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Multi-kink quantile regression based analysis for industrial structure of non-high-income economies

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Abstract

This paper examines the non-linear relationship between industrial structure and GDP per capita in non-high-income countries using a Multi-Kink Quantile Regression (MKQR) framework. Building on classical growth theory and applying the empirical methodology proposed by Zhong et al. (2022), we use data from 125 countries for the years 2002 and 2023 to identify income thresholds at which structural shifts occur in the contribution of industry to economic output. The findings reveal a consistent three-phase pattern across quantiles: an initial stage of rapid industrial expansion, followed by a period of slower growth, and ultimately a phase of deindustrialization as higher income levels are reached. Notably, the estimated turning points vary according to the level of industrial development, with less industrialized countries reaching the peak of industrialization at significantly lower levels of GDP per capita. These results underscore both the heterogeneity of the industrialization process and the increasing challenges faced by developing economies in sustaining industrial growth.

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1. Introduction

Economists have long theorized that industrialization is a powerful engine of growth in the early stages of development. Classic dual-sector models like Lewis (1954) illustrate how transferring labor from traditional agriculture to modern industry boosts output. Other approaches, such as Kaldor (1961), also posit manufacturing as the "engine of growth." However, theory also recognizes that this effect cannot continue indefinitely. Kaldor and others acknowledged that as an economy matures, diminishing returns to further industrialization set in. Early development theorists like Rostow (1960) described a take-off stage fueled by industrial investment, followed by a drive to maturity where growth relies more on technological progress and diversification (often into services).

The foundational models seem to imply a kinked relationship between industrial share and development. At low incomes, expanding industry (especially manufacturing) has high returns – raising productivity, employment, and incomes. But at higher incomes, other constraints emerge (e.g. demand shifts to services, rising wages, technological changes) that make an ever-growing industrial share neither feasible nor necessary for further growth. Instead, advanced economies naturally transition to service-led growth. This theoretical perspective sets the stage for the empirical inverted-U pattern observed in data. Recent empirical research reinforces and modernizes these foundational insights. Atolia et al. (2020) revisit structural transformation under globalization, emphasizing how premature deindustrialization and the shifting nature of global production have challenged the classical trajectory of manufacturing-led growth. Forero & Tena-Junguito (2024) provide long-run evidence from Latin America, showing that industrialization consistently correlates with episodes of growth acceleration, especially in larger economies with greater capacity for scale economies and learning-by-doing effects. Meanwhile, Kruse et al. (2021) document signs of a "manufacturing renaissance" in parts of Asia and sub-Saharan Africa, where recent data suggest a partial recovery in industrial employment shares, challenging overly pessimistic views about the end of industrialization opportunities in the developing world.

Works such as Syrquin & Chenery (1989) and Haraguchi & Rezonja (2011) documented that as countries get richer from low to middle income, the share of manufacturing in GDP rises, but after a certain income level it peaks and then begins to fall. Evidence from developing and emerging economies over the last few decades supports the early part of the inverted U (the benefits of initial industrialization) but shows a worrying shift in the peak and downturn happening sooner than in the past. Rodrik (2016) coined the term "premature deindustrialization" to describe the phenomenon that many low- and middle-income countries are seeing stagnant or declining industrial shares at income levels much lower than those at which advanced economies began deindustrializing.

One concern is that if countries start deindustrializing "prematurely" (at lower income levels and lower industrial shares), they may forego some of the growth benefits that past industrializers enjoyed. Felipe et al. (2019) found evidence suggesting that becoming rich through industrialization has therefore become much more difficult. McMillan & Rodrik (2014) find that since the 1990s, many developing countries, especially in Latin America and Sub-Saharan Africa, have experienced growth-reducing structural change, with labor shifting away from high-productivity manufacturing to lower-productivity services or informal activities. In contrast, several Asian economies have sustained productivity-enhancing structural change by expanding modern industrial employment. Their findings highlight the importance of considering not just the level but the direction of industrial transformation, and the conditions under which it contributes to overall growth.

