

Economic Triggers and Strategic Use of Blended Automation in Semi-Automatic Corrugated Box Manufacturing MSMEs: A Managerial Economics Framework Based on Cobb-Douglas Production Function

Kushal Pal Singh¹, Bhupinder Singh^{2*}, Madhukar Deshmukh³

1.Sharda University, Greater Noida, Uttar Pradesh, India. Email: kushal.pundir07@gmail.com

2*. Sharda University, Greater Noida, Uttar Pradesh, India Email: bhupender.singh@sharda.ac.in

3. JSPM University, Pune, Maharashtra, India. Email: mmd.secs@jspmuni.ac.in

*Corresponding Author

Abstract

Financial decisions are very important, especially in Micro, Small and Medium Enterprises (MSMEs) when cost of production outweighs the profits. The increased production leads to inefficiency in operations and reduction in expected quality even when highly trained manpower manages the operations. This leads to loss of profit margins. Increased manpower may also not enhance the profit margins. This is the moment when human led functions must be automated. Further, the shortages in availability of trained manpower and MSMEs being feebly or semi-automated, is aggravating the problem of operational inefficiency. Furthermore, non-availability of funds makes it difficult for MSMEs to afford complete automation. Automation is frequently perceived as a necessary response; however premature or excessive automation often results in financial stress and underutilized capacity. This paper proposes a framework that is economically grounded and adopts selective automation called blended automation combined with parameter sensing, data-based monitoring supported by managerial interventions. This paper uses firm level data of a feebly automated corrugated-box manufacturing firm and used Ordinary Least Square (OLS) and Three-stage Least Squares (3SLS) to estimate the Cobb-Douglas production function. Estimated output elasticities is used to derive marginal productivity and marginal revenue-marginal cost conditions. This indicates that input material is the predominantly drives the production output while labor and capital input exhibit reducing marginal productivity. The study points out the economic trigger moment at which targeted automation becomes economically justified. This framework aims to provide digitized decision-making tool for MSME firm owners thereby contributing to automation efforts in resource-constrained manufacturing environments in the country.

Keywords: MSMEs, corrugated box industry, blended automation, production function, marginal productivity

Introduction and Research Context

Expansion of the firm with existing semi-automatic processes becomes economically inefficient, when marginal revenue falls below marginal cost ($MR_t < MC_t$). This is the rational trigger for selective automation based on Value Stream Mapping (VSM), process redesign and enhanced digitized monitoring together called *Blended Automation*. Corrugated-box manufacturing in India is characterized by constrained capital availability, cost sensitivity and demand variability. Selective automation can be potentially a driver for enhancing productivity with expected quality while full-scale automation often will lead to disproportionately increasing fixed costs causing financial stress for MSMEs [1, 2]. The classical production theory points out that production output is generated utilizing capital, material, energy and labor. Progress in technology and learning of the processes enhances the productivity and quality [3,4]. The production decisions cannot be analyzed in isolation since both the revenue generation, and accumulation of cost influence the production process [5,6,1]. The proposed integrated approach that results in economic and operational framework for decision making on automation is relevant to MSMEs in India in general and corrugated-box manufacturing firms in specific due to its potential in influencing the marginal enhancement in quality and consistency of the products that can generate the higher margins on profit.

Methodology and Model Specification

The paper discusses a firm-level production-revenue-cost framework to examine productivity behavior and automation decision triggers in a semi-automatic corrugated box manufacturing MSME. The methodology uses microeconomic production theory, where optimal operational decisions are guided by marginal revenue (MR) and marginal cost (MC) conditions [7]. Cobb-Douglas production framework is employed to estimate the input elasticities and gives economically interpretable marginal analysis, making it particularly apt for MSME-level manufacturing firms [8] [3]. The interrelationship between production, cost and revenue is endogenous. Initially, we employed OLS estimation techniques to obtain estimates of baseline elasticities. However, it is found that this approach may result in biased and inconsistent estimates due to simultaneity, we further employed the 3SLS approach [9] which jointly estimates the elasticities.

