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Integrating Logistics into Global Production: A New Approach

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Abstract: *Background:* Logistics has become a key driver of global economic production. This study investigates the role of logistics in global economic production by presenting a novel theoretical framework that integrates logistics performance into traditional models as a determinant production factor. *Methods:* Using panel data from 85 countries between 2007 and 2022, the research measures logistics performance through the Logistics Performance Index (LPI). *Results:* The analysis reveals that logistics performance, specifically factors such as customs efficiency, infrastructure quality, and tracking and tracing of shipments, significantly enhances global economic output. On the other hand, negative elasticities were observed for shipment timeliness and the cost competitiveness of international shipments, suggesting that inefficiencies in these areas can hinder economic growth. *Conclusions:* The findings underscore the need for targeted public policies to improve logistics infrastructure and efficiency, particularly in customs and trade logistics, to increase global production. Additionally, the study highlights the potential for improving the logistics sector to support sustainable development and economic interdependence among countries. This research provides important insights for policymakers and managers, indicating that effective logistics management can drive substantial improvements in production efficiency and overall economic performance.

Keywords: global production; production function; logistics performance index; fixed effects model; random effects model

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1. Introduction

In the context of an increasingly globalized economy, the role of logistics has become critically important. Logistics encompasses the comprehensive process of planning, implementing, and controlling the movement of goods and services from their origin to their final consumption point. This includes key activities such as transportation, storage, inventory management, and distribution. Furthermore, logistics plays a critical role in international trade by enabling companies to access new markets and expand their operations [1]. According to the OECD report on international trade among member countries [2], the logistics sector accounts for approximately 10% of GDP on average in OECD countries, underscoring its economic significance. Projections indicate that these contributions will continue to grow in the coming years, highlighting the sector's expanding influence.

Advancements in logistics represent one of the most transformative social and economic developments of recent decades, frequently characterized as a revolutionary shift in production, storage, distribution, and transportation processes [3]. This revolution has redefined the efficiency and reach of supply chains, enabling more dynamic and responsive business models.

The crucial role of logistics in economic development is demonstrated by its significant impact on reducing costs, improving service delivery, and enhancing overall market efficiency [4]. Additionally, logistics improvements contribute to the smooth functioning of global supply chains, fostering greater economic interdependence and resilience [5,6].

Assessing the impact of logistics on global production growth is of great academic and practical interest. However, despite its critical importance in today's world, logistics has been insufficiently examined as a global production factor in the existing literature. This research addresses this gap by demonstrating that incorporating logistics into the global production function enhances empirical estimates compared to models [7,8] that exclude it. Furthermore, by decomposing logistics into its various components, the study provides a clearer understanding of its strengths and weaknesses, leading to more accurate economic interpretations.

2. Literature Review

Classical economists such as Adam Smith, Robert Malthus, David Ricardo, John Stuart Mill, and Karl Marx examined the reasons behind economic growth in some nations and stagnation in others. Their collective contributions often referred to as the "Magna Theories", laid the foundation for economic growth theory, emphasizing the central roles of labour, capital, and resources as key drivers of development.

Building on this foundation, Refs. [9,10] introduced the concept of a balanced growth path. Ref. [11] later shifted attention to the role of technological progress, although his model treated technological advancement as an exogenous factor outside the economic system.

The emergence of "endogenous growth theories", beginning with [12], brought human capital, innovation, and knowledge into focus as internal drivers of growth. Subsequent studies by [8,13,14] further emphasized human capital as a critical factor in economic production. These models demonstrated that investments in education, research, and technology could generate sustained increases in productivity. In particular, human capital was highlighted as a key determinant of economic performance, with empirical evidence showing that countries with stronger education systems and institutional frameworks tend to experience faster and more robust growth.

In addition to human capital and technological progress, the ability to generate and implement new ideas (institutional quality or cultural factors) has been considered in the literature as a contributor to long-term growth. However, these aspects are exogenous in growth models, though works by [15,16] identify them as fundamental causes of global income distribution inequality. Institutional barriers to factor mobility and free trade, traditionally emphasised by economic theory, contribute to inter-country and intra-country inequalities in growth rates, per capita income, and factor remuneration.

Recent studies have evaluated the positive impact of logistics development on economic growth [17,18]. Using the Logistics Performance Index (LPI) to measure logistics performance across various developing economies through the Cobb–Douglas production function, Ref. [17] found evidence that economies with strong logistics performance see a greater contribution of capital to economic growth compared to those with weak logistics. Additionally, Ref. [18] suggested that logistics developments associated with the China-Pakistan Economic Corridor have the potential to significantly contribute to Pakistan's economic growth by improving connectivity, infrastructure, and efficiency. Ref. [19] highlighted the importance of aligning trade policy with logistics and supply chain development in their investigation of the role of logistics in international and national trade in a developing country such as Oman.