Existing literature provides strong support for a kinked, inverted U-shaped pattern: rapid economic growth is typically associated with industrial expansion in the early stages of development, followed by diminishing returns—or even negative effects—once certain per capita income thresholds are exceeded. We investigate this hypothesis using data from 125 non-high-income countries, applying the Multi-Kink Quantile Regression (MKQR) method developed by Zhong et al. (2022) to identify potential non-linearities in the relationship between the share of industry and GDP per capita. This approach allows the slope of the conditional quantile function to change at unknown thresholds (kink points) of the explanatory variable—in our case, GDP per capita—while maintaining continuity at those points. The MKQR model offers greater flexibility than linear or single-threshold models, particularly in capturing regime shifts along the development path of an economy.

This methodology is particularly valuable, as it enabled the identification of two types of asymmetries. First, it revealed that the relationship between income and the industrial share is heterogeneous across different industrial quantiles. Second, it allowed us to detect two kink points, resulting in three distinct income intervals in which the nature of the relationship between income level and industrial share changes after each threshold is crossed. In the first interval, the industrial share increases rapidly with GDP per capita until the first kink point is reached. In the second interval, following this threshold, the industrial share continues to grow but at a slower pace. Finally, after the second kink point—associated with a higher income level—the relationship reverses, and the share of industry in the economy begins to decline.

In this paper, we contribute to the literature by uncovering two distinct kink points in the relationship between industrial share and economic development in non-high-income countries. While earlier works such as Zhong et al. (2022) provide evidence that industrial expansion slows once countries surpass an initial income threshold, our findings advance this discussion by showing that if these economies reach a higher level of GDP per capita, the process does not merely decelerate but reverses, marking the onset of deindustrialization. This result highlights a previously underexplored dimension of structural transformation, underscoring that industrialization is not only subject to diminishing returns but may eventually give way to contraction at higher stages of development. In addition, by adopting a multi-kink quantile regression approach, our analysis captures heterogeneous trajectories across different levels of industrialization, demonstrating that less industrialized economies experience these turning points much earlier than their more advanced peers. These contributions expand the empirical understanding of the inverted-U hypothesis, providing new evidence on the dynamics and timing of industrial peaks in the development process.

This study is structured as follows: Section 2 outlines the empirical methodology used to estimate the non-linear relationship between industrial structure and GDP per capita. Section 3 presents the data and empirical results. Finally, Section 4 offers concluding remarks.

2. Methodology

In order to examine the potentially nonlinear relationship between industrial structure and GDP per capita, we applied the Multi-Kink Quantile Regression (MKQR) model developed by Zhong et al. (2022). It is defined as follows

$$Q_Y(\tau \mid X_t, \boldsymbol{Z}_t) = \alpha_0 + \alpha_1 X_t + \sum_{k=1}^{K} \beta_k (X_t - \delta_k) I(X_t > \delta_k) + \gamma^{\top} \boldsymbol{Z}_t + e_t, \quad t = 1, \ldots, 125 \tag{1}$$

Where $Q_s(\tau | d_t, Z_t)$ is the τ^{th} quantile of a response variable Y_t - industry (% GDP), given X_t and $\boldsymbol{Z}_t$; $\tau \in (0, 1)$. X_t represents the threshold variable - GDP per capita. e_t's are independent random errors; K is the number of kink effects and δ_k are kink points, $k = 1, \ldots, K$. $\boldsymbol{Z}_t$ is a vector of covariates and $\boldsymbol{\gamma}$ is the vector of coefficients of these covariates.

Both regression coefficients and kink effects are endogenously estimated by the Bootstrap Restarting Iterative Segmented Quantile (BRISQ) regression technique (Zhong et al., 2022). It is much more computationally efficient than the grid search algorithm and not sensitive to the initial values due to the bootstrap restarting idea of Wood (2001). See details of BRISQ algorithm in Zhong et al. (2022).

