Department of Economics

Course: Economic Growth and Sustainable Development

Robert Hart

Research paper

Analyzing the relationship between plastic pollution and economic growth

Submitted by:

Ronja Kwasniok

Kolfatsvägen 10

75647 Uppsala

rokw0002@stud.slu.se

Contents

1 Introduction

Since the 1950s, global plastic production has surged from two million to over 450 million tons annually (Ritchie et al. 2023). While plastic is an extremely useful material and has become indispensable to many sectors, its production heavily relies on non-renewable fossil hydrocarbons, and the industry is projected to account for 20% of global oil by 2050 (Geyer et al. 2017; World Economic Forum 2016). Second, most common plastics are non-biodegradable and turn into environmental pollutants when mismanaged[1] (Geyer et al. 2017; Ritchie et al. 2023). The escalating production, shift to single-use plastics, and inadequate waste management contribute to a global "tragedy of the commons" in our oceans and waterways (Barnes 2019). With one to two million tons of plastic entering oceans annually, plastic pollution[2] consitutes a global externality (Ritchie et al. 2023; Barnes 2019).

Some pollutants seem to follow an inverted U-shaped pathway with increasing income, commonly referred to as the Environmental Kuznet's Curve (EKC) (Hart 2021; Grossman and Krueger 1995). This raises the question as to how plastic pollution will develop in the future. Will it continue to increase, plateau, or decline in the long-term? This paper attempts to answer this question in two parts: First, historical data on mismanaged plastic waste and GDP per capita is used to investigate global and country-specific trends in plastic pollution. This is accompanied by a discussion of the potential of the EKC to fully explain the relationship between economic growth and plastic pollution. Second, treating plastic pollution as a by-product of natural resource use, the model with alternative and substitutable inputs by Hart (2021) is used to roughly predict its future development.

2 Plastic pollution and economic growth

The Environmental Kuznet's Curve (EKC) generally implies that pollution initially rises with income at low levels, then decreases as income grows (Grossman and Krueger 1995). This theory suggests that in early economic development, people prioritize income over environmental quality due to financial constraints, leading to weaker regulation and increased pollution. As income rises, willingness to pay for environmental quality increases, and regulations become more effective, reducing pollution (Dasgupta et al. 2002). While empirical studies support this relationship for issues like air pollution, especially within one country

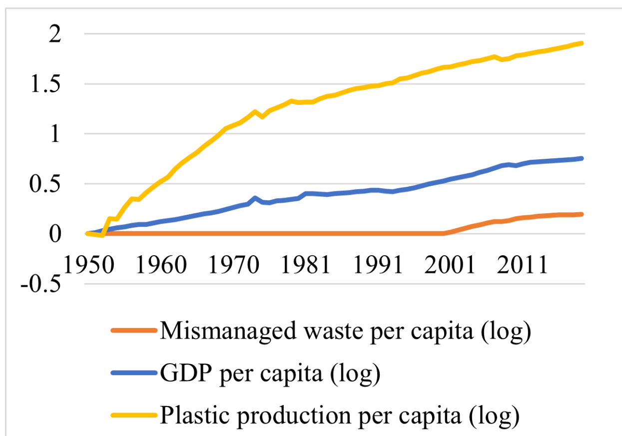
[1] Mismanagement of plastic waste implies that it is incinerated, dumped in sealed landfills, or not recycled.

[2] Throughout this paper, plastic pollution is used synonymously with mismanaged plastic waste.

over time, the pattern becomes less clear when comparing trends across multiple countries (Hart 2021).

Analyzing the link between plastic pollution and economic growth is challenging due to limited empirical studies[3] and scarce historical data on mismanaged plastic waste (Barnes 2019). While Ritchie et al. (2023) offer a comprehensive overview, their datasets often cover only recent years. This analysis uses data on plastic from OECD (2023) and Geyer et al. (2017) and OECD (2022) processed by Our World in Data, along with GDP and population data from the Maddison Project Database 2020 (Bolt and van Zanden 2020). Figure 1 depicts the evolution of plastic production and mismanaged plastic waste compared to GDP per capita over time.

