring in various factors of production, and the role of technology in the production of output. Then, the impact of emission abatement, in the context of population density, on the overall welfare of the society is studied, by linking emission abatement to output, which in turn is linked to population growth and price. Having done this, a game is developed to better understand the strategies faced by a nation under different price situations, specifically in the context of the regulations on the emissions put in place by the global community.

The objective of this section is to develop an analytical framework by which the impact of the climate change talks on a country can be studied. This is done by dividing the analysis into two parts. First, a relation between price and output is developed, after factoring in the relationship between output and emissions, and then factoring in the abatement costs. Having done this, a game, as played between two countries, is developed and analysed, based on the derived relationship between price, output, emissions and abatement costs. Before deriving the relationship between prices, output and abatement costs, a theoretical justification for the reason behind wastes being in direct proportion to output is laid out. While deriving the relationship between prices, output and abatement costs, three cases are considered. The first is the case where in the emission waste is a linear function of the output.

The second and third are where the wastes are exponential functions of output.

Before we delve deeper, it is necessary to understand the economic processes of an economy. The following proposition seeks inspiration from the Material Balance Principle. Let us consider the inputs in an economy. These can be broadly classified into physical capital, labour, Schumpeterian technology, and resources. These four inputs are used to produce output, of which Hicksian technologies is one, consumed output is another, and emission is the third. Each of the different types of output produced, in some way, and to some extent, gets absorbed by the production process. Thus, it is not far-fetched to think of Hicksian technologies being reabsorbed into the input-side of the production process for all inputs, except the resources. Similarly, the emissions produced may be reabsorbed in to the production process through all inputs, except the Schumpeterian technology, primarily because the Schumpeterian technology is largely intangible, while all the other inputs are tangible, as a result of which there is a possibility of their being affected by the emissions. Consequently, we are left with two leakages from the economic processes, namely, the consumed output, and wastes resulting out of the emissions that have not been absorbed. This is illustrated in Figure 5.

Figure 5: The Economic Processes



Source: Authors' representation.

Using the above understanding of the economic processes, a relationship between emission waste and output can be deduced. Of course, what is fairly evident is that emissions generated from the economic processes are only considered. Wastes generated by discarding old capital, for instance, have not been considered. Consequently, it should be noted that capital, in the given context, means only the capital that is being put to use, the active capital, in other words, and not the capital that is being discarded, that is, not the inactive capital.

THE MODEL

Hypothesis: *Output and emission waste are directly related*

While proving the afore-mentioned proposition, we make a few assumptions. We assume that the production function in an economy is of the Cobb-Douglas type. We also assume a similar function for the production of emissions, and for Hicksian Technology. We also assume that the flow of emissions back into the production process is through the Capital, Labour, and Resources. We then try to decompose the output generated into technology, consumed output, and waste. The proof of the proposition is as follows:

Let Y be output, K be the stock of physical capital, L be the stock of labour, R be the stock of resources, T_s be the stock of Schumpeterian technology, T_h be Hicksian technology, C be consumed output and E be emissions. On the input side, we have

$$Y = K^{y_k} L^{y_l} R^{y_r} T_s^{y_{t_s}} \tag{1}$$

Where, y_i is the elasticity of the i^{th} factor input, $\forall\ i = k,\ l,\ r,\ t_s$

On the output side, we have

$$Y = T_h^{y_{t_h}} E^{y_e} C^{y_c} \tag{2}$$

Where, y_i is the elasticity of the i^{th} form of output $\forall i = t_h, e, c$

The flow of emissions, E back into the process is given by:

$$E = K^{e_k} L^{e_l} R^{e_r} W^{e_w} \tag{3}$$

Where, e_i is the emission elasticity of the i^{th} input; $\forall i = k\ ,\ l,\ r,\ w$, where w denotes waste. Similarly, Hicksian technology flows back into the process as follows:

$$\mathrm{T}_h = K^{t_{hk}} L^{t_{hl}} T_s^{t_{ht_s}} \tag{4}$$

Where, t_{hi} is the elasticity of the i^{th} input, $\forall i = k,\ l,\ t_s$

Taking natural logarithm for each of the four equations, we have

$$\ln Y = y_k \ln K + y_l \ln L + y_r \ln R + y_{t_s} \ln T_s \tag{5}$$

$$\ln Y = y_c \ln C + y_{t_h} \ln T_h + y_e \ln E \tag{6}$$

$$\ln E = e_k \ln K + e_l \ln L + e_r \ln R + e_w \ln W \tag{7}$$

$$\ln T_h = t_{hk} \ln K + t_{hl} \ln L + t_{ht_s} \ln T_s \tag{8}$$

Substituting (7) and (8) in (6), we have

$$\ln Y = y_c \ln C + y_{t_h}(t_{hk} \ln K + t_{hl} \ln L + t_{ht_s} \ln T_s) + \\ y_e(e_k \ln K + e_l \ln L + e_r \ln R + e_w \ln W) \tag{9}$$