The production process is modelled using a Cobb-Douglas production function, expressed as in Equation-1:

$$Q_t = AK_t^\alpha L_t^\beta M_t^\gamma E_t^\delta e^{\lambda T_t} \quad (1)$$

To facilitate estimation, Equation (1) is log-linearised and the baseline production model is specified in logarithmic form as:

$$\log Q_t = \log A + \alpha \log K_t + \beta \log L_t + \gamma \log M_t + \delta \log E_t + \lambda T_t + u_t \quad (2)$$

Equation (2) enables direct interpretation of coefficients as output elasticities such that

Q_t = monthly output (represented by monthly sales volume/value)

K_t = capital input (depreciation proxy)

L_t = labor input (wages)

M_t = material input (kraft paper consumption and consumable)

E_t = energy input (electricity and fuel)

T_t = time trend (learning effect)

A = Total factor productivity learning-by-doing and incremental process improvements

u_t = error term (captures random short-term shocks.)

The coefficients α , β , γ , and δ represent output elasticities of respective inputs. The intercept term A represents **total factor productivity**, capturing managerial efficiency, process discipline, layout effectiveness, and other unobserved firm-specific factors. Importantly, A is empirically estimated rather than assumed, consistent with standard productivity analysis [10][3].

To marginal revenue analysis is done wherein output is linked to observed revenue through a revenue function:

$$\log(R_t) = \phi_0 + \phi_1 \log(Q_t) + \phi_2 \log(P_t) + u_{2t} \quad (3)$$

where:

- R_t = total revenue
- Q_t = total output
- P_t = average selling price or realization per unit (price proxy)
- u_{2t} = error term

In the context of corrugated box manufacturing MSMEs, selling prices are often contract-based and relatively stable over short horizons. Consequently, variations in revenue are primarily driven by changes in output volume, and the elasticity ϕ_1 is expected to be close to unity. This specification allows estimation of marginal revenue without requiring a full demand function, which would be impractical at the firm level.

Equation (4): Cost Function

The cost structure is represented by a log-linear cost function:

- $\log C_t = \theta_0 + \theta_1 \log Q_t + \theta_2 \log W_t + \theta_3 \log R_{mt} + u_{3t}$ (4)
- C_t = total production cost
- W_t = labor cost proxy
- R_{mt} = raw material cost proxy
- u_{3t} = disturbance term

The coefficient θ_1 captures the elasticity of cost with respect to output and forms the basis for marginal cost estimation.

Initially, Equations (2)–(4) are estimated independently using Ordinary Least Squares (OLS). However, as output appears in both revenue and cost equations, simultaneity bias may arise. To address this, the system comprising Equations (2)–(4) is jointly estimated using **Three-Stage Least Squares (3SLS)**, following [11]

Data and Variable Measurement

Monthly operational and accounting data were obtained from a semi-automatic corrugated box manufacturing unit. Due to the absence of continuous physical measurement systems typical of MSMEs, financial proxies were employed for production inputs. Such proxy-based measurement is widely accepted in applied manufacturing and MSME studies where physical input data are unavailable or inconsistent [11]. All monetary variables were expressed in logarithmic form to stabilize variance and enable elasticity interpretation.

Derivation of Marginal Revenue and Marginal Cost

Estimated coefficients from the revenue and cost equations are used to derive marginal measures

$$MR_t \approx \phi_1 \times R_t / Q_t$$

$$MC_t \approx \theta_1 \times C_t / Q_t$$

These expressions provide empirically grounded approximations of marginal revenue and marginal cost, enabling evaluation of economic efficiency under existing operating conditions.

