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Assessing Ecological Footprint Dynamics in India: A Jevons' Paradox Perspective

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Abstract: *This paper attempts to revisit Jevons' Paradox for the Indian economy by examining whether long-run improvements in environmental efficiency have translated into reductions in absolute environmental pressure. Using ecological footprint as a comprehensive measure of environmental impact, the study analyses three complementary indicators- total ecological footprint, ecological footprint per capita, and ecological footprint intensity- over the period 1961-2022. A phase-wise analytical framework is adopted to align ecological footprint dynamics with major policy and growth regimes in India's development trajectory. The empirical analysis relies on trend assessment and compound annual growth rates to evaluate the interaction between efficiency gains, economic scale, and consumption patterns. The results reveal a persistent divergence between declining ecological footprint intensity and rising total and per capita ecological footprints across all phases. This pattern becomes increasingly pronounced during periods of rapid economic growth, providing robust descriptive evidence consistent with Jevons' Paradox. The findings highlight the limitations of efficiency-centric environmental strategies and emphasizes the need for policies that explicitly address consumption dynamics and the scale of economic activity in rapidly growing economies.*

Introduction

Improving environmental efficiency has long been viewed as a central strategy for reconciling economic growth with environmental sustainability. Advances in technology, energy efficiency, and resource productivity are often expected to reduce environmental pressure by lowering resource use per unit of output. However, the long-standing insight associated with Jevons' Paradox challenges this expectation, suggesting that efficiency improvements may ultimately lead to higher overall resource consumption if they stimulate economic expansion and increased demand (Jevons, 1865).

In recent decades, this paradox has gained renewed attention in the context of global environmental challenges, particularly in rapidly growing economies. While efficiency gains are widely documented, absolute reductions in environmental pressure remain elusive. This raises a critical question: do efficiency improvements alone suffice to curb environmental degradation, or are they systematically offset by scale and consumption effects?

India provides a particularly compelling context for examining Jevons' Paradox and the long-run relationship between efficiency improvements and environmental pressure. As one of the world's largest and fastest-growing emerging economies, India has experienced profound structural transformation over the past six decades, characterised by rapid population growth, sustained economic expansion, and increasing integration into global markets. At the same time, India remains constrained by ecological limits, making the tension between development objectives and environmental sustainability especially salient. From a theoretical perspective, Jevons' Paradox is most likely to manifest in economies undergoing rapid growth, where efficiency gains can significantly reduce production costs and stimulate expansion in both output and consumption. India's development trajectory exhibits precisely these characteristics.

Most empirical studies on the growth–environment relationship rely on carbon emissions and econometric tests of the Environmental Kuznets Curve (EKC). While informative, such approaches often focus on intensity measures and may obscure changes in absolute environmental pressure. This paper adopts an alternative perspective by using ecological footprint, a comprehensive indicator that captures the aggregate demand placed on ecological systems, including land use, energy consumption, and resource appropriation (Wackernagel and Rees, 1996).

The objective of this study is to revisit Jevons' Paradox in India by jointly analysing total ecological footprint, ecological footprint per capita, and ecological footprint intensity over a long historical period. By adopting a phase-wise, diagnostic approach, the paper seeks to provide clear and policy-relevant evidence on whether efficiency-led growth has translated into reductions in absolute environmental pressure.

Literature Review

Jevons' Paradox and the Rebound Effect

The Jevons Paradox, first articulated by William Stanley Jevons in *The Coal Question* (1865), challenges the conventional assumption that improvements in resource-use efficiency necessarily leads to reductions in aggregate resource consumption. Jevons observed that technological advances, most notably James Watt's improvements to the steam engine, substantially increased the efficiency of coal use in nineteenth-century Britain, yet coincided with a dramatic expansion of national coal consumption. Rather than conserving coal, efficiency gains reduced its effective cost, expanded the range of profitable applications, and accelerated industrial growth, thereby increasing total resource demand (Jevons, 1865).

This insight has since been formalised in modern resource and energy economics through the concept of the rebound effect which captures the behavioural and systemic responses to efficiency improvements. Rebound effects operate through multiple channels. Direct rebound effects arise when efficiency improvements lower the effective price of energy services, inducing greater use of those services. Indirect rebound effects occur when cost savings from efficiency improvements are reallocated to other forms of consumption or production that themselves require additional resource inputs. At the macroeconomic level, economy-wide rebound effects emerge as efficiency-driven cost reductions stimulate economic expansion, structural change, and increased aggregate demand (Greening et al., 2000; Sorrell, 2009).