$$= y_c \ln C + y_{t_h} t_{hk} \ln K + y_{t_h} t_{hl} \ln L + t_{t_h} t_{ht_s} \ln T_s \\ + y_e e_k \ln K + y_e e_l \ln L + y_e e_r \ln R + y_e e_w \ln W$$

Equating (5) and (9), we have

$$y_k \ln K + y_l \ln L + y_r \ln R + y_{t_s} \ln T_s = \\ y_c \ln C + y_{t_h} t_{hk} \ln K + y_{t_h} t_{hl} \ln L + y_{t_h} t_{ht_s} \ln T_s + \\ y_e e_k \ln K + y_e e_l \ln L + y_e e_r \ln R + y_e e_w \ln W$$

and,

$$y_e e_w \ln W = \ln K(y_k - y_{t_h} t_{hk} - y_e e_k) + \\ \ln L(y_l - y_{t_h} t_{hl} - y_e e_l) + \ln R(y_r - y_e e_r) + \\ \ln T_s(y_{t_s} - y_{t_h} t_{ht_s}) - y_c \ln C$$

Further,

$$\ln W = \frac{\ln K(y_k - y_{t_h} t_{hk} - y_e e_k) + \ln L(y_l - y_{t_h} t_{hl} - y_e e_l) + \ln R(y_r - y_e e_r) + \ln T_s(y_{t_s} - y_{t_h} t_{ht_s}) - y_c \ln C}{y_e e_w} \tag{10}$$

Let,

$$\frac{y_k - y_{t_h} t_{hk} - y_e e_k}{y_e e_w}$$

$$= \lambda_{k,} \quad \frac{y_l - y_{t_h} t_{hl} - y_e e_l}{y_e e_w}$$

$$= \lambda_{l,} \quad \frac{y_r - y_{t_h} t_{hr} - y_e e_r}{y_e e_w}$$

$$= \lambda_{r,} \quad \frac{y_{t_s} - y_{t_h} t_{ht_s}}{y_e e_w} = \lambda_{t_s}$$

Exponentiating on both sides, we have

$$\Rightarrow W = K^{\lambda_k} L^{\lambda_l} R^{\lambda_r} T_s^{\lambda_{t_s}} \tag{11}$$

Clearly, $\lambda_j \forall y_j \forall j = k, l, r, t_s$, thus, *W* is always less than *Y* and in direct proportion to *Y*

$$W = \alpha Y \tag{12}$$

Q. E. D.

The total output generated (including the waste) gets partially absorbed, while a small proportion of it leaks out of the economic process. The waste generated, which is only a proportion of the total output, gets redistributed back into the production process, albeit with different elasticities, as in the case of the production function. These elasticities are determined by deducting that part of the waste that is reabsorbed into the production process through each of the factor inputs, and the emissions generated by that particular factor input, in the context of its proportion with respect to the total output. Thus, a major chunk of the original output gets reabsorbed and redistributed. Consequently, the waste generated is always a fraction of the total output produced. Now, empirically, a linear relationship between the waste generated and the output produced is observed. However, theoretically, waste could be an exponential function of the output generated. If the output gets reabsorbed into the system, then it is not inconceivable to think of the natural logarithm of the waste being a linear function of the natural logarithm of each of the factor inputs. Thus, there is a theoretical possibility of waste being an exponential function of the output produced.

Specifically, the possibility of natural logarithm of wastes being a linear function of the factor inputs is of particular interest. This form, which implies a log linear relationship, can perhaps explain the gradual rise in the rate of increase of emissions over time. In order to analyse these cases, we look at them in greater detail. A relationship between the objectives of the economy, namely, to increase output, under the constraint of reducing emissions is considered. The conventional profit maximizing technique is used, as it is assumed that an economy would want to minimize emissions, while maximizing output to-at the very least-cater to the needs of an ever increasing population. It is for this reason that the population density variable is considered, and it is with respect to this that we maximize the objective function.