In an innovative work, the connection between logistics and sustainability is explored by, among others, [20–22]. Concerning small and medium enterprises, Ref. [23] examined the impact of supply chain resilience on performance in Saudi Arabia, finding that agility and flexibility are crucial for enhancing both production and marketing/sales performance.

Recent research underscores the transformative role of logistics in the global economy, particularly in the areas of digital transformation, automation, and sustainability. Ref. [24] highlight the integration of digital supply chain twins as a strategy to manage disruption risks and enhance resilience in logistics operations. This approach significantly improves efficiency and reduces costs, allowing for more responsive and adaptive logistics networks.

Similarly, Ref. [25] discuss how blockchain technology is revolutionizing logistics by increasing transparency and reducing delays in international trade. Their analysis indicates that the ability to track shipments and verify transactions in real-time enhances supply chain resilience against disruptions, making it a vital tool in contemporary logistics management.

The importance of sustainable logistics practices is also gaining prominence. Ref. [26] provides an analytical review that highlights the role of green logistics in achieving sustainable development, emphasizing strategies that align environmental goals with operational efficiency. Expanding on these themes, Ref. [27] examine the shift from Industry 4.0 to Industry 5.0, highlighting a move from automation to a more human-centered approach, integrating technology with human expertise to enhance efficiency, sustainability, and adaptability in logistics.

3. The Model

Most models that aim to approximate the long-term global production function typically include capital, labour, and technological progress as input factors. In its simplest form, the production function is formally represented by the following Cobb-Douglas equation:

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

In Equation (1), Y represents the total output or Gross Domestic Product (GDP) of each country, A is the level of technology, K is physical capital, L is the amount of labour, and α is the capital share in production (a constant between 0 and 1). In this model, total output Y depends on the amount of physical capital K, the amount of labour L, and the level of technology A, where A is exogenous, typically estimated by including the variable t, such that t must be positive to indicate that technological progress positively affects over time, akin to "manna from heaven".

MRW [8] extend this basic framework by incorporating human capital as an additional "endogenous" production factor. This leads to a more comprehensive formulation of the global production function where a country's total output (Y) can be expressed as follows:

$$Y = (KH)^{\alpha}(K)^{\beta}\,(AL)^{1-\alpha-\beta} \tag{2}$$

In Equation (2), KH denotes human capital, K represents physical capital, A indicates the level of technology, and L stands for the amount of labour. The coefficients α and β represent the shares of human and physical capital in the production process, respectively. The term $(AL)^{1-\alpha-\beta}$ captures technological capital, which is derived by combining the technology level A with the amount of labor L, raised to the power $(1-\alpha-\beta)$. This expression represents the portion of total production not accounted for by human and physical capital.

In the [8] model, the level of technology A is an abstract construct that represents the overall technological progress within an economy. As a latent variable, A cannot be directly measured, as it encompasses various aspects of knowledge, innovation, and the efficiency of combining production factors. Consequently, different scholars have sought to estimate technological progress using three main proxies or indirect indicators. The first indicator is research and development (R&D) expenditures, with higher R&D spending typically reflecting greater technological progress. The second indicator is the number of patents and intellectual property rights (P), as these can signal the level of innovative activity within an economy. The third indicator is production efficiency (ET), where improvements in the ratio of output to inputs suggest advancements in technology.

This research proposes a new specification that extends traditional models by incorporating logistics as a determinant of global production. Furthermore, the level of exogenous technological progress, A is represented by the three previously mentioned indicators: R&D expenditures, patents, and technical efficiency. The production equation can then be written as follows:

$$Y = (KH)^{\alpha}(K)^{\beta}\,(L)^{\gamma}(LPI)(A)^{£} \tag{3}$$

where:

- Y is total output or GDP, as an endogenous variable to be explained.
- KH is human capital raised to the power α, considered an endogenous variable.
- K is physical capital raised to the power β, considered an endogenous variable.
- L is the working population raised to the power γ, considered exogenous in the short term but endogenous in the long term. The working population is used to convert the variables Y, KH, and K into per capita terms.
- LPI is the Logistics Performance Index raised to the power μ. This variable is subdivided into six components, with three considered exogenous and three endogenous. Therefore, the aggregate LPI cannot be definitively classified as either exogenous or endogenous.
- A is a constant representing the level of technological progress at a given time for a country, raised to the power λ, considered an exogenous variable as firms combine inputs to produce outputs, register patents, and conduct R&D.