When the combined magnitude of these effects fully offsets the potential resource savings from efficiency improvements, rebound effects approach 100 per cent. In cases where rebound effects exceed 100 per cent- a phenomenon termed "backfire"- efficiency gains result in higher total resource consumption than would have occurred in the absence of technological improvement (Alcott, 2005; Polimeni et al., 2008). This possibility fundamentally challenges techno-optimistic narratives in environmental policy that treat efficiency improvements as a sufficient condition for environmental sustainability.

The relevance of Jevons' Paradox extends directly to the Environmental Kuznets Curve (EKC) hypothesis, which posits that environmental degradation initially increases with income but eventually declines beyond a certain level of economic development. Rebound dynamics provide a compelling explanation for why technological modernization and efficiency gains may fail to produce the environmental improvements anticipated in the declining phase of the EKC. In rapidly industrializing and high-growth economies, efficiency-induced reductions in environmental intensity may be systematically outweighed by scale and consumption effects, resulting in continued growth in absolute environmental

pressure (Stern, 2004; York, Rosa, & Dietz, 2003). As such, Jevons' Paradox offers a critical theoretical lens for understanding why improvements in environmental efficiency do not automatically translate into reductions in total ecological impact.

Ecological Footprint as a Measure of Environmental Pressure

Ecological footprint provides a broad measure of human demand on ecological systems by estimating the biologically productive land and water area required to sustain consumption and absorb waste (Wackernagel and Rees, 1996). Unlike single-pollutant indicators such as CO_2 emissions, ecological footprint captures multiple dimensions of environmental pressure, making it particularly suitable for long-run sustainability analysis.

Several studies have used ecological footprint to examine the relationship between economic growth, consumption, and environmental pressure (York, Rosa, and Dietz, 2003; Dietz, Rosa, and York, 2007). These studies emphasize the importance of analyzing total, per capita, and intensity measures jointly to disentangle scale, affluence, and efficiency effects.

Evidence from Developing and Emerging Economies

Empirical evidence from developing economies suggests that efficiency improvements often coexist with rising absolute environmental pressure, particularly during periods of rapid growth (Stern, 2004; Wiedmann et al., 2015). In the Indian context, existing studies have largely focused on emissions-based indicators and econometric testing of the EKC hypothesis. Relatively few studies have examined long-run ecological footprint dynamics using a diagnostic framework grounded in Jevons' Paradox.

This paper contributes to the literature by providing a long-run, ecological footprint-based assessment of rebound dynamics in India, explicitly distinguishing between efficiency improvements and absolute environmental outcomes.

Data and Methodology

Data Sources and Variables

The analysis uses annual data for India covering the period 1961–2022. Ecological footprint data is obtained from the Global Footprint Network's National Footprint and Biocapacity Accounts, which provide a comprehensive measure of human demand on ecological resources expressed in global hectares (gha). Economic data, including real GDP (constant 2010 U.S. dollars) and population figures, are sourced from World Bank national accounts data, and OECD National Accounts data files.

As mentioned before, three complementary ecological footprint indicators are employed to capture different dimensions of environmental pressure:

- *Total Ecological Footprint (EF),* measured in global hectares, representing absolute environmental pressure.
- *Ecological Footprint per Capita (EFpc),* measured in global hectares per person, capturing average consumption-related environmental pressure.
- *Ecological Footprint Intensity (EFint),* defined as the ratio of total ecological footprint to real GDP, representing ecological pressure per unit of economic output and serving as a proxy for environmental efficiency.

Using these three indicators jointly allows the analysis to distinguish between scale effects, consumption effects, and efficiency effects, which is central to assessing Jevons' Paradox.

Methodology

The empirical analysis proceeds in three sequential steps. Firstly, the long-run trends in total ecological footprint, ecological footprint per capita, and ecological footprint intensity are examined using **graphical analysis**. This provides an initial assessment of whether improvements in efficiency have been accompanied by reductions in absolute environmental pressure.

