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Application of Cobb-Douglas Production Function on the Indian Printing Industry

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Abstract
This research examines the Indian printing industry from the post-independence period of 1950–51 through 2023–24, utilizing the Cobb-Douglas production function. By applying a multiple regression model to longitudinal data concerning labour (total persons engaged), capital (total investment), and annual output, the study analyses industrial evolution and development over a seventy-four-year horizon. The empirical evidence indicates that enhanced productivity is primarily contingent upon capital deepening. Although labour remains fundamental to industrial operations, its marginal contribution has reached a plateau. Consequently, to facilitate further growth in output, the industry must prioritize strategic investments in technology and infrastructure. These findings suggest a highly capital-intensive production environment where capital investment serves as the principal driver of expansion. The study concludes that the Cobb-Douglas specification offers a technically superior framework for evaluating these temporal dynamics and provides precise estimations of output elasticities.

Keywords: Printing, Cobb-Douglas, Production Function, Linear Regression, Time-Series Analysis

Introduction

The printing sector represents one of the most venerable segments of the global manufacturing industry. While it originated as a manual, labour-intensive craft, centuries of technological and engineering advancements have redefined it as a highly sophisticated manufacturing domain in the twenty-first century. Contemporary printing processes integrate cutting-edge innovations from various engineering disciplines, necessitating a highly skilled workforce to manage such technological complexity. Having incorporated artificial intelligence and machine learning, the industry has evolved beyond the standards of Industry 4.0. Consequently, an empirical examination of the respective contributions of capital and labour to industrial output is warranted.

The printing industry maintains an extensive presence throughout India, established through numerous industrial clusters and significant manufacturing units. Its output encompasses a comprehensive range of products and professional services. This includes the production of newspapers, periodicals, books, and brochures, as well as specialized items such as maps, posters, and security papers including currency, banknotes, and taxation stamps. Furthermore, the industry provides advanced technical services including direct printing upon diverse substrates such as textiles, glass, and metal, alongside specialized processes like engraving, etching, and binding services.

The printing industry in India is a part of the manufacturing sector of the Indian economy. It is classified by the National Industrial Classification (NIC) for all economic activities Division, Group and Sub-classes. The same has been revised a few times and the study is based on the NIC Industrial Classification 1970, 1987, 1998, 2004 and 2008 [1]. The study is based on the classification of the industry according to the respective codes as classified in them. This industry has added a total output of INR 3.546 trillion by employing 134054 persons with an invested capital of INR 1928.9380 in 2023-24 [2]. It has contributed about 2.935% of manufacturing output by value and 0.483% of net value added in the year 2023-24. The industry's invested capital accounts for 0.237% of the manufacturing industry and the proportion of labour accounts for 0.684% for the same period [2].

Source: The National Sample Survey 1950 to 1960 and Annual Survey of Industries 1960 to 2024

Fig 1: Year-wise Labour, Capital and Output of the Indian Printing Industry

Objectives of the Study

The main objectives of the study are as follows:

To estimate the production function of the printing industry in India.

To understand the effect of labour and capital on the output of the industry over the period of study.

Review of Literature

The literature of study of using Cobb-Douglas production function on production and productivity of manufacturing industry and its constituent subsets in India are replete with a number of research papers. Cobb-Douglas function [3] constitute one of the most challenging bodies of findings in applied economics and Douglas himself could survey twenty-nine of them and (could ascertain) the consistency of their numerical results and their analytical significance [4]. Phelps Brown states that he Cobb-Douglas estimates "the historical rates of growth of labour, capital and the product" [4].

Baltagi [5], Christensen [6], Ingene and Lusch [7], Patalinghug [8], Prajneshu [9], Antony [10], and Singh *et al.* [11], amongst others who have used linear regression models to measure the log-linear Cobb-Douglas (C-D) type production processes. Greeshma and Muraleedharan use the estimate of the Cobb Douglas production function to study the impact of quota removal on productivity is positive and significant in the case of spinning, weaving, and finishing of textiles as well as in the manufacture of wearing apparel [12].

Azam Chaudhry uses Cobb-Douglas and translog production functions to calculate total factor productivity (TFP) in Pakistan over the period 1985 – 2005, for the manufacturing, then for the economy as a whole and finds that the productivity increased at an average of 2.4% per year with output growth being driven mainly by increases in capital [13]. César Lenin Navarro-Chávez *et al.* analysed the behaviour of Total Factor Productivity (TFP) the productivity in Latin America with an objective to examine the role of labour (L), capital (K), and technological change (A) in the evolution of Total Factor Productivity (TFP) during the period 1990-2019 using Cobb-Douglas function [14].

