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Simultaneous Estimation of Cost Drivers

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SYNOPSIS AND INTRODUCTION: Managers frequently choose the amounts to expend in various activities simultaneously rather than sequentially. Quality costs provide a common example. When managing quality, decisions to invest in different types of prevention activities are made jointly. For example, spending more on maintenance simultaneously reduced the spending necessary on supervision. Similarly, scrap costs are often traded off against the costs of prevention and appraisal activities.

Our article is motivated by field observations at an automobile lamp manufacturing plant. Specifically, we estimate two observed effects: (1) the influence of lamp design on the consumption of overhead resources during manufacturing (e.g., the effect of multicolor designs on supervision costs) and (2) the interdependence among supervision, maintenance, and scrap costs.

One way to understand cost drivers and manage costs is to employ an activity-based costing approach (Cooper and Kaplan 1991, chap. 5; Young and Selto 1991). With this approach, prevention costs of supervision and maintenance are allocated to products on the basis of hours of supervision and maintenance, and scrap costs are apportioned on the basis of physical scrap levels. Quality-related costs are reevaluated after products are redesigned and processes reconfigured to determine if quality related costs have indeed decreased. With such an approach, simultaneous effects of costs are not estimated.

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In our approach, we simultaneously estimate interdependencies among activities. Instead of supervision hours, maintenance hours, and physical scrap levels, we use product and process design variables as cost drivers of supervision, maintenance, and scrap costs. Selecting product and process variables as cost drivers allows us to estimate the effect of alternative lamp designs on quality costs incurred during manufacturing. We also explicitly consider simultaneity. For example, our estimation procedure recognizes that maintenance costs affect supervision costs and vice versa and that both costs are affected by product and process design choices.

Our analysis provides valuable information to managers. At our site, designers use quality costs associated with different design features to guide future product designs and modifications. Similarly, as operations managers experiment with different methods to manage complexity, the simultaneous cost estimation enables them to evaluate which prevention activities are successful in reducing scrap.

Key Words: *Product costing, Cost drivers, Simultaneous cost estimation, Costs of quality, New products.*

Data Availability: *The data upon which this article is based may be obtained from the authors on request, subject to release by the company.*

THE organization of the paper is as follows. Section I describes the research site and provides a description of the cost categories and product and process characteristics that drive cost. Section II discusses the simultaneous equations estimation of our study. Key results are presented in section III. Concluding comments are presented in section IV.

I. Research Site

Our research site is a manufacturing facility for lamp assemblies for automobiles and trucks. A lamp has two components, a lens and a housing. But the products are diverse, ranging from simple lamps, such as park and signal lamps, to complex rear lamps equipped with multicolor lenses with special geometry and intricate optics. An injection-molding operation is the primary manufacturing process at the plant. The process consists of shooting molten plastic into a mold (also called a die or tool), which is designed to give the lens its desired shape and form when the plastic cools and solidifies.

Overhead costs at the plant are a substantial proportion of total costs, and are the focus of attention for cost management. We examine four major categories of overhead—supervision, tool maintenance, quality control and inspection, and scrap cost. The existing cost-accounting system assigns these overhead costs to products on the basis of traditional drivers, labor and machine hours. To verify whether the overhead costs allocated are representative of the demands placed on resources by individual products, we directly identify the overhead resources of supervision, inspection, tool maintenance, and scrap associated with individual products. At our research site, direct identification is possible due to the nature of production flows and the level of specialization at the plant. Each part is typically produced in a single molding department. Supervisors assigned to a specific department oversee the production of only 10–15 components.

Description of Costs

Supervision costs account for careful monitoring by supervisors to reduce tool breakages, tool maintenance, and the need for preventive maintenance. Part defects are also reduced as more care is taken by supervisors to prevent such defects from occurring. The time spent by supervisors on individual components was determined using structured interviews. The data are validated, triangulated, and cross-checked by using informal logs, sampling, and observation by the researchers.

Tool maintenance costs consist of the direct labor and material costs incurred in maintaining molds and the indirect costs of tool room supervision, stocking and tracking of tools, and maintenance of tool room equipment. Tool maintenance activities include cleaning the mold after use and stripping it after a certain number of cycles. Maintenance requires replacing moving parts (e.g., rollers, core lifts, and sliding cores), resurfacing the mold for surface finish, ensuring the proper and smooth functioning of moving parts, and making necessary adjustments whenever lens tolerances are violated. The tool maintenance resources consumed by individual products were determined from detailed toolroom records of the time spent on maintaining and repairing individual tools. Each tool is uniquely identified with a particular product so that tool maintenance can be directly traced to individual products.

Quality control and inspection costs are the indirect costs of quality. They include the efforts of technicians and inspectors responsible for ensuring that only defect-free products are sent out to assembly centers. As the probability of a product being out of tolerance increases, greater quality control costs are incurred to screen out defective units. An approach similar to supervision costs was adopted to collect data on quality control and inspection costs.

Scrap costs are computed on the basis of detailed records of rejected lenses and revised identification of costs to products. The quantity of rejects recorded by supervisors was validated with records maintained by the quality assurance department.