Thus, output is expressed as a function of population density, and wastes are a function of output. Three cases, of a linear relationship, of an exponential relationship, and of a log linear relationship, are considered. The final solution obtained in all the three cases expresses the general price level in an economy as a function of the abatement cost, and the proportion of emissions to output. As a result, we can conclude that changes in emissions or abatement costs can affect the welfare state of a society, by affecting the price. Thus, the three cases are presented below. Let us assume that P is the price level in the economy, Y is the output, a is the abatement cost per unit of waste emitted, and α is the waste generated as a proportion of output. Let w denote wastes, d denote population density, and l denote land area.

Proposition 1: When wastes are a linear function of output

Further,

$$\text{Let } W = \alpha Y \tag{13}$$

and

$$\text{Let } Y = (ld)^{\beta_1} \tag{14}$$

Where β_1 is the rate of change of $\ln Y$ with respect to total population. Thus, for an economy, we have to maximize the difference between output produced and the abatement costs, π.

$$\pi = PY - a\alpha Y$$

$$\pi = P(ld)^{\beta_1} - a\alpha(ld)^{\beta_1} \tag{15}$$

Maximizing w. r. t population density (d), we have

$$\frac{\partial \pi}{\partial d} = \beta_1 P l^{\beta_1} d^{\beta_1 - 1} - a\alpha\beta_1 l^{\beta_1} d^{\beta_1 - 1}$$

$$\frac{\partial \pi}{\partial d} = \beta_1 l^{\beta_1} d^{\beta_1 - 1}(P - a\alpha)$$

Equating the above equation to zero, we have

$$\beta_1 l^{\beta_1} d^{\beta_1 - 1}(P - a\alpha) = 0 \qquad (16)$$

Now, $\beta_1 \neq 0$ [$\because$ this implies that $y = 0$, which is absurd]

$l \neq 0$ [$\because$ this implies that land area is zero, which is absurd]

$d \neq 0$ [$\because$ this implies that population density is zero, which is absurd]

$$P - a\alpha = 0 \qquad (17)$$

$$P = a\alpha$$

Q. E. D.

Proposition 2: When wastes are an exponential function of output

Let $W = Y^{\alpha}$ (18)

As in the above case,

Let $Y = (ld)^{\beta_1}$ (19)

Thus, for an economy, we have to maximize the difference between output produced and the abatement costs, π.

$$\pi = PY - aY^{\alpha}$$

$$\pi = P(ld)^{\beta_1} - a((ld)^{\beta_1})^{\alpha}$$

Maximizing w. r. t population density (*d*),

$$\frac{\partial \pi}{\partial d} = \beta_1 P l^{\beta_1} d^{\beta_1 - 1} - a\alpha\beta_1 l^{\alpha\beta_1} d^{\alpha\beta_1 - 1}$$

$$\frac{\partial \pi}{\partial d} = \beta_1 l^{\beta_1} d^{\beta_1 - 1}(P - a\alpha l^{\beta_1(\alpha-1)} d^{\beta_1(\alpha-1)}) \tag{20}$$

Equating above equation to zero, we have

$$\beta_1 l^{\beta_1} d^{\beta_1 - 1}(P - a\alpha l^{\beta_1(\alpha-1)} d^{\beta_1(\alpha-1)}) = 0$$

Now, $\beta_1 \neq 0$ [$\because$ this implies that $y = 0$, which is absurd]

$l \neq 0$ [$\because$ this implies that land area is zero, which is absurd]

$d \neq 0$ [$\because$ this implies that population density is zero, which is absurd]

$$P - a\alpha l^{\beta_1(\alpha-1)} d^{\beta_1(\alpha-1)} = 0$$

$$P = a\alpha l^{\beta_1(\alpha-1)} d^{\beta_1(\alpha-1)})$$

$$P = a\alpha (ld)^{\beta_1(\alpha-1)}$$

$$P = a\alpha Y^{\alpha-1}$$

$$\frac{P}{Y^{\alpha-1}} = a\alpha \tag{21}$$

Q. E. D.

Proposition 3: When wastes are a log linear function of output

Let $W = e^{\alpha Y}$ (22)

Further,

Let $Y = (ld)^{\beta_1}$ (23)

Thus, for an economy, we have to maximize the difference between output produced and the abatement costs, π.

$$\pi = PY - ae^{\alpha Y}$$
$$\pi = P(ld)^{\beta_1} - ae^{\alpha Y}$$

Maximizing w. r. t population density (*d*),

$$\frac{\partial \pi}{\partial d} = \beta_1 P l^{\beta_1} d^{\beta_1 - 1} - a\alpha\beta_1 e^{\alpha Y} l^{\beta_1} d^{\beta_1 - 1}$$

$$\frac{\partial \pi}{\partial d} = \beta_1 l^{\beta_1} d^{\beta_1 - 1}(P - a\alpha e^{\alpha Y}) \tag{24}$$