Secondly, to account for structural changes in India's development trajectory, the sample period is divided into four distinct phases based on major policy and growth regimes:

- *1961–1990 (pre-liberalisation),*
- *1991–2003 (economic reforms and early globalisation)*
- *2004–2019 (high-growth and consumption expansion)*

- *2020–2022 (pandemic shock and rebound).*

This **phase-wise analysis** allows for a more meaningful interpretation of ecological footprint dynamics by aligning environmental outcomes with underlying economic conditions, rather than relying solely on statistical break tests.

Thirdly, for each phase, **compound annual growth rates (CAGR)** are computed for total ecological footprint, ecological footprint per capita, and ecological footprint intensity. CAGR is used to smooth short-term fluctuations and to enable direct comparison across phases of unequal length. The CAGR for a given variable Xover a phase of length $n$years is calculated as:

$$\text{CAGR} = \left(\frac{X_{\text{end}}}{X_{\text{start}}}\right)^{\frac{1}{n}} - 1$$

This phase-wise growth accounting provides a quantitative basis for evaluating whether efficiency improvements are outweighed by scale and consumption effects.

Empirical Results

This section presents the empirical findings on the evolution of ecological footprint indicators in India and assesses whether improvements in environmental efficiency have translated into reductions in absolute environmental pressure. The analysis proceeds in a stepwise manner, beginning with long-run trends, followed by phase-wise growth analysis and a formal diagnostic of Jevons' Paradox.

- **Long-Run Trends in Ecological Footprint Indicators**

An examination of India's ecological footprint indicators over the period 1961–2022 reveals a clear divergence between improvements in environmental efficiency and trends in absolute environmental pressure. As shown in Figure 1, India's total ecological footprint increases from approximately 254 million global hectares (gha) in 1961 to nearly 1.47 billion gha by 2022, representing an almost sixfold increase over the study period. The upward trend is gradual in the earlier decades but becomes noticeably steeper after the early 2000s, coinciding with accelerated economic growth and expansion in consumption. Although a temporary decline is observed in 2020 when total ecological footprint falls to around 1.35 billion gha, this reduction is short-lived, with the footprint rebounding sharply in subsequent years. The long-run trajectory therefore indicates that India's absolute demand on ecological resources has continued to rise despite periodic slowdowns.

Figure 2 provides further insight by examining ecological footprint on a per capita basis. Ecological footprint per capita increases from around 0.56 gha per person in 1961 to approximately 1.04 gha per person in 2022, nearly doubling over the period. The horizontal reference line marking the 1961 level highlights the extent of this long-term increase. While per capita footprint remains relatively stable during the early decades, growth accelerates after the mid-2000s, reflecting rising incomes, urbanization, and shifts in consumption behavior. Even during the pandemic-induced contraction in 2020, per capita footprint declines only modestly, indicating that consumption-related environmental pressure remains structurally higher than in earlier periods. This trend suggests that rising per capita resource demand has been an important contributor to the increase in total ecological footprint, alongside population growth.

In contrast to the upward trends in total and per capita ecological footprint, Figure 3 shows a pronounced decline in ecological footprint intensity, defined as ecological footprint per unit of real GDP (2010 USD). Ecological footprint intensity falls from about 0.00179 gha per dollar of GDP in 1961 to roughly 0.00049 gha per dollar by 2022, implying a reduction of more than 70 per cent over the study period. This sustained decline indicates substantial improvements in environmental efficiency, as progressively less ecological pressure is generated per unit of economic output. Such improvements are consistent with technological progress, structural change, and gradual shifts toward more efficient production processes.

When these three indicators are considered jointly, a clear divergence emerges between environmental efficiency and environmental outcomes. Despite a sharp and sustained decline in ecological footprint intensity, total ecological footprint increases by more than 1.2 billion gha, and per capita ecological footprint nearly doubles over the same period. This divergence indicates that efficiency gains have been outweighed by scale effects associated with expanding economic activity and rising consumption. In other words, reductions in ecological pressure per unit of output have not translated into reductions in overall ecological demand.

This pattern is consistent with the logic of **Jevons' Paradox**, which suggests that efficiency improvements, while reducing resource use per unit, can lead to higher total resource consumption when they facilitate economic expansion and increased demand. In the Indian context, the figures indicate that efficiency-led growth has coexisted with rising absolute environmental pressure, highlighting the limitations of relying solely on efficiency-oriented strategies to achieve environmental sustainability.

Overall, the evidence from Figures 1 to 3 suggests that while improvements in environmental efficiency are necessary, they are insufficient on their own to curb ecological pressure in a rapidly growing economy. Addressing absolute environmental impacts will require complementary policies that engage with consumption patterns, demand growth, and the scale of economic activity.

