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Rethinking Economic Growth: Integrating Environmental Constraints into Growth Theories

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Abstract

Theories of economic growth over the decades have classically been divided into exogenous (neoclassical) and endogenous growth models based on different ways of conceiving the long-run rate of expansion of the economy. Solow (1956) established an exogenous growth model that knows the effect of external factors for example technological co-development and accumulation of capital on economic growth; in contrast, Romer (1986) and Lucas (1988), developed an endogenous growth model wherein human capital, innovation, and spillovers of knowledge drive economic growth. But these models often pass over the critical effect of environmental constraints and sustainability on economic trajectories. This research paper, which introduces the idea of environmental pollution, extends traditional growth models. Based on the literature of Nordhaus (1991, 1994), on climate-economy coupling, Grossman and Krueger (1995) on the Environmental Kuznets. Using Popp (2012)'s directed technological change, we ask how environmental policies and green innovation as well as sustainable use of resources can affect economic growth. This research paper suggests an adjusted context founded on both economic expansion and ecological preservation by enveloping environmental pollution design coordination solutions and growth models.These outcomes show that integrating environmental elements into growth models can help in developing a better understanding of where economic growth can be designed to not only be sustainable in the sense of not creating detrimental GDP developments but also stabilize and/or reverse environmental degradation. This theory gives a solid ground for future empirical analysis regarding how economic growth and environmental sustainability interact with each other.

Keywords: *Exogenous Growth, Endogenous Growth, Environmental Pollution, Sustainable Development, Climate-Economy Interaction.*

I. INTRODUCTION

Economic growth has been one of the most important subjects in economic theory for decades, and scholars have built a variety of different economic models to clarify the sources and mechanisms of sustainable development. It has been described broadly that exogenous and endogenous growth models deliver key elements of growth of economies during last few decades. The exogenous growth theory, first introduced by Solow (1956), explains long-run economic growth as significance of external forces to the economy (e.g., technological innovation and labor force growth). Approaching the question from another angle, while exogenous growth theory emphasized the role of external factors such as technological progress, endogenous growth theory developed by Romer (1986) and Lucas (1988) highlights the importance of investment in human capital, innovation, and knowledge spillovers in producing sustained economic growth driven by inherent forces within the economy itself.

However, the economic growth cannot be understood without considering environmental constraints. Scholars comprehend that industrial activities are increasingly affecting resource depletion, climate change, and ecological degradation, which is why the models they employ to examine growth now contain environmental factors. Nordhaus (1991, 1994) formalized the connection between economic growth and climate science (Salih, 2018). Grossman & Krueger (1995) studied the Environmental Kuznets Curve (EKC) which states that at low-income levels an increase in income is related with worsening in the environment, whereas in higher income levels income growth reasons the environmental quality to improve. Furthermore, Acemoglu et al. (2012) found out that the role of directed technological change in transitioning to cleaner energy and sustainable development.

The research paper contributes to the literature on economic growth by extending the theoretical context of exogenous and endogenous growth theory by integrating environmental constraints and sustainability concerns, which we term environmental pollution. The quality of the environment, regulatory policies, and green innovations underlie economic performance and long-term sustainable development. The objective of this paper is to generate a more holistic theoretical structure that connects the dots between traditional growth theories and eco-friendly development, providing clearer visions into the ways societies can follow harmonious and sustainable development. The contribution of this research paper not only highlights the need for a more nuanced understanding of the relationship between economic growth and environmental sustainability but also raises important questions about the role of environmental pollution in shaping this relationship.

II. THEORETICAL FRAMEWORK OF ECONOMIC GROWTH THEORIES

The theory of economic growth provides a theoretical framework to detect and understand the growth of economic will be made in the economy. Growth theory is a means of understanding the factors that encourage growth within a nation via providing models, mechanisms, clarifications and a predictive framework. Several theoretical and empirical studies attempted to identify the factors that can improve economic growth and performance so as to provide recommendations for policymakers in order to fill the gap between developed and developing nations, and to generate sustainable development. Thus, this section is focused on two main growth theories, namely the exogenous growth theory and the endogenous growth theory. These narrowly investigate the recent developments in economic growth theories, and investigate the vital main drivers of economic growth in the short-run and in the long-run, and how they work.

- *Exogenous Growth Theory*

The exogenous growth model, generally known as the neo-classical growth theory or Solow-Swan economic growth model, was founded by economists (Solow, 1956). This model considers that growth is produced through a determinant of two factors of production such as the stock of capital and labour force. According to this model, an upsurge in the stock of capital will lead to increase economic growth assuming that the volume of labour and the technology level remain constant (Salih *et al*, 2020). Thus, growth rate is determined by the capital accumulation, which is determined by the rate of saving, rate of population growth and rate of capital depreciation (Yaqub 2024). Furthermore, Neo-classical model introduced the idea of convergence in their theory. They assumed that developing countries that have a lower initial level in stock of capital per worker tend to have greater revenues and greater growth rates of economy, which finally make them to catch up with the developed countries and converge with them in the long-term. Therefore, the rate of economic growth in less-developed states might be fast for a period, but would slow down when the gap with the developed nations diminished.