3. MANUFACTURING PROCESS ENGINEERING AND PROCESS MAPPING

The corrugated box manufacturing process comprises of multiple interlinked stages, beginning with procurement planning and culminating in dispatch of finished goods. Raw material handling and corrugation operations determine material input (M_t), capital utilization (K_t), labor deployment (L_t), and energy consumption (E_t), which jointly influence output (Q_t). Subsequent conversion, stitching, storage, and dispatch stages affect cost accumulation (C_t) and revenue realization (R_t). Since output simultaneously influences both revenue and cost, the production, revenue, and cost equations form a structurally interdependent system. Initially, each relationship is estimated independently using Ordinary Least Squares (OLS). However, to address simultaneity and cross-equation error correlation inherent in the manufacturing process, the system is jointly estimated using Three-Stage Least Squares (3SLS). This integrated framework enables evaluation of economic triggers for selective, or blended, automation across different production stages.

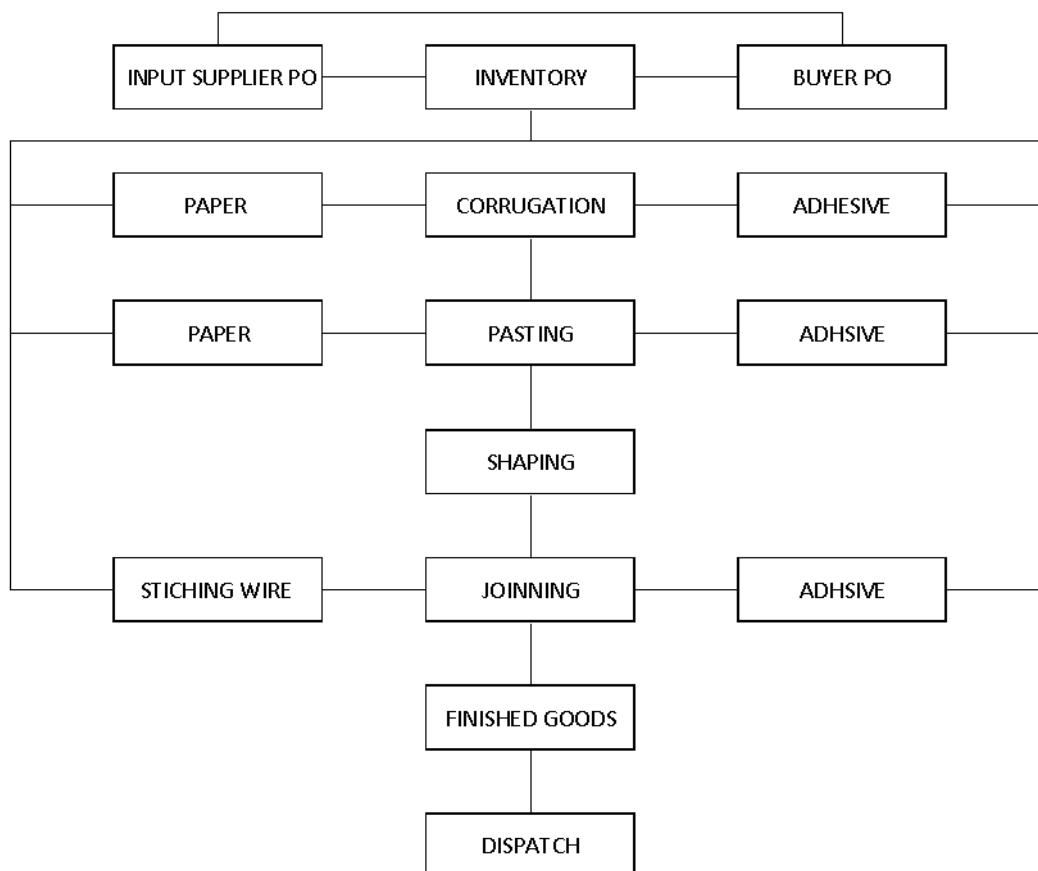


Fig 1. Manufacturing process of semi-automatic corrugated boxes

Table 1 Process Stages and Automation Opportunity

Process Stage	Process Explanation	Nature of Operation	Automation Opportunity	Blended Automation Justification
Stage 1: Input Procurement	Manufacturing begins with buyer POs defining specifications, which then trigger supplier POs for raw materials like kraft paper and adhesives.	Predominantly manual and managerial; relies on experience-based decisions and is highly dependent on order variability.	Low-cost digital automation, such as PO tracking via Excel/Tally, demand dashboards, and historical analytics.	Full ERPs may increase fixed costs unnecessarily; simple digital tools provide high marginal benefit at low marginal cost ($MR > MC$).
Stage 2: Inventory Management	Raw materials are stored and issued based on daily planning; paper quality (GSM, moisture) is critical for production efficiency.	Semi-structured; involves manual checks and often reactive procurement in MSMEs.	Selective automation using barcode-based tracking, GSM data logging, and FIFO-based digital sheets.	Improves material yield and reduces wastage, increasing the Average Product of Material (APM) with minimal capital expenditure.