Figure 1: Plastic pollution, GDP and plastic production on a global scale



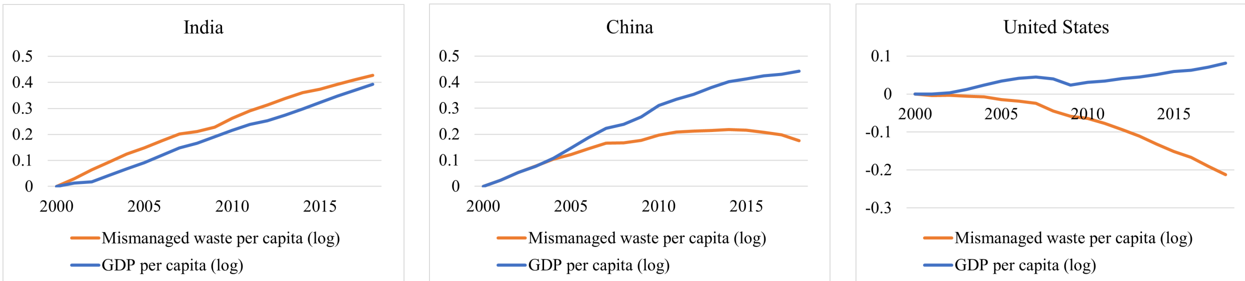
Source: Own illustration and calculations based on data by Bolt and van Zanden (2020), OECD (2023), Geyer et al. (2017) and OECD (2022) processed by Our World in Data. Logarithmic scale normalised to zero in 1950. Data on plastic waste only available from 2000 to 2019. Missing value for 1974 in data on plastics production. GDP and population data available from 1950 to 2018.

Globally, plastic production per capita outpaced GDP per capita growth significantly from 1950 to 1970, continuing in parallel but at a higher level until 2019. Mismanaged plastic waste per capita has steadily risen since 2000, the first year with available data, but appears to stabilize in the years preceding 2019. Thus, at the global scale, it is difficult to determine a clear EKC pattern for the trend in plastic pollution and economic growth. It remains uncertain whether plastic pollution will decrease after 2019, or if mismanaged waste per capita will continue to increase slowly or remain constant. This motivates a closer look at country-specific trends, with a focus on the United States, China, and India as representatives

[3]To my knowledge, only Barnes (2019) and Kocakaya (2023) have so far modelled the relationship between plastic waste and economic development.

of high-income, upper-middle-income, and lower-middle-income countries, respectively[4].

Figure 2: Plastic pollution and GDP per capita across countries



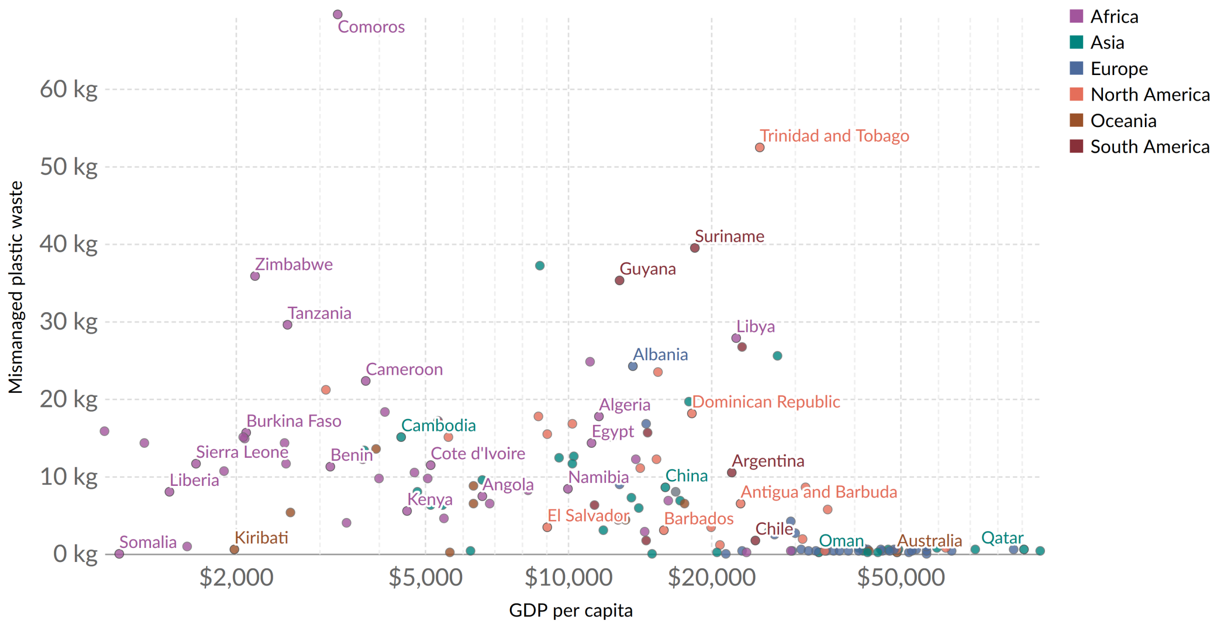
Source: Own illustration and calculations based on data by Bolt and van Zanden (2020), OECD (2023), Geyer et al. (2017) and OECD (2022) processed by Our World in Data. Logarithmic scale normalised to zero in 2000.