A non-zero value for β_k means the presence of a kink effect at $X_t = \delta_k$. Therefore, we apply the test the existence of kink effects. Under the null hypothesis, there exists at least one statistically significant kink point at the τ^{th} quantile level. See details in Zhong et al. (2022).

3. Data and Estimation

This study compiles data from 125 countries for the years 2002 and 2023. The country sample includes nations classified by the World Bank as Low income, Lower middle income, or Upper middle income. To investigate the non-linearity of the relationship between industry and GDP per capita, we use industry, value added (% GDP), denoted by Y_t and GDP per capita (constant 2015 US$), denoted by X_t.

We also included some control variables: (i) Government Expenditure (% GDP), (ii) Gross Fixed Capital Formation (% GDP), (iii) Human Capital, (iv) Government Effectiveness, (v) Trade Openness (% GDP), (vi) Foreign direct investment, net inflows (% of GDP), denoted by Z_{t1}, Z_{t2}, Z_{t3}, Z_{t4}, Z_{t5}, Z_{t6} respectively. Sources and further description of the data are reported in Table I.

Table I. Data description and sources

a) **Source**: World Bank - https://databank.worldbank.org/source/world-development-indicators	
Variable	**Description**
GDP per capita	GDP per capita is gross domestic product divided by midyear population. GDP is the sum of gross value added by all resident producers in the economy plus any product taxes and minus any subsidies not included in the value of the products. It is calculated without making deductions for depreciation of fabricated assets or for depletion and degradation of natural resources. Data are in constant 2015 U.S. dollars.
Industry	Industry (including construction), value added (% GDP) comprises value added in mining, manufacturing, construction, electricity, water, and gas. Value added is the net output of a sector after summing all outputs and subtracting intermediate inputs.
Expenditure	Cash payments for operating activities of the government in providing goods and services (% GDP).
Gross Fixed Capital Formation	Gross capital formation (formerly gross domestic investment) consists of outlays on additions to the fixed assets of the economy plus net changes in the level of inventories. Fixed assets include land improvements (fences, ditches, drains, and so on); plant, machinery, and equipment purchases; and the construction of roads, railways, and the like, including schools, offices, hospitals, private residential dwellings, and commercial and industrial buildings (% GDP).

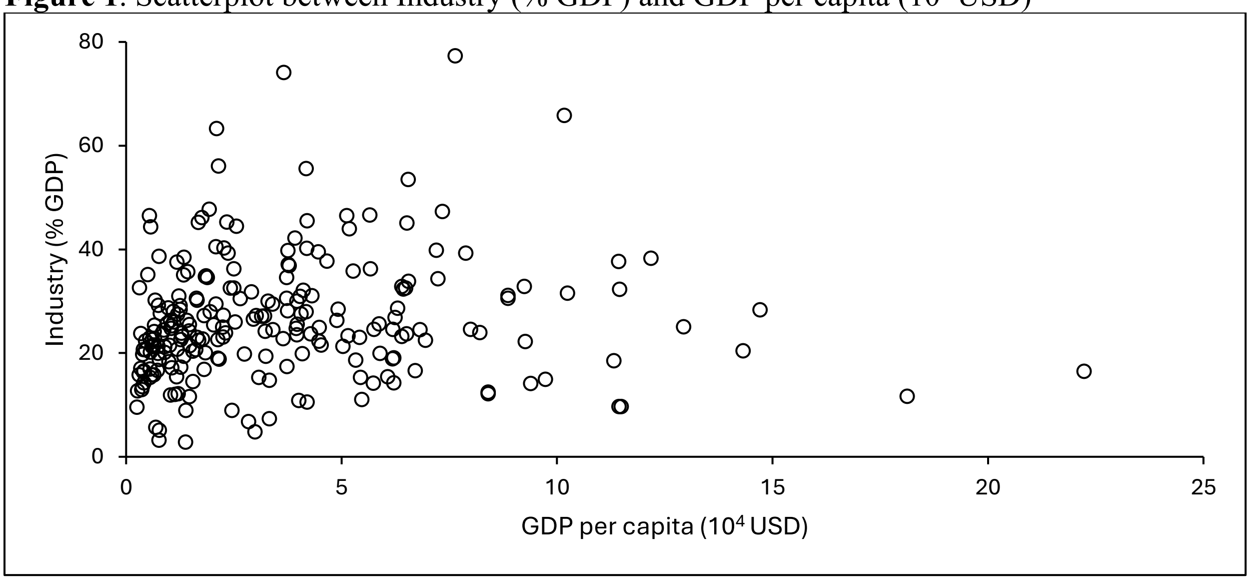
Human capital index	The HCI calculates the contributions of health and education to worker productivity. The final index score ranges from zero to one and measures the productivity as a future worker of child born today relative to the benchmark of full health and complete education (scale 0-1).
Trade Openness	Trade Openness is the sum of exports and imports of goods and services measured as a share of gross domestic product (% GDP).
Foreign direct investment	Foreign direct investment is the net inflows of investment to acquire a lasting management interest (10 percent or more of voting stock) in an enterprise operating in an economy other than that of the investor. It is the sum of equity capital, reinvestment of earnings, other long-term capital, and short-term capital as shown in the balance of payments. This series shows net inflows (new investment inflows less disinvestment) in the reporting economy from foreign investors, and is divided by GDP.