Hossain and Khalid Said Al-Amri analyse the relationship between capital, labour, and output in Omani manufacturing, applying the Cobb-Douglas production function to input-output data to assist in identifying efficient production methods finding that most selected industries exhibited increasing returns to scale [15]. Krishnaswamy and Medha in their paper use Cobb-Douglas production function to estimate average and incremental output-capital ratio, average and incremental output-labour ratio, comparison between the growth of total remuneration and labour productivity, combined input efficiency and annual average growth rate of output and input variables and return to scale of Indian printing industry [16].

Aliyu Abubakar Musa *et al.* show how parameters of the Cobb-Douglas production function are estimated using Ordinary Least Squares (OLS) method for an economy or industry of interest [17]. Roman G. Smirnov *et al.* employed the R programming language to fit the formulae for the parameters of the Cobb-Douglas production function generated via the bi-Hamiltonian approach to the same data set utilised by Cobb and Douglas and concluded that the formulae for the output elasticities and total factor productivity are compatible with the original 1928 data [18].

The preceding discussion underscores that the majority of existing literature focuses on productivity analysis within the manufacturing sector. Consequently, there has been a notable absence of research specifically examining the production function of the Indian printing industry through the Cobb-Douglas model during the defined timeframe. This study endeavours to address this empirical void by conducting a comprehensive analysis of production factors within the printing industry spanning the post-independence era.

Data and Description of Variables

The data for this study has been sourced from the National Sample Surveys (NSS) for the years 1951-52 to 1959-60 of the respective years and from 1960-61 to 2021-22 from the Annual Survey of Industries published by the Government of India. The data for the year 1972-73 has been estimated from various published sources as no direct data is available. The Annual Survey of Industries (ASI) covers the factories which are registered through sections 2m (i) and 2m (ii) of the Factories Act 1948 engaging 10 or more workers using power and those employing 20 or more workers but not using power on any day of the preceding 12 months. The study covers the period from 1951-52 to 2023-24. The analysis of productivity, the study considers a composite output and two major inputs of production in printing units in India. The output is measured by the gross value of production which consists of net value added and depreciation. The study uses the total number of persons engaged, which includes workers, hired and other workers, working proprietors, managers and supervisors who work both fulltime and part time. The capital invested is obtained from the capital investment data given in the ASI reports.

Research Methodology

The printing sector which is a constituent of the manufacturing industry is characterised by value-adding processes. A production function delineates the maximum attainable output derived from a specific set of inputs, serving as a purely technical relationship that links factor inputs to outputs. This function elucidates the laws of proportion, governing the transformation of inputs into outputs within a defined temporal period. Representing the technological framework of an industry, firm, or broader economy, the production function encompasses all technically efficient methodologies. Furthermore, such functions facilitate the measurement of marginal factor productivity, factor intensity, and returns on inputs.

Labour and capital constitute the primary inputs of any production process, the culmination of which is realized as output. This study employs the Cobb-Douglas production function to analyse and establish the formal relationship between these two variables and the resulting output. The Cobb-Douglas Production Function is extensively utilised within economic research due to its adherence to fundamental economic principles and its facility regarding estimation, computation, and the interpretation of empirical results. Within this framework, output is defined as the value added through manufacturing over a one-year period. Specifically, outputs are quantified as the "Total Output" generated annually, while inputs are measured by the "Number of Persons Engaged" and the 'Invested Capital' per unit of time.

The Total Output is "defined to include the ex-factory value, (i.e., exclusive of taxes, duties, etc. on sale and inclusive of subsidies etc., if any) of products and by-products manufactured during the accounting year, and the net value of the semi-finished goods, value of own construction and also the receipts for industrial and non-industrial services rendered to others, rent received for building, plant & machinery and other fixed assets, net balance of goods sold in the same condition as purchased, value of electricity generated and sold and an amount equal to expenses on research & development (R&D). Value of gross output and total output has been used in the text inter-changeably to mean the same thing" [19].

The Labour is all the 'Persons Engaged' by "the factory whether for wages or not, in work connected directly or indirectly with the manufacturing process and include all administrative, technical and clerical staff as also labour in production of capital assets for factory's own use. This is inclusive of persons holding position of supervision or management or engaged in administrative office, store-keeping section and welfare section, watch and ward staff, sales department as also those engaged in the purchase of raw materials etc. and production of fixed assets for the factory. It also includes all working proprietors and their family members who are actively engaged in the work of the factory even without any pay and the unpaid members of the co-operative societies who work in or for the factory in any direct and productive capacity. Persons in the head office connected with the manufacturing activity of the factory are also included in this item [19]. The Capital is "is the total of fixed capital and physical working capital" [19]. The following model was applied for estimating the Cobb-Douglas Production Function using the data on inputs and output.

$$Y = A\, L^{\alpha} K^{\beta}$$

Where;