Figure 2 confirms that the relationship between plastic pollution and economic growth varies across countries with different income levels. In India, mismanaged waste and GDP per capita show parallel trends, with pollution increasing even at a higher level than income. In contrast, the United States exhibit divergent trends, with GDP rising and mismanaged waste declining over time. China's trends resemble the EKC the most, with an initial rise in plastic waste per capita until 2014, followed by a slow decline, while GDP per capita continues to grow slowly. India appears to be in the pre-turning point stage, experiencing increasing plastic pollution over time at comparatively lower levels of GDP per capita. The USA seem to be in the post-turning point stage, with less plastic pollution. This simple analysis suggests some support for the EKC regarding plastic pollution and economic growth at the country level, in line with the few empirical results supporting the EKC by Barnes (2019) and Kocakaya (2023). The following chart 3 by Our World in Data, plotting per capita plastic waste against per capita GDP across numerous countries for the single year 2019, also resembles an inverted U-shape.

Despite signs of an Environmental Kuznet's Curve (EKC) for plastic pollution, identifying a common turning point across countries based on a specific GDP per capita level or time remains challenging. Furthermore, doubts arise whether the EKC can fully explain the economic growth-plastic pollution relationship. EKC-like patterns in GDP and mismanaged plastic waste per capita may not solely result from higher incomes leading to stricter plastic waste regulations and reduced pollution. For example, the United States have no nationwide ban on single-use plastic, while India has banned single-use plastic since July 2022 and China

[4]Two reasons: 1. The plastic waste dataset covers only a few individual countries, with the remainder aggregated by regions. 2. Analyzing each country individually would exceed the scope of this paper.

Figure 3: Mismanaged plastic waste per capita vs. GDP per capita in 2019



Source: Illustration by Our World in Data (2023) based on multiple data sources.

plans to phase it out by 2025 (Wang et al. 2022; Waste360 2020; Seaside Sustainability 2021; Government of NCT of Delhi 2022). The US also did not adopt a national recycling strategy until 2021 (EPA 2021). Given that the US was the world's largest producer of plastic waste in 2016, the absence of plastic regulations raises skepticism about whether this simple analysis accurately reflects the extent of mismanaged waste in the US (Law et al. 2020). For example, estimates of plastic waste entering oceans often consider only domestic emissions (Ritchie 2022). The enormous amounts of plastic waste exported by higher-income countries to low-income countries with poor waste management, disguised as recycling, is often not accounted for (Karlsson et al. 2023)[5]. According to Statista (2020), the United States collected 0.15 to 0.99 million tons of plastic waste for recycling in 2016, exporting it to countries with inadequate waste management, increasing the risk of entering oceans. China was the primary destination until a complete ban on recycled plastic imports took effect in January 2018 (Statista 2023a). IIn 2022, the second-largest share of US plastic waste was exported to India, Malaysia, Vietnam, and Indonesia. The Chinese import ban in 2018 may contribute to the slightly steeper decline in mismanaged waste per capita from 2017 onwards (see Figure 2).

The discussion on trade in plastic waste suggests that the EKC cannot fully explain the

[5] Karlsson et al. (2023) suggest that previous estimates likely underestimated the actual volume of plastic waste trade, as the indicator in the UN Comtrade database only captures a subset of the total plastic waste.

relationship between economic growth and plastic pollution. The EKC does not capture the export of plastic waste from high-income to low-income countries, potentially leading to an overestimation of pollution reduction in wealthy nations although they are just shifting the problem elsewhere. Economic growth alone is insufficient to mitigate pollution from mismanaged plastic waste. To effectively curb pollution, stricter regulations on plastic waste trade, alongside improved waste management and recycling, are essential, even in wealthy countries. While reducing overall plastic production and usage seems challenging due to widespread reliance on plastics, investing in more sustainable, less polluting forms of plastic is crucial.