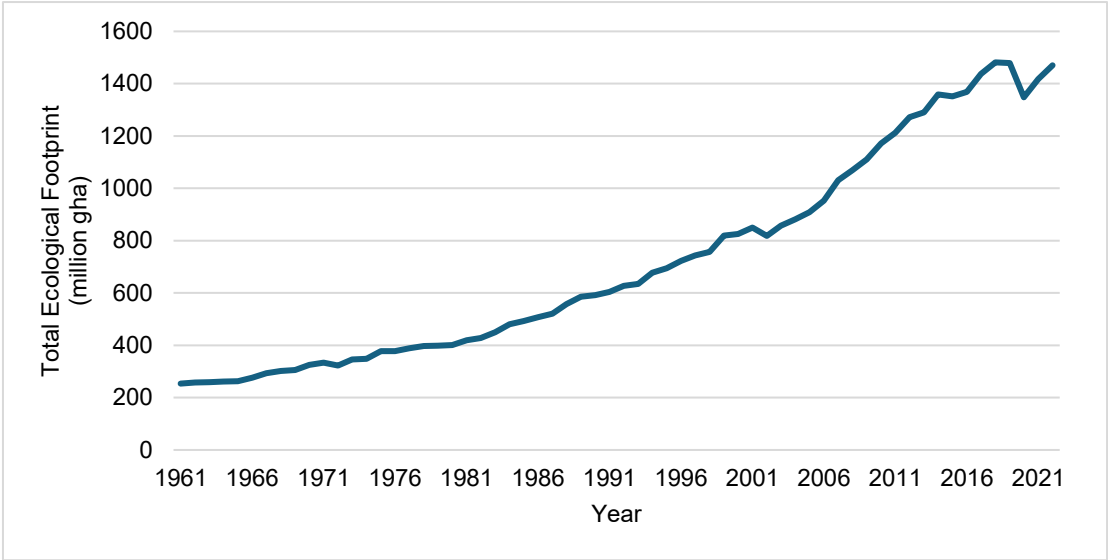

Figure 1: Total Ecological Footprint in India (1961–2022)

Source: Author's calculations based on Global Footprint Network, *National Footprint and Biocapacity Accounts*, and World Bank World Development Indicators.

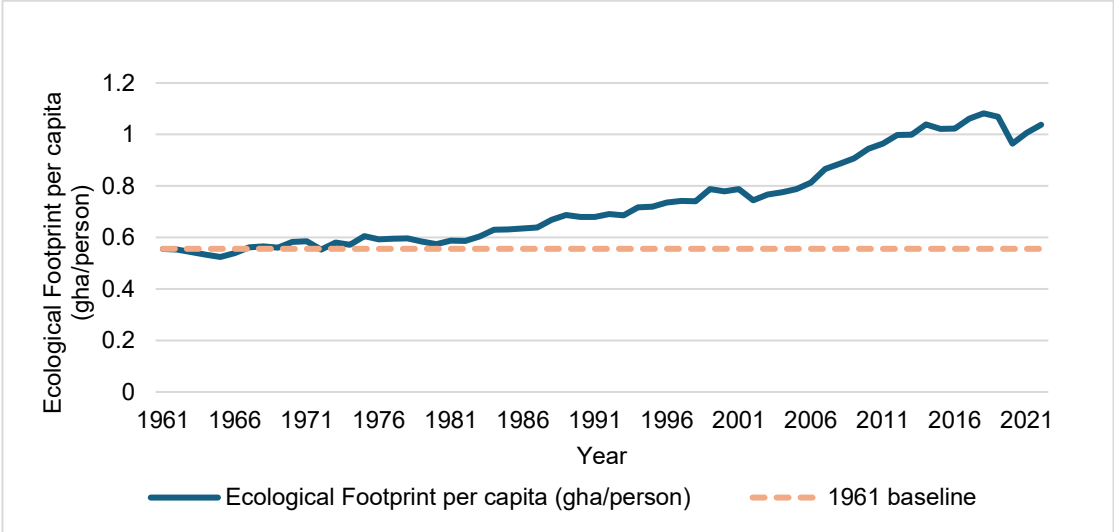

Figure 2: Ecological Footprint per Capita in India (1961–2022)

Source: Author's calculations based on Global Footprint Network, National Footprint and Biocapacity Accounts, and World Bank World Development Indicators.