b) Source: World Bank - https://databank.worldbank.org/source/worldwide-governance-indicators

Variable	**Description**
Government Effectiveness	Government Effectiveness captures perceptions of the quality of public services, the quality of the civil service and the degree of its independence from political pressures, the quality of policy formulation and implementation, and the credibility of the government's commitment to such policies. Percentile rank indicates the country's rank among all countries covered by the aggregate indicator, with 0 corresponding to lowest rank, and 100 to highest rank.

First, we present an initial visual exploration of the relationship between the industrial share of GDP and GDP per capita across 125 non-high-income countries for the years 2002 and 2023. Figure 1 displays a scatterplot illustrating the distribution of these two variables.

Figure 1. Scatterplot between Industry (% GDP) and GDP per capita (10^4 USD)



The scatterplot in Figure 1 visually highlights the potential nonlinearity in the relationship between the industrial share of GDP and GDP per capita among non-high-income countries. The distribution of data points suggests that this relationship may vary significantly across different segments of the industrial distribution. At lower industrial levels, the data appear more concentrated, indicating a narrower range of variation in the industrial share, whereas at higher income levels, the dispersion increases substantially, pointing to greater variability. This pattern implies that a conventional linear specification would likely fail to capture the underlying complexity and the shifting dynamics of industrial development across income levels.

Consequently, the observed heteroscedasticity and potential structural shifts underscore the relevance of adopting a quantile-based, kinked regression framework, as proposed in this study.

We let $\tau = 0.25, 0.5$ and 0.75 to investigate the economies at different development industrial levels. Table II reports the main results of the Multi-Kink Quantile Regression (MKQR) estimation, including p-values for testing the existence of kink effects based on 1,000 bootstrap replicates, the estimated number of kink points, the estimated parameters, and their corresponding standard errors.

Table II. Parameter estimation and test results of the MKQR model at different quantile levels