The correlations among the per unit costs of supervision, tool maintenance, quality control and inspection, and scrap across various products (computed on the basis of the time spent and resources consumed) are positive (see table 1). However, as discussed in section III, after controlling for complexity, the correlations between prevention activities (supervision and tool maintenance) and scrap costs become negative.

Factors of Product and Process Complexity

Our choices of complexity factors that drive demands for overhead resources were based on detailed studies of the plant, and knowledge of the physics and engineering aspects of the plastic injection-molding process. The critical activity in the molding process is the functioning of the mold or tool itself. The complexity of the mold increases with the cross sectional area and the number of moving parts required to give the lens its shape, contours, and curves. The area over which the molten plastic flows

Table 1
Correlations Among Cost Categories

Variables	*Supervision*	*Tool Maintenance*	*Quality Control*	*Scrap*
Supervision	1.000	0.280	0.697	0.245
Tool Maintenance	0.280	1.000	0.124	0.186
Quality Control	0.697	0.124	1.000	0.232
Scrap	0.245	0.186	0.232	1.000

and cools is a measure of complexities resulting from the size of the mold as well as manufacturing complications associated with heating and cooling cycles. A larger area increases the problems of spots, cracks, and "short shots" (which arise when the entire mold is not filled with molten plastic). Hence, we define moving-part complexity as the product of the number of moving parts and the cross-sectional area.[1] Data on moving parts and area were obtained from the tool specification report and were cross-checked with the tool audit report.

Multicolor molding is a complex operation requiring molten plastic of two or more colors to be injected into the mold at different points in the manufacturing cycle. The complexity arises because, to prevent two colors from mixing, the first color must completely dry out and solidify before the next color is injected. The process requires careful and rigorous monitoring of temperatures and pressures, and heating and cooling cycles. The advantage of multicolor molding is the excellent finish imparted to the lens. The complexity of multicolor molding increases with the surface area over which the plastic must flow and form. We therefore define multicolor molding complexity as the product of a dummy variable (1 if the product is multicolor molded, 0 otherwise) and area. Data on multicolor molded parts and area were obtained from the product design records and were cross-checked with the tool specification report.

Supervisors have to ensure that the temperature profile during start-up follows specifications, and molding of production parts begins only after the required thermal stability is achieved. The duration of the warm-up period varies by products and machine instrumentation. The longer the period, the greater the care and attention required from supervisors during production runs. The thermal stability factor, defined as the ratio of the run length to warm-up period, captures the relative complexity of the molding process from a supervisory standpoint. This factor was obtained from the process specification drawn up by the quality assurance department.

Depth captures the complexity of plastic flow to mold a part. Also, deep tools are difficult to maintain and modify since certain parts of the mold are harder to reach and clean. Furthermore, the quantity of plastic required across the length of the lens is not uniform. This causes complications in the heating and cooling cycles. The depth of each component was measured in inches and obtained from product design and tool specification reports.

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[1] This measure is closely correlated with the number of moving parts in the mold. The interaction term is a better representation of engineering complexity.

Table 2
Summary Statistics
(N=121)

Cost Variable	Mean	Variance
Endogenous (cost per unit)		
Supervision	0.056	0.036
Tool maintenance	0.171	0.049
Quality control	0.007	0.000
Scrap	0.510	0.864
Exogenous		
Direct labor hours (per unit)	0.826	1.622
Moving-parts complexity (per unit)	0.006	0.000
Multicolor molding	4.300	5.782
Thermal factor	8.245	3.178
Number of functions	1.917	1.360
Machine complexity	0.157	0.262
Depth	1.092	1.198
Direct labor inspection (hours per unit)	0.050	0.002

Lenses frequently perform multiple functions. For example, a multifunction (or combination) lamp may have a rear lamp, license plate lamp, and back-up lamp all combined into a single product. These lamps must be built to meet the functional specification of each component product. Combination lamps require simultaneous satisfaction of tolerances and complex interactions among tolerances, and hence place increased demand on manufacturing overhead resources. The variable for number of functions measures the number of different lamps that are combined into a single lamp. Data on number of functions were obtained from detailed part drawings.