Stage 3: Corrugation	Paper reels are fluted, adhesive is applied, and liners are bonded to define output quantity (Q) and quality metrics.	Semi-automatic and operator skill-dependent; sensitive to heat, speed, and moisture.	High-impact blended automation using temperature sensors, glue consumption monitoring, and real-time data logging.	Sensor-based monitoring improves consistency where the MR from quality improvement exceeds the MC of sensors at critical points.
Stage 4: Pasting / Adhesive Application	Adhesive is applied during formation and conversion; quality affects bonding strength and drying time.	Operator-controlled with high variability across different shifts.	Process-control automation, including viscosity measurement and flow rate indicators.	Measurement-based automation ensures consistency at low cost, improving the Marginal Physical Product (MPP) of adhesive.
Stage 5: Shaping	Corrugated boards are converted into box blanks using slotting and creasing machines.	Semi-automatic but set-up time intensive with common changeover losses.	Partial automation via digital job cards, setup parameter memory, and production counters.	Justified for setup reduction and accuracy rather than full robotics to keep fixed costs under control while improving throughput.
Stage 6: Stitching / Joining	Boxes are joined using stitching or adhesive depending on the required strength.	Highly labour-intensive; quality is dependent on the specific skill of the operator.	Limited automation, utilizing semi-automatic machines and quality checklists rather than vision systems.	Full automation increases MC disproportionately; skill-based labour remains optimal due to low labour cost elasticity.
Stage 7: Finished Goods Storage	Completed boxes are bundled, counted, and stored while awaiting dispatch.	Manual counting and stacking; often space-constrained in MSME environments.	Information automation, such as production-linked dispatch planning and inventory ageing reports.	Digitizing information flow (not physical movement) improves reliability without capital-intensive warehousing systems.
Stage 8: Dispatch	Finished goods are dispatched according to the schedules provided by the buyer.	Manual coordination with variability depending on transport factors.	Low-cost automation through dispatch dashboards and invoice-reconciliation.	Improves revenue realization (R) without increasing production costs, positively affecting profit maximization.

Key Insights from the Decision Framework

Rational Triggers: Automation decisions are treated as a rational trigger based on the relationship between marginal revenue and marginal cost. When $MR_t < MC_t$ under current semi-automatic conditions, the system identifies a need for "blended automation" monitoring and/or mechanization to restore efficiency.