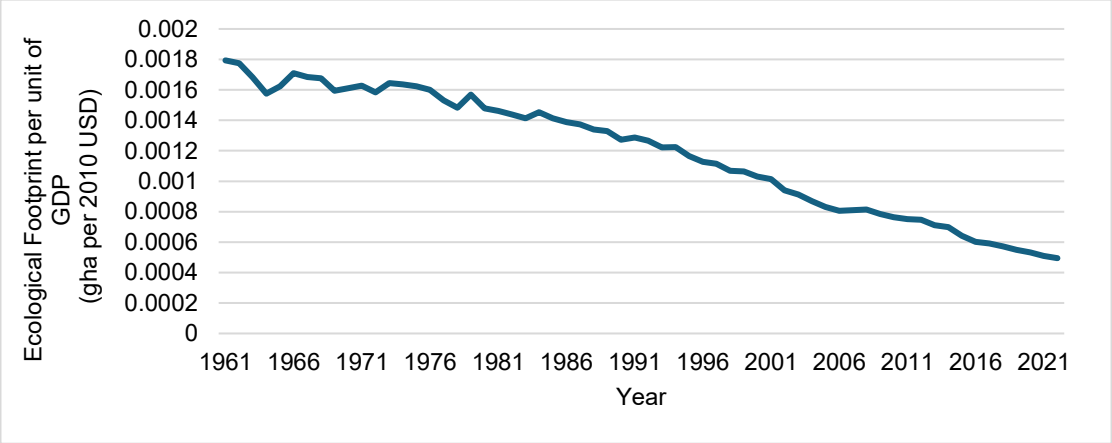

Figure 3: Ecological Footprint Intensity in India (1961–2022)

Source: Author's calculations based on Global Footprint Network, National Footprint and Biocapacity Accounts, and World Bank World Development Indicators.

- **Phase-wise Growth Dynamics of Ecological Footprint Indicators**

This section examines the evolution of ecological footprint dynamics across distinct development phases in India to assess whether improvements in environmental efficiency have translated into reductions in absolute environmental pressure. Using phase-wise compound annual growth rates (CAGR) of total ecological footprint, ecological footprint per capita, and ecological footprint intensity, the analysis provides a structured diagnostic of Jevons' Paradox over the period 1961–2022.

The phase-wise approach aligns ecological footprint trends with major policy and growth regimes in India's development trajectory, allowing for a meaningful interpretation of how scale, consumption, and efficiency effects interact over time.

- **Phase I: 1961–1990 — Pre-liberalization Period**

During the pre-liberalization period, India's total ecological footprint increased at an average annual rate of 2.97 per cent, indicating a steady rise in aggregate environmental pressure, as depicted in Table 1. Over the same period, ecological footprint per capita grew at a relatively modest rate of 0.70 per cent per year, suggesting that growth in environmental pressure was driven primarily by population expansion and gradual increases in economic activity rather than rapid growth in individual consumption. At the same time, ecological footprint intensity declined at an average rate of 1.18 per cent per year, reflecting modest improvements in environmental efficiency. These efficiency gains likely stemmed from incremental technological progress and structural changes within a largely regulated and inward-oriented economic framework. However, the magnitude of efficiency improvements was insufficient to offset the combined effects of demographic growth and expanding output. Taken together, the coexistence of declining ecological footprint intensity and rising total ecological footprint during this phase indicates that scale effects outweighed efficiency gains, resulting in a net increase in absolute environmental pressure.

- **Phase II: 1991–2003 — Economic Reforms and Early Globalisation**

The post-1991 reform phase marks a significant shift in the dynamics of ecological footprint growth. During this period, total ecological footprint continued to grow at an annual rate of 2.95 per cent, similar in magnitude to the earlier phase. However, the composition of this growth changed noticeably. Ecological footprint per capita increased at a faster rate of 1.01 per cent per year, reflecting rising incomes, increased trade openness, and changes in consumption patterns following economic liberalisation. Simultaneously, ecological footprint intensity declined sharply at an average rate of 2.82 per cent per year, more than twice the rate observed in the pre-liberalisation period. This indicates substantial improvements in environmental efficiency, likely driven by structural transformation, technological adoption, and market-oriented reforms. Despite these pronounced efficiency gains, both total and per capita ecological footprints continued to rise. The widening divergence between declining intensity and increasing aggregate pressure during this phase provides clear evidence of rebound effects, consistent with the logic of Jevons' Paradox.