Unlike the models of [8,11], the models presented in this study are compatible with increasing returns to scale, which allows for greater flexibility. Under the above assumptions, in Equation (3) the parameters to be estimated are α, β, and μ, representing the shares of KH, K, and LPI in production, respectively. In the economic literature, Refs. [28,29] previously included the LPI as a production factor.

In this study, the sample spanned from 2007 to 2012, inclusive, and utilised the synthetic LPI to explain technical efficiency alongside other variables, resulting in significant and positive findings. The LPI employs standard statistical techniques to aggregate data into a single indicator, converting qualitative information into quantitative data before aggregation and weighting. It is based on an online survey of logistics professionals from multinational freight forwarders and major express carriers. The data is collected through a survey.

The LPI synthesises data on six core performance components into a single aggregated measure via a survey covering the six components. These components are the efficiency of customs and border management ($LPI1$); the quality of trade and transport-related infrastructure ($LPI2$); the ease of arranging competitively priced international shipments ($LPI3$); the competence and quality of logistics services ($LPI4$); the ability to track and trace consignments ($LPI5$); and the frequency with which shipments reach consignees within the scheduled or expected delivery time ($LPI6$). These indicators were chosen based on theoretical and empirical research and the practical experience of logistics professionals involved in international cargo transport.

The indicators can be divided into two groups. The first group comprises $LPI1$, $LPI2$, and $LPI4$, where public policies can be implemented concerning the main inputs for the supply chain, such as customs, infrastructure, and services. The second group comprises $LPI3$, $LPI5$, and $LPI6$, which pertain to supply chain performance: cost, reliability, and time, determined exogenously by the market. Consequently, by making the pertinent substitutions, Equation (3) can be formulated as follows:

$$Y = (KH)^{\alpha}(K)^{\beta}(L)^{\gamma}(LPI1)^{\mu 1}(LPI2)^{\mu 2}(LPI3)^{\mu 3}(LPI4)^{\mu 4}(LPI5)^{\mu 5}(LPI6)^{\mu 6}(A)^{£} \quad (4)$$

In Equation (4), the variable that captures the level of technological progress is A, the endogenous variables influenced by public policies are KH, K, $LPI1$, $LPI2$, and $LPI4$, and the exogenous variables are L, $LPI3$, $LPI5$, and $LPI6$. Again, in this model (4) as in (3), A is assumed to be the constant that reflects the level of technological progress raised to £. However, this model makes no assumptions about the values of the other parameters or their sum, unlike the models of [8,11]. Thus, there are fewer restrictions, allowing for decreasing, constant, and increasing returns to scale.

Equation (5) is converted into intensive terms, meaning the variables Y, KH, and K are divided by the working population L. Subsequently, logarithms are taken, and with a panel of data available, the following equation is estimated:

$$\log Y_{it} = \log A + \alpha \log KH_{1it} + \beta \log \mathrm{K}_{2\mathrm{it}} + \mu_1 \log LPI1_{3it} + \mu_2 \log LPI2_{4it} + \mu_3 \log LPI3_{5it} + \mu_4 \log LPI4_{6it} + \mu_5 \log LPI5_{7it} + \mu_6 \log LPI6_{8it} + \varepsilon_{it} \quad (5)$$

4. Data

This document conducts an empirical test of the proposed model using indicators from the World Bank's World Economic Indicators database [30]. The World Bank is an international organisation with various objectives, most of which are closely related to poverty alleviation and the economic development of all countries. Since its inception in 1944, it has increasingly devoted its resources to collecting statistics and indicators, which are organized into databases.

For our empirical analysis, we consider a sample of 85 countries, for which we have a complete panel of data for the years available for the LPI and its components: 2007, 2010, 2012, 2014, 2016, 2018, and 2022.

Table 1 provides a detailed description of the variables included in the production function estimation. The dependent variable, Y, is the real Gross Domestic Product per capita, and the independent variables are fixed capital, K, real Gross Fixed Capital Formation per capita for each country, and human capital, KH, measured by $KH2$ and $KH3$, which represent the percentages of the population enrolled in secondary and tertiary education relative to the population of the corresponding age group.

Table 1. Variable definitions.