3 Modelling the future development of plastic pollution

Increased public awareness of environmental issues related to fossil-based plastics has fostered research into more sustainable alternatives (Statista 2023b). Bioplastics which are biodegradable and produced from renewable resources (bio-based) are the most sustainable choice. Examples include starch-based bioplastics from corn, cassava, potato, and wheat, as well as polylactic acid (PLA) and Polyhydroxyalkanoate (PHA) (Europe 2023; Maximize Market Research 2023). While they are not a complete solution to pollution, bio-based and biodegradable bioplastics break down over time, with a potentially lesser impact on marine life and ecosystems compared to fossil-based plastics (Van den Oever et al. 2017). Shifting from fossil-based to bioplastics can also reduce fossil fuel dependence and greenhouse gas emissions. Currently, bioplastics constitute only about 1% of global plastic production, but their production capacity is projected to increase from 2.2 million tons in 2022 to 5.3 million tons by 2027 (Statista 2023b).

The availability of alternative inputs for plastic production alongside fossil resources motivates to examine the long-term trend in plastic pollution using the alternative inputs model by Hart (2021) where pollution is treated as a by-product of natural resource use. As the biodegradable bioplastic industry is in its early stages, data on production, prices, and environmental impacts are scarce. Consequently, the model cannot be calibrated with actual data, and the analysis relies on scientific statements and projections.

Assuming several competitive firms producing a single aggregate final good the price of which is normalized to 1, the production function of the representative firm in equilibrium is Cobb-Douglas. L denotes labour, A_L labour productivity and R a resource-intensive intermediate input, herein plastic.

$$Y(t) = [A_L(t)L(t)]^{1-\alpha} R(t)^{\alpha} e^{-P(t)^{\phi}} \tag{1}$$

α is the share of plastic, P is the aggregate flow of plastic pollution and ϕ is greater than 1. A_L and L are exogenously given, and effective labour $A_L L$ grows at a constant rate g. Plastic production R is the sum of inputs from n different, but perfectly substitutable resource inputs j and k. The analysis assumes that the production of the intermediate plastic input includes both fossil-based and biodegradable resources D_j denotes the quantity of input j, so that

$$R = \sum_{j=1}^{n} D_j. \tag{2}$$

Using input quantity D_j results in emission of pollution $\psi_j D_j$ with $\psi \geq 0$. Aggregate pollution is modelled as

$$P = \sum_{j=1}^{n} \psi_j D_j \tag{3}$$

The production cost per unit of input is w_j.
Alternative inputs for plastic production include oil-based high-density Polyethylene (HDPE) as the dirtiest and cheapest option. Corn grain-based PLA is the cheapest among biodegradable inputs but less clean than sugar- or plant-oil based PHA, which is the most expensive but currently considered the cleanest bioplastic input (Naser et al. 2021). However, none of these inputs are perfectly clean. Oil is viewed as natural resource competitively extracted from a large homogeneous stock, while corn grain and sugar, although not strictly raw natural resources, are assumed to come from large homogeneous stocks for simplicity.
Aggregate production net of extraction cost is denoted as Z

$$Z = (A_L L)^{1-\alpha} \left(\sum_{j=1}^{n} D_j \right)^{\alpha} e^{-(\sum_{j=1}^{n} \psi_j D_j)^{\phi}} - \sum_{j=1}^{n} w_j D_j \tag{4}$$

To solve the model from a social planner's perspective, we initially consider two alternative inputs: oil-based HDPE (D_1) and corn grain-based PLA (D_2). The planner maximizes Z by choosing the optimal combination of D_1 and D_2. Taking the first-order conditions on equation 4 in D_1 and D_2, yields

$$\begin{aligned} FOC \quad D_1 : \alpha Y/(D_1 + D_2) &= w_1 + \phi(\psi_1 D_1 + \psi_2 D_2)^{\phi-1}\psi_1 Y \\ FOC \quad D_2 : \alpha Y/(D_1 + D_2) &= w_2 + \phi(\psi_1 D_1 + \psi_2 D_2)^{\phi-1}\psi_2 Y \end{aligned} \tag{5}$$

In both equations, the left-hand side represents the marginal benefits of producing an additional unit of intermediate good R (plastic) using input j and the right-hand side indicates the marginal costs. Marginal benefits are consistent, whether oil or corn grain is used to produce plastic, but marginal costs differ. The costs are the sum of the input costs for both resources w_j and the pollution damage costs $\phi P^{\phi-1}\psi_j Y$. For plastic, pollution damage costs occur as emissions from the production process and environmental harm resulting from littered plastic waste.