When the economy situation is away from its steady state level, the convergence rate relies positively on the rate of saving and negatively on the labour-force growth rate. However, since different countries in the world have different rates of saving and labour-force growth rates, they can be converging to different steady states (Yaqub 2024). The seminal papers of Solow (1956) shaped the basis for much of applied economic growth analysis within the neoclassical model.

The Two Equations Below Demonstrate the Role of Investment in Economic Growth (Neoclassical Growth Model).

The first equation shows a total production function viewing the nexus between outputs (**Y**) as a dependant variable, and capital input (**K**), labour input (**L**) and technology (**A**) as independent variables,: (model 6)

$$Y = AK^{\alpha}L^{1-\alpha} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Y = total output

A = efficiency with which factors of production are used (total factor productivity)

K = capital supply

L represents labour force,

The second equation, known as a capital accumulation equation, explores the nexus between investment in tangible assets (**I**), and capital stock (**K**):

$$\Delta Kt = It - dKt\text{-}l \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots [2]$$

In Equation (2) Δ represents a discrete change, **Kt** is a capital stock in current time (year) and **d** is depreciation in capital stock.

$$\Delta \ln Y = \beta k\ \Delta \ln K + \beta L \Delta \ln L + \Delta \ln A \ldots\ldots\ldots\ldots\ldots [3]$$

In equation 3 **βk** is capital's share of output, **βL** is labour's share of output, and the neoclassical model assumes that **βk+βL = 1**.

Equation [2] and [3] demonstrate the direct relationship between investment in tangible assets and economic growth. Especially, in this model capital accumulation contributes to economic growth in proportion to capital's share of state yield.

As we have seen in equations (1 and 3) that Solow does not explain in the model how technology variable is improved. According to this theory, the technology term, **A,** is assumed to be exogenous to the model and it is defined in equation [4]:

$$\frac{\dot{A}}{A} = g \Leftrightarrow A = A_0 e^{gt} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots [4]$$

In spite of its popularity, the neoclassical model brings about some troubling results. For instance, since capital accumulation is subject to diminishing returns, without technical progress. The main argument in the neo-classical growth theory is that the growth of production factors has no impact on output per capita in the long-term. Furthermore, technical progress *A* is assumed exogenous in this theory (The theory leaves unclear what determines technological progress) and technical improvement only determines the growth of output per capita**.** This is a main failing of the model because it does not clarify long-term economic growth and technological progress at all (Salih *et al*, 2020a). The long-term economic growth can be increased via technological improvement and if FDI positively affect technology, then it will be growth advancing. Another weakness of the exogenous model is related with the meaning of the term of capital accumulation. In recent times, much more has been debated on the meaning of capital itself. For instance, Mankiw et al. (1992) improved Solow's model and they argued that ignoring human capital accumulation in Solow's model would cause biased estimation of the coefficient on population and saving growth. In addition, they argued that cross-country differences in income-per-capita are a function of differences in the rate of population growth, the rate of saving, and the level of labour productivity (Yaqub 2025). In addition, this model has been criticized due to its arbitrary and overly simplistic nature and was challenged by the introduction of the endogenous model by Romer (1986) and Lucas (1988). The challenge for the new school was to discover the determinants and influence of technological progress. The endogenous model relaxes the restriction posed by diminishing returns to scale or at least proved that the marginal product of capital does not tend towards zero.

- *Endogenous Growth Theory*

In the mid-1980s, the exogenous model for economic growth became theoretically unacceptable in illumination the factors of long-term economic growth. So, endogenous economic growth theory was established by Romer in his 1986's article, which focused on two determinants of economic growth. Romer published an interesting paper about how technological progress takes place. He pointed out that technological progress, A(.), is a function of the stock of research and development (R&D). Romer (1994) considered that investment in knowledge will produce natural externalities. He mentioned: that the creation of new knowledge by one company or firm is considered to have a positive external impact on the production volume of other firms since knowledge cannot be completely patented or kept secret for long time. These new ideas lead to an increase in the stock of knowledge or ideas (A) in the economy.

Formally, Romer Proposes the Following Production Function:

$$Y = K^{\alpha}\left(AL_Y\right)^{1-\alpha} \quad (5)$$

It can be seen that this equation (Equation 5) is similar to the one in the Solow economic growth model with technology except for the variable L_Y, the part of labor that works in production. Romer used the variable L_A to denote the labor force working in research; the remaining labor force he considered as working in production.