Table 2 Stage decision Nodes

Stage / Decision Node	Key Decision Question	Econometric Logic & Rationale	Linked Variables	Strategic Decision
D1: Procurement & Planning	Does automation reduce planning errors and stock-outs significantly?	Automation is triggered when $MR_t > MC_t$; otherwise, existing processes remain.	M_t, C_t (Indirect)	Information automation only (Spreadsheets/Dashboards)
D2: Raw Material Inventory	Does measurement automation reduce material wastage?	Moisture and GSM variations impact material elasticity (γ). High MR is achieved even through small wastage reductions.	M_t, C_t, Q_t	Selective measurement automation
D3: Corrugation (Core Node)	Does sensor-based control improve output quality and consistency?	Highest-priority node. Enhances revenue elasticity of output (ϕ_1), improves Q_t , and lowers C_t by reducing rejects.	K_t, L_t, M_t, Et, Q_t	IoT/Sensor-based automation (ESP32 Logic)
D4: Adhesive Application	Does automation improve bonding without increasing glue cost?	Controlled application improves bond strength (BS) while preventing the high marginal costs (MC) associated with excess glue.	M_t, Q_t, C_t	Control automation (Not full mechanization)
D5: Conversion (Slotting & Creasing)	Does automation reduce setup time more than its cost?	Justified only for frequent job changes where changeover time significantly hinders effective output (Q_t).	K_t, L_t, Q_t	Conditional automation
D6: Stitching / Pasting	Does automation substitute labour economically?	In MSMEs, labour elasticity (β) is often low-cost; automation may sharply increase fixed costs, making it inefficient.	L_t, C_t	Manual preferred
D7: Storage & Dispatch	Does automation improve cash flow and delivery reliability?	Faster dispatch cycles directly improve revenue (R_t) with minimal additional investment cost.	R_t, C_t	Information automation

Blended Approach: This logic prioritizes information and control automation (Nodes D1, D2, D4) over expensive mechanization where the economic benefit (such as labor substitution in Node D6) does not justify the cost.

Table3: Mapping of Corrugation Process Stages to Model Variables

Process Stage	Description	Model Variable	Role in OLS / 3SLS
Stage 1: Buyer & Supplier PO	Order receipt and procurement planning	—	Exogenous managerial decision (context variable)
Stage 2: Raw Material Inventory	Kraft paper, fluting medium, adhesives	M_t	Material input in Cobb–Douglas production function
Stage 3: Corrugation (Board Formation)	Fluting, heating, bonding	Q_t	Endogenous output variable (core system variable)
	Machine availability, heaters, corrugator	K_t	Capital input
	Operators, helpers	L_t	Labour input
	Steam / electricity / PNG	E_t	Energy input
	Learning, maintenance, layout improvement	T_t	Technological progress (time trend)
Stage 4: Adhesive Application	Glue preparation and application	M_t	Material productivity driver
Stage 5: Slotting / Creasing	Conversion of board to blanks	Q_t	Affects effective output realization
Stage 6: Stitching / Pasting	Final box formation	L_t	Labour-intensive stage
Stage 7: Finished Goods Storage	Inventory holding	C_t	Cost accumulation
Stage 8: Dispatch	Shipment to customer	R_t	Revenue realization

Variable Mapping: The framework ensures that every technological intervention directly addresses specific econometric variables, such as capital (K_t), labour (L_t), and output quality (Q_t), preventing over-investment in non-critical stages.

4. Results and Discussion

The estimated elasticities indicate that material input has the highest contribution to output, reflecting the material-intensive nature of corrugated box manufacturing. Labor and capital elasticities are positive but relatively low, suggesting diminishing marginal productivity under existing semi-automatic operating conditions. Energy elasticity is minimal, indicating its primary influence on cost rather than output expansion.

The positive and statistically significant technology trend reflects gradual productivity improvement attributable to learning-by-doing and incremental process improvements, consistent with classical learning theories [9]. These results enable the derivation of marginal productivity and marginal revenue measures for individual inputs.

When marginal revenue generated by labor or capital falls below their marginal cost, the firm enters a zone of economic inefficiency. This condition represents a rational trigger for selective automation or process redesign rather than wholesale mechanization

5. Limitations and Scope for Future Research

The study is based on data from a single manufacturing unit, limiting statistical generalization. However, the objective is analytical generalization and methodological demonstration. Future research may extend the framework using multi-firm datasets, real-time operational data from Sensors and IOT, and longitudinal comparisons before and after automation adoption.

6. Conclusion

This paper demonstrates that automation decisions in semi-automatic corrugated box manufacturing MSMEs can be economically justified using production and cost data. By identifying marginal revenue–marginal cost trigger points, the blended automation framework supports sustainable productivity enhancement without imposing excessive capital risk. The study contributes to applied MSME research and provides actionable insights for practitioners and policymakers.

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