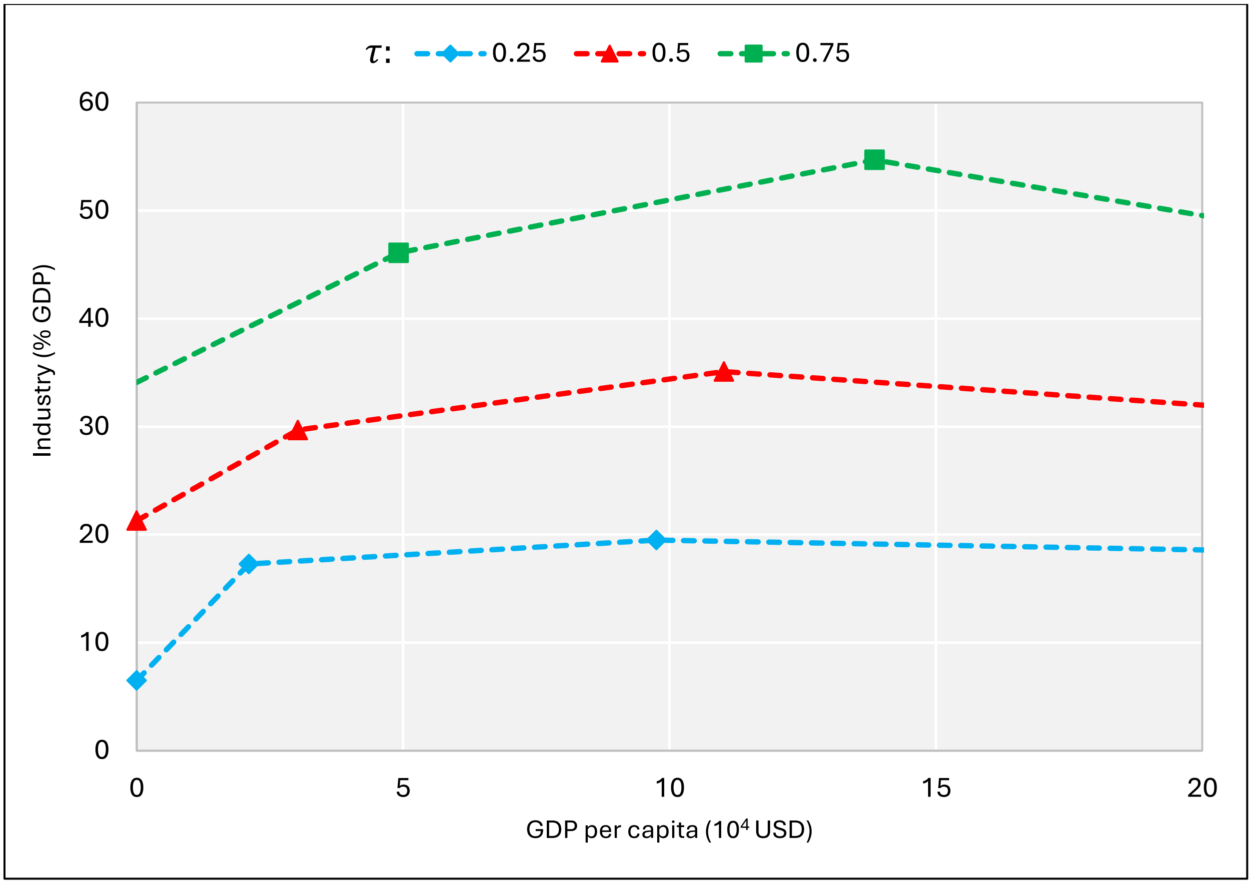
	$\tau = 0.25$		$\tau = 0.5$		$\tau = 0.75$	
p-value	0.042		0.006		0.000	
$\widehat{K}$	2		2		2	
$\hat{\alpha}_0$	0.065	(0.018)	0.213	(0.002)	0.341	(0.000)
$\hat{\alpha}_1$	0.187	(0.031)	0.123	(0.009)	0.115	(0.052)
$\hat{\beta}_1$	-0.149	(0.016)	-0.068	(0.025)	-0.039	(0.011)
$\hat{\beta}_2$	-0.055	(0.031)	-0.082	(0.043)	-0.132	(0.055)
$\hat{\delta}_1$	2.105	(0.576)	3.024	(0.387)	4.912	(0.811)
$\hat{\delta}_2$	9.754	(0.669)	11.021	(1.066)	13.851	(0.909)
$\hat{\gamma}_1$	-0.315	(0.509)	-0.977	(0.248)	-0.135	(0.237)
$\hat{\gamma}_2$	1.122	(0.029)	1.175	(0.023)	1.294	(0.021)
$\hat{\gamma}_3$	0.593	(0.027)	0.554	(0.016)	0.619	(0.017)
$\hat{\gamma}_4$	0.679	(0.434)	0.734	(0.129)	0.703	(0.651)
$\hat{\gamma}_5$	0.343	(0.139)	0.103	(0.117)	0.426	(0.116)
$\hat{\gamma}_6$	1.194	(0.031)	1.531	(0.025)	1.362	(0.141)

Note: standard errors in parentheses were based on 1,000 bootstrap replicates.