Equating above equation to zero, we have

$$\beta_1 l^{\beta_1} d^{\beta_1 - 1}(P - a\alpha e^{\alpha Y}) = 0$$

Now, $\beta_1 \neq 0$ [$\because$ this implies that $Y = 0$, which is absurd]

$l \neq 0$ [$\because$ this implies that land area is zero, which is absurd]

$d \neq 0$ [$\because$ this implies that population density is zero, which is absurd]

$$P - a\alpha e^{\alpha Y} = 0$$

$$P = a\alpha e^{\alpha Y}$$

$$\frac{P}{e^{\alpha Y}} = a\alpha \tag{25}$$

Q. E. D

Each of the three cases yields solutions that illustrate three different possibilities. In the first case, in which we study a linear relationship between waste and output, at the equilibrium, the price is exactly equal to the abatement cost per unit of emission, multiplied by the ratio between emissions and output. This fraction, $\alpha << 1$. Thus, as greater output is produced, the emissions rise, causing the price level to go up, even if the abatement costs were to remain the same. However, as technology is adopted to abate the emission of waste, the emissions as a proportion of output reduce, but the abatement costs rise, primarily driven by an increase in the emission abatement technologies. This balance between abatement costs per unit of emission and the quantity of waste emitted unabated determines the price level. Simultaneously, the development of abatement technologies further increases output, as it enters the production process through either of the technology variables, that is, either by being marketed Hicksian technologies, or by just adding to the knowledge base, in which case it would be a Schumpeterian technology.

This balance between the output produced, the technologies developed in abating emissions, their cost, and the emissions left unabated determines the price level. This, of course, has welfare impacts. This illustrates that the abatement of emissions for the long term benefit has to be traded off with short term welfare fluctuations arising out of price fluctuations. In a country like India, price changes such as these can have severe welfare impacts, primarily because a significant proportion of the population is poor.

In the second case, where in we study an exponential function, the price has to be discounted by a term, $b = Y^{\alpha-1}\ (\text{say})$, in order for it to equal $a\alpha$ at the equilibrium. Thus, in this case, price is greater than the abatement cost per unit of emission produced, and the proportion of output that comes out as waste. Again, as $0 \leq \alpha << 1$, the quantity by which the price is multiplied, b is fairly insignificant, and for very low α values, the price is almost equal to $a\alpha$. For higher values of α, the inequality between P and $a\alpha$ increases. Further, as the output is directly related to population density, as the population density increases, output increases, thereby causing an increase in the price level.

This is again likely to increase poverty, and exacerbate the negative effects of the price rise due to increasing need for abatement. In the third case, the price again exceeds the $a\alpha$ term, as the $a\alpha$ is not multiplied by $e^{\alpha Y} >> 1$. Interpretations of the third case are nearly identical to that of the second one. However, it must be noted that while the second case is derived from theory, the third case is likely to fit the emissions-output data, with a low α value.

INTERNATIONAL AGREEMENTS, OBLIGATIONS AND ABATEMENT TECHNOLOGIES

Here, in Table 1, a hypothetical payoff matrix is constructed to illustrate the consequences of different scenarios a hypothetical country, A, faces, when it engages with the global community to reduce emissions. Here, the second country, B, represents the rest of the world.

Table 1: Payoff Matrix of Two Countries "A" and "B"

Country A	**Country B**		
	$P = a\alpha$	$P >> a\alpha$	$P << a\alpha$
$P = a\alpha$	(5,5)	(5,7)	(5,3)
$P >> a\alpha$	(7,5)	(7,7)	(11,4)
$P << a\alpha$	(-4,4)	(-4,6)	(-5, -5)

Source: Authors'.