Variable	Definition and Units
Y	Gross Domestic Product per employee in $
K	Gross Capital Formation per employee in $
$KH2$	School enrollment, secondary (%)
$KH3$	School enrollment, tertiary (%)
$LPI1$	Customs
$LPI2$	Infrastructure
$LPI3$	International shipments
$LPI4$	Logistics quality and competence
$LPI5$	Tracking and tracing
$LPI6$	Timeliness

Source: World Bank (2024).

To obtain the LPI, the World Bank conducted a global survey of terrestrial operators (global freight forwarders and express carriers), providing feedback on the logistics friendliness of the countries in which they operate and those with which they trade. This study combines in-depth knowledge of the countries they operate in with qualitative assessments of other countries where they trade in global logistics environments. The operators' feedback is complemented with quantitative data on the performance of key logistics chain components in the country, resulting in six indices shown in Table 1 and a synthetic index derived from the average of the six.

Table 2 presents the descriptive statistics, sources, and units for 85 countries in the world that present complete data on all variables for the period 2007–2023 (504 observations).

Table 2. Main descriptive statistics.

Variables	Min.	Max.	Mean	Std. Dev.
Y	1340	248,000	47,400	39,300
K	185	118,000	11,500	11,000
$KH2$	16.2	162	92.3	25.7
$KH3$	2.1	150	43.6	32.1
$LPI1$	1.57	4.21	2.91	0.612
$LPI2$	1.53	4.60	3.02	0.701

Table 2. *Cont.*

Variables	Min.	Max.	Mean	Std. Dev.
$LPI3$	1.67	4.24	3.05	0.497
$LPI4$	1.67	4.40	3.09	0.613
$LPI5$	1.60	4.38	3.19	0.605
$LPI6$	1.80	4.80	3.49	0.580

Source: Own elaboration. Note: The data for Y and K are in dollars. The data for KH 3 and $KH2$ refer to the enrolled students over the net percentage of students of enrollment age for each educational cycle. For this reason, this percentage is sometimes higher than 100%, given that there are students of younger and older ages who enroll in such training cycles. The values of the logistics performance indicators range from 1 to 5.

5. Results

Table 3 presents the results of the estimation of the proposed model for a panel of data from 2007 to 2022, estimated by the fixed effects and random effects model. (The Hausman test is used to decide between a fixed-effects model and a random-effects model. The null hypothesis of the Hausman test posits that the random-effects model is both consistent and efficient. Given the low p-value, the null hypothesis is rejected, favoring the fixed-effects method).

Table 3. Estimation results for the period 2007–2022.

	Fixed Effects	Random Effects
Const.	1.191 ***	−0.519 **
	(3.63)	(−1.961)
lK	0.511 ***	0.645 ***
	(20.94)	(31.30)
$lKH2$	0.116 ***	0.199 ***
	(3.454)	(3.047)
$lKH3$	0.245 ***	0.132 ***
	(3.697)	(4.364)
$lLPI1$	0.076 **	0.160 *
	(2.251)	(1.697)
$lLPI2$	0.080 **	0.325 ***
	(2.204)	(3.207)
$lLPI3$	−0.049 *	−0.147 *
	(−1.951)	(−1.902)
$lLPI4$	0.076 *	0.171
	(1.858)	(1.376)
$lLPI5$	0.108 ***	0.233 ***
	(3.866)	(1.376)
$lLPI6$	−0.134 ***	−0.206 ***
	(−6.034)	(−2.868)
Observations	504	504
R^2	0.992	0.78

Notes: ***, **, and *: Below 1%, 5%, and 10%. Dependent variable: lY. Source: Own elaboration.

All variables are in logarithms, allowing them to be interpreted as elasticities of per capita income (Y) concerning each explanatory variable. The sum of the elasticities in the best-fixed effects estimates, as per the Hausman test, is approximately one, indicating constant returns to scale. This suggests that, on an aggregate level, income distribution follows the product exhaustion theorem, meaning the remuneration of factors equals their marginal productivities, supporting the presence of perfect competition at the aggregate level across these countries.

As illustrated in Table 3, the estimated per capita global production function for the 85 countries with World Bank data from 2007 to 2022 is explained by per capita fixed capital (K) and per capita human capital, represented by the variables for secondary education ($KH2$) and tertiary education ($KH3$). These variables are both significant and positive in the fixed and random effects estimations. For the fixed effects estimation, a 1% increase in

K, $KH2$, and $KH3$ corresponds to increases of approximately 0.51%, 0.11%, and 0.24% in GDP per employee, respectively.