Our empirical analysis confirms the presence of two significant kink effects in the relationship between GDP per capita and the industrial share of GDP across non-high-income countries for all values of τ. It is important to note that all estimated coefficients — including those of the control variables — were statistically significant at conventional levels. Figure 2 illustrates the fitted Multi-Kink Quantile Regression (MKQR) curves at quantiles τ = 0.25, 0.5, and 0.75, clearly revealing distinct nonlinear dynamics across different stages of economic development.

At the lower quantile (τ = 0.25), corresponding to relatively less-developed economies, the industrial share initially rises rapidly with increasing GDP per capita, highlighting the strong role of industrialization as a driver of growth and indicating a steep positive slope ($\hat{\alpha}_{1|\tau=0.25} = 0.187$). This trend continues up to the first kink point at 2,105 USD. Beyond this point, slope decreases drastically, signaling a structural transformation after which the marginal contribution of the industrial sector to further economic growth diminishes substantially ($\hat{\alpha}_{1|\tau=0.25} + \hat{\beta}_{1|\tau=0.25} = 0.038$). This slower trajectory persists until a second kink point is reached at 9,754 USD. From this level onward, the share of industry in GDP begins to decline ($\hat{\alpha}_{1|\tau=0.25} + \hat{\beta}_{1|\tau=0.25} + \hat{\beta}_{2|\tau=0.25} = -0.017$), signaling the onset of a stabilization phase in the industrial composition of output.

Figure 2. Fitted MKQR curves at different quantile levels.



Note: ◆,■,▲ markers the estimated kink points.

For the intermediate quantiles (τ = 0.5), the initial slope is less steep compared to the lower quantile ($\hat{\alpha}_{1|\tau=0.5} = 0.123$). The first kink points occur at higher income levels (3,024 USD). Beyond these points, the slope again decreases ($\hat{\alpha}_{1|\tau=0.5} + \hat{\beta}_{1|\tau=0.5} = 0.055$) until reaching the second kink point (11,021 USD), after which the share of industry in GDP begins to decline ($\hat{\alpha}_{1|\tau=0.5} + \hat{\beta}_{1|\tau=0.5} + \hat{\beta}_{2|\tau=0.5} = -0.027$), indicating the onset of a gradual process of deindustrialization.

At the highest quantile (τ = 0.75), the initial slope up to the first kink point is steeper than in the intermediate quantiles. ($\hat{\alpha}_{1|\tau=0.75} = 0.115$). Moreover, this first turning point occurs at a considerably higher income level (USD 4,912), underscoring that countries in the highest quantile experience industrial expansion at more advanced stages of economic development. After this threshold, the slope decreases substantially ($\hat{\alpha}_{1|\tau=0.75} + \hat{\beta}_{1|\tau=0.75} = 0.076$), yet it remains steeper than those observed in both the intermediate and lower quantiles. This suggests a growing divergence, as countries in the upper quantile sustain a stronger industrial momentum and continue to distance themselves from the others in terms of industrial development. This trajectory persists until the second turning point, after which the share of industry in GDP begins to decline ($\hat{\alpha}_{1|\tau=0.75} + \hat{\beta}_{1|\tau=0.75} + \hat{\beta}_{2|\tau=0.75} = -0.057$), marking the onset of a deindustrialization phase.