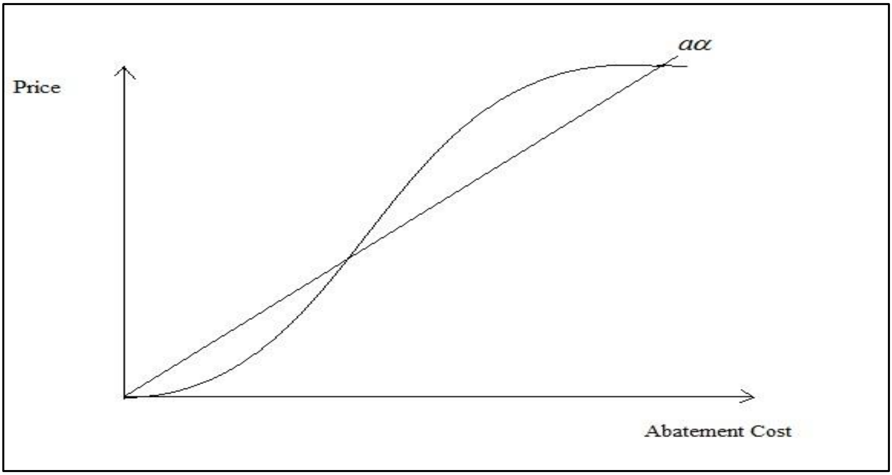
Let S_1 be the scenario faced by a country when, $P = a\alpha$. Let S_2 be the scenario faced by a country when, $P >> a\alpha$. Let S_3 be the scenario faced by a country when, $P << a\alpha$. When both countries A and B are faced with the first scenario, the obligation on country A to reduce emissions yields a positive payoff, as the country has the potential to do so. When country A faces S_1 and Country B faces S_2, the payoff does not really change and remains broadly the same. The payoff for Country B increases, as it can now set more stringent regulations to reduce emissions. Also, it can export technologies to country A and further add to the output. When Country A is faced with S_1 and Country B is faced with S_3, the payoff for country A falls, as it is able to meet the rather lax emission reduction requirements, and also because there is now a possibility of exporting technologies to Country B. Country B faces a low payoff because it cannot reduce the emissions as is desired, as the abatement cost is too high.

When Country A faces S_2 and country B faces S_1, the payoffs for country A are high as it can easily meet the emission reduction obligation, and further export technology to Country B. Country B has a mediocre payoff, as it can meet the emission reduction requirements it has set. When both Country A and B are faced with S_2, the payoffs are high, because greater emission reduction can now take place. When Country A faces S_2 and B faces S_3, Country A's payoffs are really high, as it can reduce greater emissions (after having mastered the emission reduction technology), and can export the technology to B. B faces low payoffs because of the fairly lax emission reduction requirements it would have likely set.

When Country A faces S_3 and B faces S_1, the payoffs for A are negative, as it cannot keep up it emission reduction obligations. Country B's payoffs fall because A is unable to reduce the emissions, which acts as a negative externality on B. When A is faced with S_3 and B is faced with S_2, a similar reaction is observed, although the payoffs for B are higher. When A and B are faced with S_3, the payoffs for both are negative, as there is no reduction in the emissions. As has been observed, the economic system is extremely complex, and the various processes within it have to be studied carefully, in order to understand its rather cyclic nature. For instance, emissions and technology tend to flow back into the production process, while wastage and consumption are considered are leakages.

For countries like India, which has a very large population density, the trade-off between short-run welfare benefits arising out of labour employment, and the production benefits arising out of increased use of capital, is one that is extremely hard to resolve. While it cannot be denied that the increased reliance on capital intensive techniques has caused the environment harm, it must also be conceded that this might just lead to development of emission abating technologies. When placed in the context of the global fight against climate change, the impact on welfare in the Indian society might be dramatic. Placing a cap on the emissions might increase the per unit emission cost, which might cause prices to increase. If India is not able to develop technologies to abate emissions, it is forced to be reliant on developed partners such as the US, which might cause the price of abatement technologies to rise. Indeed, it can be argued that, the development of abatement technologies requires a very high investment, and is also highly risky, thus restricting entry into the global abatement technologies market. Consequently, such a market is likely to have monopolistic tendencies, and could hence cause the abatement costs to rise which, in turn, escalate the price level in an economy. Consequently, over the short run, one is likely to witness a greater increase in abatement cost and a lesser increase in the fall of emissions, thus causing prices to rise. However, over time, the fall in emissions is likely to be accompanied by more marginal increases in abatement costs, thus moderating the rate of price rise, and thus ensuring lesser volatility in welfare changes as presented in Figure 6.

Figure 6: Price Behaviour with Respect to Abatement Cost



Source: Authors'

CONCLUSION

In summary, India stands to gain the most by importing technologies, and developing over to suit for the Indian context. The abatement of emissions in the Indian case is particularly hard, and any development is likely to be a slow, gradual process. The Indian government is forced to walk a fine line, between ensuring short term benefits for the poor, and the long run environmental sustainability of the nation. Consequently, India’s ability to fulfil the regulations put in place by the international community is contingent on several factors, and there is a good chance that India will require greater freedom in this regard, in order to ensure welfare for its society. It becomes apparent that development of updated and modern technologies is expensive in the Indian case. However, development of such technologies can be stimulated through institutional supports.

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