PLA currently holds the largest market share among bioplastics and comes closest to conventional plastics in terms of manufacturing costs (Wellenreuther et al. 2022). The average price of corn-grain-based PLA is estimated at approximately 1.374 USD/kg, while high-density Polyethylene (PE), derived from petroleum, has an average price of 1.106 USD/kg in 2022 (Wellenreuther et al. 2022; Statista 2023c).
The cost to produce the cleaner input D_2 is slightly higher than the one of the dirtier input D_1. So, $w_1 < w_2$ and $\psi_1 > \psi_2$. According to theory (Proposition 2), as Y increases, damages from plastic pollution become more important, leading to pollution abatement within input D_1 and reducing the difference between the social costs of D_1 and D_2. The transition to the cleaner input D_2 starts when social costs are equal. Due to limited data on bioplastics and their production cost evolution, it's uncertain if this model prediction aligns with reality. While some scenarios suggest stable prices for corn-grain-based PLA until 2030 (Wellenreuther et al. 2022), the great growth potential of PLA may lead to future cost reductions. In contrast, costs for HDPE, affected by global oil prices, could increase if oil becomes scarcer or prices rise due to carbon pricing (Statista 2023c). If social costs converge, the plastic industry may transition to corn-based PLA. However, corn-based PLA is associated with environmental issues: It needs to be recycled in special composting facilities at high temperatures and, if discarded in landfills, biodegrades very slowly during which with methane is released, which has a larger greenhouse effect than CO_2 (Swiftpak 2023). Thus, a shift from PLA to HDPE is is unlikely to result in zero plastic pollution.
PHA plastic, derived from plant oils and sugar, offers a higher potential to reduce pollution compared to PLA. PHA is more biodegradable and biocompatible than PLA, being both

compostable and biodegradable, even in marine environments (Sehgal and Gupta 2020). Additionally, PHAs are non-toxic and can significantly reduce fossil energy use and greenhouse gas emissions when replacing petroleum-based polymers. However, PHA is currently much more expensive than PLA and HDPE, estimated at an average price of 8 USD/kg in 2018 (Chavez et al. 2022). As PHA production is in its early stages, it may take a while to become competitive. However, the PHA market has significant growth potential and is projected to increase from 93 million USD in 2023 to 195 million USD by 2028, leading production costs to decline in the coming decades Markets and Markets (2023). Costs could also be reduced by using food and agricultural waste instead of pure sugar (Rajendran and Han 2022).

Extending the model to multiple inputs suggests that the shift to corn-based PLA might be followed by another transition to sugar- or plant-oil-based PHA when social costs become equal, leading to a more substantial decline in plastic pollution. However, achieving near-zero plastic pollution is unlikely to happen in the next decades and simultaneously across the globe, as financial resources for technological research and PHA production vary greatly across countries.

4 Conclusion

This paper explores the future of plastic pollution and whether its trend can be explained by the Environmental Kuznet's Curve (EKC). The basic data analysis in section 2 generally supports the EKC but highlights that economic growth alone doesn't fully explain lower plastic pollution in wealthier countries. Relying solely on the EKC and neglecting factors like plastic waste trade may overstate reductions by high-income countries. A better approach to predict the future trend of plastic pollution may be to treat it as a by-product of natural resource use. Section 3 presents such a model with alternative resource inputs based on Hart (2021). It discusses biodegradable bioplastics as sustainable alternatives and roughly analyses how the plastic industry could shift from oil-based PE to corn-based PLA and eventually to PHA, the cleanest but costliest bioplastic, reducing pollution after each transition. However, due to the lack of data on bioplastics, the modelling exercise is only based on rough estimates from existing literature. Also the data analysis in section 2 is rather simplistic and limited due to constraints in data on plastic pollution.

Future research should employ better data for a more comprehensive empirical analysis to discern the true relationship between economic growth and plastic pollution and to improve predictions of future trends.

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