For Simplicity, let us Consider the Fraction of the Population that Works in the Research Sector:

$s_R = \frac{L_A}{L}$ is constant.

$$L_Y + L_A = L \quad \text{and} \quad L_Y = (1 - s_R)L \quad \ldots\ldots\ldots\ldots\ldots (6)$$

As we have mentioned, Romer considers A as the stock of ideas or knowledge. Stock of knowledge is considered to be an endogenous factor in Romer's model. This means that Romer suggests a mechanism of how the stock of ideas improves over time. He suggests a production function for knowledge. He assumes

$$\dot{A} = \bar{\delta}L_A \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (7)$$

Where L_A is the number of people working in the research sector. If there are more people working in the research sector, then the stock of Ideas (knowledge) increases.

$\bar{\delta}$ is the productivity of one researcher? One more researcher raises the stock of knowledge by $\bar{\delta}$ units (Zia et al; 2024).

On the other hand, Lucas (1988) modelled h(.) is a function of the stock of human capital and he specified that he wanted to consider the external effects which contribute to higher productivity of all factors. Lucas (1988) assumes that human capital is another factor of production, not essentially different from physical capital, but only produced by labor via certain activities (principally education or on-the-job training).

The assumption of constant returns to scale becomes more reasonable whenever, as in our circumstance, capital is generally viewed to encompass both human and physical capital. Indeed, the parameter **h** in equation (8) below represents human capital (Yaqub 2025).

The production function may be given the following expression (Lucas model);

$$Y = AK^{a}(hL)^{1-a} \quad (8)$$

Where **Y** is output, **K** is the private-sector capital, and L stands for labor force, Parameter A reflects the constant.

Lucas's conceptualization of the procedure by means of which human capital is made up is the following:

$$\dot{h} = h(1-u) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(9)$$

Where **(1 –u)** is the amount of time allocated to human capital. The more human capital has accumulated, the more productive each single member will be. The equation below about the impact of human capital on productivity will be explained.

$$Y = AK^{a}(uhL)^{1-a}h^{*} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(10)$$

The number of workers L, is multiple by u which is the fraction of time spent working, which is multiple by h. Finally, there is the term h* in the equation, which is designed to denote externality (Ibid). (De Jager 2004) argued that growth rate of economic is derived from the stock of human capital and then from technological changes. The instrument of this model about human capital is that labour rises as a share of population. Subsequently, this growth is motivated by a labour augmenting technology multiplier; this means that this growth is stimulated endogenously via labour augmenting technological change.

The glass-ceiling among the neoclassical economic growth and endogenous growth theories is the technology function. While the former consider technological improvement to be exogenous, the latter expounds technological improvement as a form of investment spillovers coming from different causes, for instance: human capital, tangible capital, and research and development expenditures. More notably, though, both theories of economic growth define capital accumulation as crucial elements to encourage growth (. Romer (1986) and Lucas (1988) pointed out that FDI accelerates growth of economic through improving human capital, and R&D; whereas Grossman and Helpman (1991) have adjusted Romer’s (1986) endogenous model and assume that technological progress is the key engine of economic growth. In addition, they emphasize that an increase in competition and innovation will outcome in technological improvement and increase productivity and, therefore, promote growth of economic in long term. Therefore, in this theory the technological progress in the form of the generation of new ideas is a vital determinant in avoiding to diminishing returns to capital in the long-term.

However, the greatest limitation of this model of growth is that its invalid predictive ability in economic growth convergence to allow for the heterogeneity of countries and their different growth patterns. In general, developing countries suffer from lack the necessary background—in terms of liberalized markets, human capital, and level of infrastructure, social and economic stability, so as to be able to innovate and produce new discoveries. Consequently, they can get advantages from the diffusion of technology that originates elsewhere.

III. EXOGENOUS GROWTH THEORY WITH ENVIRONMENTAL SUSTAINABILITY

A. Adding Environmental Degradation

We introduce a negative externality (e.g., pollution) that is a function of output or production as our goal is to account environmental degradation. We can do this simply in the model by adding a pollution term P such that as we generate output the pollution increases. This term is the one that deteriorates the environmental quality or the welfare of society. We adjust the model to the following:

$$Y = AK^{\alpha}L^{1-\alpha} - \lambda Z(Y)$$

$\lambda Z(Y)$ is the per-unit effect of pollution on output, represents the elegance factor that determines how much pollution decreases the output.

$Z(Y)$ is a function of output i.e $Z(Y) = \Theta Y$ *where* Θ is a constant showing the relation between pollution and output.The modified output equations then become,

$$Y = AK^{\alpha}L^{1-\alpha} - \lambda Z(Y)$$

This equation implies that economic growth (raised) leads to increased pollution, and, in turn, has a negative contribution to overall output. At the same time, as pollution rises, so too does the net productive output of the economy (Ahmed 2023).