Furthermore, the logistics performance indicators show diverse effects. Positive elasticities are observed for customs efficiency ($LPI1$ at 0.07), infrastructure quality ($LPI2$ at 0.08), logistics quality and competence ($LPI4$ at 0.07), and tracking and tracing ($LPI5$ at 0.10). However, negative elasticities are noted for the cost competitiveness of international shipments ($LPI3$ at -0.04) and shipment timeliness ($LPI6$ at -0.13). Thus, a 1% increase in $LPI3$ and $LPI6$ is associated with a 0.04% and 0.13% decrease in GDP per employee, respectively. These findings align with previous studies by [18,28,29,31]. Refs. [28,31] found significant positive results for LPI in explaining global growth. Ref. [18] demonstrate that advancements in a country's logistics infrastructure have a significant positive effect on economic growth in both the long term and the short term within the context of the China–Pakistan Economic Corridor. Ref. [29] found logistics to be a key factor in explaining global technical efficiency.

6. Conclusions

Logistics has played a pivotal role in transport costs and an increase in the importance of networks in the evolving global economy. This paper contributes to the literature by proposing a new production model that integrates logistics performance factors for 85 countries over the period 2007–2022, grounded in classic economic models. The results underscore the substantial impact of logistics on global production. The findings offer several innovative insights that deepen our understanding of global production dynamics and open new avenues for research.

Firstly, this study highlights logistics as a crucial, yet often overlooked, driver of global production. Unlike traditional models that prioritize technological progress, human and physical capital, our model incorporates logistics related indicators, offering a more comprehensive perspective of global production. This integration reflects a significant advancement in economic modeling by capturing the real-world complexities of supply chains and their direct impact on productivity.

Secondly, the findings reveal a dual impact of logistics on global production. On one hand, four logistics-related indicators—customs efficiency, infrastructure quality, logistics quality and competence, and tracking and tracing—are shown to positively influence GDP per worker. These positive elasticities suggest that improvements in these areas can significantly enhance global production. On the other hand, two indicators—shipment timeliness, and international shipments—exhibit negative elasticities, indicating that inefficiencies in these areas can hinder economic growth.

The novelty of this research lies not only in identifying logistics as a critical production factor but also in highlighting areas susceptible to improvement within the within the logistics industry. Thus, by focusing on these specific areas, the study suggests that global productivity could increase significantly.

There are several areas for future research. First, further studies should investigate how emerging technologies such as artificial intelligence and blockchain can reshape logistics operations and contribute to the growth of global production. Secondly, it would be advisable to explore the mechanisms through which logistics inefficiencies impact different sectors and regional areas.

7. Theoretical and Managerial Implications

The findings of this study offer both theoretical advancements and practical insights for managers and policymakers. Theoretically, the model expands traditional production models by incorporating logistics as an endogenous factor, highlighting its critical role in modern production. This result suggests that logistics is not merely a supportive activity but a key economic driver.

Results hold significant implications for managers. Investments in logistics infrastructure should be prioritized, particularly by improving the efficiency and quality of customs infrastructure, as these elements directly influence overall productivity. In addition, companies should optimize logistics services by focusing on improving the quality and competence of their logistics operations, including tracking and tracing capabilities, which are crucial to ensuring more efficient and reliable supply chains. In addition, careful management of costs related to international shipping and efforts to improve shipment timeliness is essential. Strategies such as route optimization, investment in faster modes of transportation, and adoption of advanced logistics technologies can help mitigate the negative impacts identified in the current study.

Our results are also meaningful to policymakers. Given these findings, policymakers should prioritize investments in customs efficiency and infrastructure quality to bolster economic growth. Enhancing the quality and competence of logistics services, as well as improving tracking and tracing mechanisms, can further amplify this positive impact. Addressing issues related to shipment timeliness and reducing the cost competitiveness of international shipments is crucial for mitigating negative influences. Governments should implement policies that reduce the cost of international shipments, such as subsidies or tax incentives for logistics companies that adopt cost-saving innovations. Additionally, regulatory frameworks should encourage competition in the logistics sector to drive improvements in service quality. By focusing on these areas, countries can enhance their logistical capabilities, thereby supporting sustainable economic development.

By incorporating these managerial and policy recommendations, countries can enhance their logistical capabilities and improve global production outcomes.

There are limitations to this research. The logistics indicators used in this study are those included in the Logistics Performance Index. These results should be contrasted using other logistics measures. Furthermore, the sample is limited to 85 countries, which should be taken into account when generalizing the results. Future research should explore additional logistics data, smaller economies, and broader economic impacts such as efficiency or sustainability.

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