Y = Output

A = Intercept

L = Labour Input

K = Capital Input

α = Coefficient of Labour

β = Coefficient of Capital

The efficiency parameter (A) and the coefficients (α and β) are estimated by applying the above equation. Parameters α and β represent the proportionate change individually in output for a proportionate change in labour and capital. It implies that $\alpha + \beta$ demonstrates the degree of returns to scale. It would indicate that increase in output would be more than proportionate to increase in inputs if $\alpha + \beta > 1$. If $\alpha + \beta < 1$, it would indicate that the increase in output would be less than proportionate to the increase in inputs. In case $\alpha + \beta = 1$, the output would increase in proportionately to the rate of increase in inputs. Hence, the resultant quantum of output nature of output can be economies of scale, constant returns to scale or diseconomies of scale depending upon the values of $\alpha + \beta$ is less than 1, equal to 1 or greater than 1. It suggests that Cobb-Douglas Production Function can be applied to any degree of returns to scale. It is theoretically expected that the input coefficients shall have to be positive and greater than zero i.e., $\alpha > 0$ and $\beta > 0$.

Empirical Results

Table 1: Empirical Results

Predictor	Coefficient	Estimate	Standard Error	T Statistics	p-value
Constant	A	10.2721	42.3899	0.2423	0.8092
Labour	L	0	0.0003	-0.1458	0.8845
Capital	K	2.3357	0.1055	22.1327	0
R-Squared	r^2	0.9321			
Adjusted R-Squared	r^2adj	0.9301			
Residual Standard Error	71 degrees of freedom	278.0127			<.001
F-statistic	On 2 and 71 degrees of freedom	486.9824			
Durbin Watson Test	Auto correlation -0.449	Statistic 2.898			p <.001
Predictors:	Constant, Labour, Capital				
Dependent Variable:	Output				

Source: Author's Calculations using JASP Team (2026). JASP (Version 0.96.0)

The dataset comprises 74 annual observations, which demonstrate a substantial upward trend across all three variables commencing approximately at time point 60. This pattern indicates a phase of accelerated growth or a fundamental structural transition within the data. Furthermore, a multiple linear regression analysis was conducted to estimate Output as a function of Labour and Capital. The model explained a substantial proportion of variance in Output, (R^2 = .932), Adjusted (R^2= .930, $F(2, 71) = 487.0$, $p < .001$. This indicates that the combination of Labour and Capital is a highly significant predictor of Output.

Capital is the primary driver of Output in this model. For every one-unit increase in Capital, Output is expected to increase by approximately 2.34 units, holding Labour constant ($p < .001$). Labour was not a significant unique

predictor in the presence of Capital (p = .885), likely due to the high overlap (multicollinearity) between the two inputs.
The Durbin-Watson statistic is 2.898. This value deviates from 2.0, and the associated $p < .001$ suggests significant negative autocorrelation in the residuals, which is common in time-series data may impact the independence of observations. The Shapiro-Wilk tests for all variables were significant ($p < .001$), indicating that the data deviates from a normal distribution.

Correlation Tests

Table 2: Correlation Tests

	Pearson				Spearman			
	r	p	Fisher's z	SE Effect size	rho	p	Fisher's z	SE Effect size
Capital-Labour	0.708	<.001	0.884	0.119	0.671	<.001	0.813	0.125
Capital-Output	0.965	<.001	2.220	0.119	0.892	<.001	1.433	0.130
Labour-Output	0.681	<.001	0.830	0.119	0.464	<.001	0.533	0.122

Source: Author's Calculations using JASP Team (2026). JASP (Version 0.96.0)

Table 3: Correlation Tests

	Kendall			
	tau B	p	Fisher's z	SE Effect size
Capital-Labour	0.510	<.001	0.563	
Capital-Output	0.772	<.001	1.026	
Labour-Output	0.357	<.001	0.373	

Source: Author's Calculations using JASP Team (2026). JASP (Version 0.96.0)

The Pearson correlation was conducted to examine the bivariate relationships and it is observed that there is a strong positive correlation between Capital and Output (r = .965, $p < .001$). While it indicates a moderate linear relationship for Labour (r = .681), Spearman's rho revealed a much stronger monotonic consistency (rho = .941). This discrepancy suggests that while the variables do not scale in a strictly linear fashion, they exhibit highly synchronized growth patterns, justifying the use of a log-transformation to capture these non-linear dynamics.
To evaluate the robust association between variables, Kendall's tau-b was calculated. The results confirmed a strong positive association between Capital and Output (tau b = .772, $p < .001$). However, the association between Labour and Output was notably weaker (tau b = .357, $p < .001$). The lower tau-b value for Labour, compared to its Pearson (r = .681), suggests that the relationship between Labour and Output is less consistent across the data ranks and may be more susceptible to the fluctuations observed in the time-series distribution.
Multicollinearity was assessed using Tolerance and Variance Inflation Factor (VIF) statistics. Results indicated that multicollinearity was not a significant concern for the model, as VIF values for both Labour and Capital were 2.01, well below the recommended threshold of 5.0. Similarly, Tolerance values were 0.50, indicating that 50% of the variance in each predictor was unique. Thus, despite the high bivariate correlation between the inputs, both variables were retained in the multiple regression analysis.