B. Resource Depletion (for Oil and Natural Gas) and Economic Growth,

A related (and more common) way to endogenise environmental concerns is to treat the depletion of natural resources as a constraint on growth. A common model for this is Hotelling’s Rule, which models the optimal extraction of exhaustible resources. In this case, economic output depends not just on a combination of capital and labor but also on a stock of natural resources. The model could look like:

$$Y = AK^{\alpha}L^{1-\alpha}R^{1-a}$$

R is the stock of natural resources (oil, forests or minerals)

Assuming, as we would to think, that R gets depleted over time through production, we can model resource extraction as a negative function of R, e.g.:

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

$\dot{R}$ is rate of change in stock of resources.

P is the rate at which resources are being used (resource depletion).

In such scenarios, economic growth needs to be mediated by the depletion of natural resources to avoid an eventual constraint to output growth. This economy, if resource constrained, will face diminishing return to R and therefore cannot result in continued economic growth in the long run without switching to sustainable practices or renewing resources (Muhammad et al; 2024).

IV. ENDOGENOUS GROWTH MODEL WITH POLLUTION

In an Endogenous Growth Model with Pollution, if pollution decreases human capital accumulation, then that would reduce innovation and technological progress, thus, decreasing long-run economic growth.

A. Key Equations:

- *Production Function:*

$$Y_t = AK_t^a H_t^b L_t^{1-a-b} p_t^{-\theta}$$

(Pollution negatively impacts output.) Pollution dampens human capital accumulation, thus hampering innovations and technologies.

V. GREEN GDP

- *Pollution-Adjusted GDP — A Green GDP Model*

One such measure is an alternative suggesting that environmental issues be included with economic growth is Green GDP. Green GDP is a metric which, although similar to traditional GDP as a measure of economic output and development, considers the environmental costs of that growth, including pollution, resource depletion and loss of biodiversity. It can be expressed as:

$$Y = AK^{\alpha}L^{1-\alpha} - \lambda Z(Y) - \Psi R$$

Green GDP = $Y = AK^{\alpha}L^{1-\alpha} - \lambda Z(Y) - \Psi R$

ΨR is the cost of depletion natural resources.

$\lambda Z(Y)$ is the environmental damage from pollution.

By taking into account depreciation of the environment, green GDP provides a more accurate evaluation of economic performance.

Summary of the Model with Environmental Issues

- *Basic Economic Growth Equation:*

$$Y = AK^{\alpha}L^{1-\alpha}$$

- *Including Pollution:*

$$Y = AK^{\alpha}L^{1-\alpha} - \lambda Z(Y)$$

- *Here, Pollution Lowers the net Output by a Factor of $\lambda Z(Y)$.*

- *Including Resource Depletion:*

$$Y = AK^{\alpha}L^{1-\alpha} R^{1-a}$$

- *Draining Stock of R is limited by Resource Depletion, which Curtails Growth in the Long Run.*

VI. CONCLUSION

It is a testament to a major evolution in our understanding of long-term economic sustainability—the incorporation of environmental factors into economic growth theories. Traditional models (Solow 1956) of exogenous economic growth cite technological progress (exogenous) and capital accumulation as external determinants, while technologically endogenous growth models attribute the economic growth of 'developing' countries to human capital, (Romer 1986) and innovation (Lucas 1988) capital as internal drivers, failing to account for the environmental constraints external to this dynamic that inform the course of economic development (Abdlaziz et al; 2022).

Generations of new research extended the time series and elucidated counterintuitive statistical relationships between economic growth and environmental factors, leading to climate change being combined into economic modeling (Nordhaus, 1991, 1994; Salih *et al*, 2019a), for example through the Integrated Assessment Model (IAM), or the introduction of the Environmental Kuznets Curve (EKC) (Grossman and Krueger, 1995), which mapped this relationship through an inverted U-shape, indicating a time lag in the returns of environmental degradation. Additionally, Acemoglu et al. (2012) examined directed technological change and its encouragement of green innovation. Such contributions highlight the importance of incorporating environmental concerns in economic growth models to promote sustainability.

This research paper proposes the theoretical appropriation of environmental pollution to the existing strands of exogenous and endogenous growth models for accommodating ecological sustainability. This paper enriches the understanding of long-term economic growth by accounting for environmental policies, clean energy innovation and resource management. The improved idioms provide useful indications for decision-makers, highlighting the need to develop economic policies that reconcile economic development to surplus heat dissipation vendible.

More empirical applications of this combined context in the future should examine how different economies respond to environmental constraints and technological transitions. Contributing to the broader conversation on the relationship between economic growth and sustainability, this paper furthers the dialogue around promoting resilient and sustainable patterns of economic progress.

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