- **Phase III: 2004–2019: High-Growth and Consumption Expansion**

The period from 2004 to 2019 represents India's high-growth phase and exhibits the strongest expansion in ecological pressure. As depicted in Table 1, the Total ecological footprint grew at an average annual rate of 3.51 per cent, while ecological footprint per capita increased at 2.16 per cent per year, more than double the rate observed during the reform phase. Over the same period, ecological footprint intensity declined at an average rate of 3.01 per cent per year, reflecting continued improvements in efficiency associated with technological progress and structural change. However, the pace of economic expansion and rising consumption clearly outweighed these efficiency gains. This phase shows the most pronounced divergence between environmental efficiency and environmental outcomes. The simultaneous acceleration of per capita ecological footprint growth and steep declines in intensity indicates that efficiency-led growth facilitated higher levels of consumption and scale, resulting in a substantial increase in absolute environmental pressure. Consequently, this phase provides the strongest empirical support for Jevons' Paradox in the Indian context.

- **Phase IV: 2020–2022: Pandemic Shock and Rebound**

The final phase captures the impact of the COVID-19 shock and the subsequent recovery. Although short in duration**,** this period is analytically important. As depicted in Table 1, the total ecological footprint increased at an annualized rate of 4.46 per cent, while ecological footprint per capita rose sharply at 3.69 per cent per year, reflecting a rapid rebound in environmental pressure following the initial contraction in 2020. During the same period, ecological footprint intensity continued to decline at an even faster rate of 3.57 per cent per year, indicating that efficiency improvements persisted despite economic disruption. The rapid recovery in both total and per capita ecological footprint underscores the structural nature of environmental pressure in India and highlights the limited capacity of efficiency gains alone to deliver sustained reductions in ecological demand.

Table 1: Phase-wise Compound Annual Growth Rates (CAGR) of Ecological Footprint Indicators in India

Phase	Period	Total Ecological Footprint (%)	Ecological Footprint per Capita (%)	Ecological Footprint Intensity (%)
Phase I	1961–1990	2.97	0.70	−1.18
Phase II	1991–2003	2.95	1.01	−2.82
Phase III	2004–2019	3.51	2.16	−3.01
Phase IV	2020–2022	4.46	3.69	−3.57

Notes:
1. Compound annual growth rates (CAGR) are calculated using start- and end-year values for each phase.
2. Total ecological footprint is measured in global hectares (gha).
3. Ecological footprint per capita is measured in gha per person.
4. Ecological footprint intensity is defined as total ecological footprint per unit of real GDP (2010 U.S. dollars); negative values indicate improvements in environmental efficiency.

Source: Author's calculations based on Global Footprint Network (*National Footprint and Biocapacity Accounts*) and World Bank World Development Indicators.

- **Jevons' Paradox Diagnostic**

To formally assess the presence of Jevons' Paradox, Table 2 summarises phase-wise growth rates of total ecological footprint, ecological footprint per capita, and ecological footprint intensity. Following the standard interpretation, Jevons' Paradox is considered present when efficiency improvements (declining intensity) coincide with rising absolute environmental pressure (increasing total ecological footprint).

Table 2: Phase-wise Jevons' Paradox Diagnostic for India

Phase	Period	Total EF CAGR (%)	EF per Capita CAGR (%)	EF Intensity CAGR (%)	Diagnostic Outcome
Phase I	1961–1990	2.97	0.70	−1.18	Jevons' Paradox (weak)
Phase II	1991–2003	2.95	1.01	−2.82	Jevons' Paradox (moderate)
Phase III	2004–2019	3.51	2.16	−3.01	Jevons' Paradox (strong)
Phase IV	2020–2022	4.46	3.69	−3.57	Jevons' Paradox (rebound phase)

Note: Negative values for ecological footprint intensity indicate improvements in environmental efficiency.

Source: Author's calculations based on Global Footprint Network (*National Footprint and Biocapacity Accounts*) and World Bank World Development Indicators.