Discussion

The results of the regression analysis provide a clear but nuanced picture of the factors driving Output. While the model explains a very high percentage of the variance (R2 = .932), the non-significance of Labour as a predictor warrants further investigation.
The primary finding is the overwhelming influence of Capital on Output. In this specific context of the industry, Capital serves as the significant engine of growth, with each unit increase yielding a substantial return. This suggests that the production process may be highly capital-intensive, where investments in technology, machinery, or infrastructure play a far more critical role in scaling production than the size of the workforce.
Although the correlation analysis showed that Labour is strongly related to Output (r = .681), it failed to reach significance in the regression model. This is likely due to multicollinearity. Because Labour and Capital are strongly correlated with each other (r = .708), they share a significant amount of 'predictive information'. In a multiple regression, the model only credits a variable for the unique variance it explains. Here, Capital effectively 'overshadowed' Labour, accounting for the vast majority of the shared variance.
The Durbin-Watson statistic (2.898) and the visual trends in the data suggest that these observations are not independent. The sharp increase in all variables toward the end of the time series indicates that the data may be influenced by external shocks, policy changes, or technological breakthroughs. The presence of negative autocorrelation suggests that the model may be over-correcting for trends, which can inflate the significance of some variables while suppressing others.

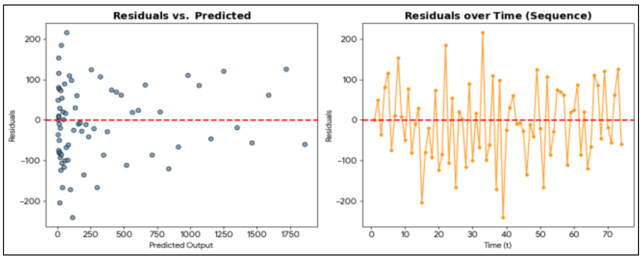
ANOVA

Table 4: ANOVA

	df	Deviance	Residual df	Residual Deviance	p	Vovk-Sellke Maximum p-Ratio: VS-MPR
NULL			73	111400		
Labour	73	1111400	0	0.000	<.001	∞
Capital	0	0.000	0	0.000		
Labour*Capital	0	0.000	0	0.000		

Source: Author's Calculations using JASP Team (2026). JASP (Version 0.96.0)

In the Log-Linear ANOVA table, Labour is highly significant (p < .001). The VS-MPR (Vovk-Sellke Maximum p-Ratio) is listed as (infinity), which is the strongest possible statistical evidence against the null hypothesis. This suggests that when looking at the data through a logarithmic lens—which often handles skewed data better—the relationship between Labour and the outcome is undeniable.



Source: Author's Calculations using JASP Team (2026). JASP (Version 0.96.0)

Fig 2: Residuals vs Predicted & Residuals over ime

The Durbin-Watson statistic of 2.898 indicated significant negative autocorrelation in the residuals (p < .001). Visual inspection of the residual time-series plot confirmed a non-random, alternating pattern in the error terms. This suggests that the standard linear model may be missing a cyclical or seasonal component, or that the rapid growth at the end of the time series is causing the model to over-correct from one period to the next.

Conclusions and Recommendations

The data provides clear evidence that the path to increased productivity lies in Capital deepening. While the workforce (Labour) is essential to the operation, its marginal contribution has reached a plateau. To unlock the next level of Output, the industry should prioritise technological and infrastructure investments, which currently offer a consistent 2.4-times return on every unit added. The predictive model is exceptionally robust ($R^2 = 0.997$). The Durbin-Watson score (2.060) confirms that these results are consistent and not influenced by hidden patterns or time-series biases.

Future scaling efforts should focus on capital acquisition or technological upgrades, as this variable offers the highest return on investment for increasing Output. Rather than increasing the quantity of Labour, focus on training or process improvements to reverse the slight diminishing returns observed in the linear model. The Log-Linear analysis suggests that at extreme scales, the data becomes more volatile. Regular 'health checks' on productivity ratios are recommended as the operation grows.

The present study focuses exclusively on the Cobb-Douglas production function, specifically examining the variables of labor and capital; consequently, resultant output and other extraneous influencing factors are excluded from this analysis. However, a comprehensive understanding of this field of production requires an investigation into several critical factors, including the heterogeneity of end products, technological advancements, and evolving consumer requirements and behaviours.

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