In sum, the industrialization process in less industrialized countries—represented by the lower quantiles—tends to reach the limit of industrial expansion at earlier stages of economic development compared to countries in higher quantiles. This premature stabilization is largely driven by the absence of structural conditions necessary to sustain a continuous process of productive transformation. In low-income contexts, the state often lacks the fiscal and institutional capacity to undertake direct investments in infrastructure or strategic industrial sectors. Simultaneously, weak domestic demand and geographically disadvantaged locations reduce the attractiveness of these markets to foreign investors. As a result, even in economies open to globalization, industrialization tends to rely heavily on the presence of multinational corporations, which are not always drawn to these countries (Narula & Dunning, 2000). Our empirical results confirm this dynamic: the high coefficients associated with gross fixed capital formation and foreign direct investment indicate that the availability of capital—whether public or private, domestic or foreign—is a key determinant in helping these countries avoid the trap of premature industrial stagnation.

The industrial development of non-high-income countries is marked by distinct levels of value-added within their productive sectors. While some economies are characterized by a primary industrial base, centered on the processing of natural resources or low-technology manufacturing, others already exhibit a more advanced stage of industrialization, with medium and high-technology sectors. This structural diversity directly influences the dynamics of the relationship with GDP per capita observed in our analysis. In the lower quantiles of industrial development, the initial impetus for growth in industrial share appears to be strongly driven by an extensive margin, characterized by the transfer of workers from the lower-productivity agricultural sector to the industrial sector. This movement generates an accelerated increase in the industrial share of GDP at lower levels of GDP per capita. However, reaching the limit of this expansion occurs relatively early, as sustaining industrial growth at higher levels requires a shift towards the intensive margin, dependent on productivity gains, investment in capital (both physical and human), and technological advancements. These factors, as previously pointed out, are strongly conditioned by the fiscal and institutional capacity of the state, as well as the attractiveness for investments, elements frequently limited in low-income contexts. In contrast, countries situated in the upper quantiles of our sample of non-high-income countries tend to exhibit a less accelerated, yet potentially more durable, industrial growth trajectory, with a larger portion of growth driven by the intensive margin.

This challenge is further underscored by the limited role of trade in driving structural transformation in many low-income economies. As shown by Fe & N'Guessan (2023), the share of manufactured goods in total exports has not significantly contributed to structural transformation in Africa. The authors emphasize that simply increasing trade volume is insufficient; structural change requires adding value to exports through industrial processing and technological upgrading. This implies that for low-income countries to make meaningful progress, trade strategies must be coupled with policies that promote value-added production, industrial diversification, and participation in global value chains.

Overall, a consistent three-phase pattern emerges across all quantiles: (i) a phase of rapid industrial expansion, (ii) a phase of decelerated but positive industrial growth, and (iii) a phase of deindustrialization. Nonetheless, meaningful heterogeneity arises across levels of industrial development. Less industrialized countries tend to reach their industrialization peak at lower income thresholds, whereas relatively more advanced economies experience this structural transition later and at higher levels of GDP per capita.

4. Conclusion

This study has explored the kinked, nonlinear relationship between economic development and industrial structure in non-high-income countries using a Multi-Kink Quantile Regression (MKQR) approach, extending the methodology originally proposed by Zhong et al. (2022). Our empirical findings strongly support classical development theories, confirming the existence of structural thresholds in the industrialization process across different stages of economic growth. Notably, the industrial sector plays a crucial role in driving early-stage growth; however, this impact diminishes substantially beyond specific GDP per capita levels, and for higher income levels, the proportion of industry declines after reaching a certain point, confirming the inverted-U trajectory observed historically and aligning with contemporary concerns about deindustrialization.

From a policy perspective, these findings highlight the importance of designing industrial strategies that are tailored to the specific stage of economic development. In less-industrialized economies, priority should be given to expanding industrial capacity. For countries at intermediate stages of industrialization, the challenge lies in recognizing the appropriate moment to pivot toward innovation, technological upgrading, and the development of high-value-added services to sustain long-term growth and prevent stagnation.

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