- **Synthesis of Empirical Findings**

Across all four phases, ecological footprint intensity declines consistently, indicating sustained improvements in environmental efficiency. However, these efficiency gains are accompanied by positive growth in total ecological footprint in every phase, with the divergence between efficiency and scale effects becoming increasingly pronounced over time. The acceleration of per capita ecological footprint growth in the post-2000 period further reinforces the role of consumption dynamics in driving environmental pressure.

Taken together, the phase-wise evidence provides robust support for the presence of Jevons' Paradox in India. Efficiency-led growth has not translated into reductions in absolute environmental pressure; instead, it has coexisted with, and in some phases facilitated, rising ecological demand. These findings highlight the limitations of relying solely on efficiency improvements to achieve environmental sustainability in a rapidly growing emerging economy.

Policy Implications and Conclusion

Policy Implications

The phase-wise analysis of ecological footprint dynamics in India yields several important policy-relevant insights. The findings demonstrate that sustained improvements in environmental efficiency, captured by the continuous decline in ecological footprint intensity, have not translated into reductions in absolute environmental pressure. Instead, rising economic scale and increasing per capita consumption have consistently outweighed efficiency gains across all development phases. This pattern has become more pronounced in the post-2000 high-growth period, providing strong evidence consistent with Jevons' Paradox.

The first implication is that **efficiency-oriented policies, while necessary, are insufficient on their own** to achieve absolute reductions in ecological pressure. Policies focused on improving energy efficiency, technological upgrading, and resource productivity remain critical, but the results indicate that such measures tend to lower the ecological cost per unit of output without constraining overall demand. In a rapidly growing economy, these efficiency gains can coexist with, and even facilitate, higher levels of production and consumption, leading to rising aggregate environmental pressure.

Second, the acceleration of **ecological footprint per capita** in recent decades underscores the growing importance of **consumption-side dynamics**. Environmental policy frameworks in India have traditionally emphasised supply-side interventions, particularly in energy and industrial efficiency. The evidence presented here suggests a need to complement these measures with policies that address consumption patterns, urban lifestyles, and material demand. Instruments such as demand management, behavioural interventions, and pricing mechanisms that internalise ecological costs may play a more central role in mitigating rebound effects.

Third, the persistence of rebound dynamics across distinct policy regimes highlights the importance of integrating **scale considerations** into sustainability strategies. Absolute reductions in ecological pressure are unlikely to be achieved without explicit attention to the scale of economic activity and resource use. This does not imply a rejection of growth per se, but rather points to the need for policy frameworks that align growth objectives with ecological limits through structural transformation, circular economy approaches, and long-term resource planning.

Finally, the rapid rebound in ecological footprint following the COVID-19 shock illustrates the **structural nature of environmental pressure** in the Indian economy. Temporary declines in economic activity can produce short-lived reductions in ecological impact, but without structural changes in consumption and production systems, these reductions are quickly reversed. This reinforces the importance of designing sustainability policies that are resilient to economic cycles and not solely dependent on efficiency improvements.

Conclusion

This study revisits Jevons' Paradox in the Indian context using a comprehensive set of ecological footprint indicators over the period 1961–2022. By jointly analysing total ecological footprint, ecological footprint per capita, and ecological footprint intensity, the paper provides a nuanced assessment of how efficiency, consumption, and scale effects have interacted across different development phases.

The empirical findings reveal a consistent pattern across all phases: ecological footprint intensity declines steadily, indicating sustained improvements in environmental efficiency, while total and per capita ecological footprints continue to rise. Phase-wise growth analysis further shows that the divergence between efficiency gains and absolute environmental pressure has intensified over time, particularly during periods of rapid economic growth. These results provide robust descriptive evidence that efficiency-led growth has not resulted in absolute reductions in ecological pressure in India, lending strong support to the relevance of Jevons' Paradox.

By adopting a phase-wise, diagnostic approach rather than a heavily econometric framework, the study highlights the value of ecological footprint indicators in capturing long-run environmental outcomes that may be obscured by intensity-based measures alone. The findings underscore the limitations of relying exclusively on efficiency improvements as a pathway to sustainability and point to the need for policy strategies that engage simultaneously with efficiency, consumption, and scale.

Future research could extend this analysis by incorporating cross-country comparisons, sectoral decomposition of ecological footprint components, or formal econometric modelling of rebound effects. Nonetheless, the evidence presented here suggests that achieving meaningful reductions in environmental pressure in rapidly growing economies will require moving beyond efficiency-centric narratives toward a more comprehensive engagement with the drivers of ecological demand.

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