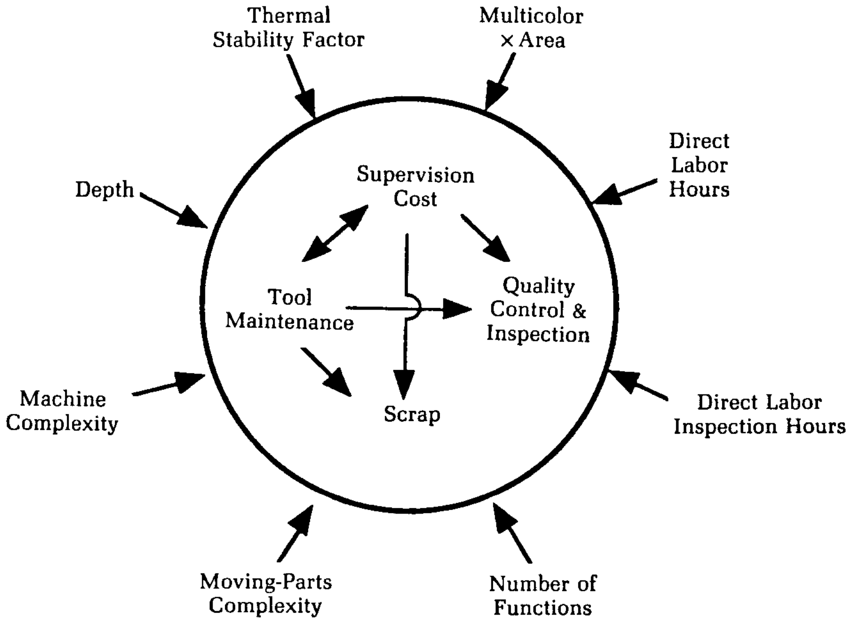
Complex machines, by definition, are difficult to operate. These machines typically have multiple controls that need to be properly synchronized for the production of good components. High-tonnage machines are also difficult to operate. The large force applied by large machines demands that the mold be carefully set to prevent damage to it and to ensure the production of defect-free units. We use the replacement cost of the machines as a surrogate for complexity and size of the machines. This information was obtained from the accounting and finance departments.

Summary statistics for all the key variables are presented in table 2. The variables are categorized as either endogenous or exogenous, which will be explained in the next section.

II. Simultaneous Estimation

As discussed earlier, product and process features committed at the design stage (e.g., moving parts in the mold and multicolor molding), affect the consumption of overhead resources during manufacturing. Further, interdependencies exist among cost categories. The thrust of our empirical estimation is to recognize that various activities are simultaneously related and do not arise sequentially or independently. For example, both product and process complexity factors and resources expended on prevention and appraisal drive scrap costs.

Figure 1
Proposed Simultaneous Cost-Engineering System



Note: The exogenous variables are represented outside the enclosed endogenous variables.

We attempt to capture the effects of complexity factors as well as other managerially controllable activities on the consumption of various overhead resources. We refer to the cost drivers of product design and process engineering (such as characteristics of the mold and the type of equipment) as *exogenous* variables (see also Banker et al. 1990) because these variables are determined outside the plant domain. Variables (such as the shape, size, and contours of individual lamps) are chosen by assembly divisions on the basis of consumer preferences, aesthetics, and functionality. Exogenous variables affect variations in resources of supervision, tool maintenance, quality control, and scrap according to variations in the manufacture of individual lamps within the plant.

We classify supervision, tool maintenance, quality control, and scrap resources as *endogenous* because their values are determined simultaneously within the plant in response to exogenous factors. The interactions among endogenous variables determine the econometric methodology to estimate the drivers of supervision, tool maintenance and quality control activities, and resources lost by way of scrap. We estimate the resources consumed within the plant as a system of simultaneous equations. Failure to recognize interdependencies among resources leads to erroneous estimates and incorrect conclusions about the effects of exogenous and endogenous variables on activities.

A schematic representation of the interdependencies among variables is presented in figure 1. All exogenous variables are outside the encircled endogenous variables.

Each endogenous variable is determined by the effect of a set of influencing exogenous variables and simultaneity effects from other endogenous variables.

We estimate the following system of equations where the endogenous variables are: $\mathit{SUPCOST/UNIT}$, the supervision cost of each lens; $\mathit{TMCOST/UNIT}$, the cost in tool maintenance incurred per unit; $\mathit{QCCOST/UNIT}$ the cost per unit of quality control and inspection; and $\mathit{SCRAPCOST/UNIT}$, the cost of scrap generated per unit.

$$\begin{aligned}\mathit{SUPCOST/UNIT} = {} & \alpha_{11} + \beta_{11}(\mathit{MVGPTS\ COMPL})/\mathit{UNIT} + \beta_{12}(\mathit{MULTCLR}*\mathit{AREA}) \\ & + \beta_{13}\mathit{THERMFAC} + \beta_{14}\mathit{NUMFUNC} + \beta_{15}\mathit{MACHCOMPL} \\ & + \beta_{16}\mathit{DIRLABHRS/UNIT} + \gamma_{11}\mathit{TMCOST/UNIT} + \epsilon_1.\end{aligned} \tag{1}$$

$$\begin{aligned}\mathit{TMCOST/UNIT} = {} & \alpha_{21} + \beta_{21}(\mathit{MVGPTS\ COMPL})/\mathit{UNIT} + \beta_{22}(\mathit{MULTCLR}*\mathit{AREA}) \\ & + \beta_{23}\mathit{NUMFUNC} + \beta_{24}\mathit{DEPTH} + \beta_{25}\mathit{MACHCOMPL} \\ & + \gamma_{21}\mathit{SUPCOST/UNIT} + \epsilon_2.\end{aligned} \tag{2}$$

$$\begin{aligned}\mathit{QCCOST/UNIT} = {} & \alpha_{31} + \beta_{31}(\mathit{MVGPTS\ COMPL})/\mathit{UNIT} + \beta_{32}(\mathit{MULTCLR}*\mathit{AREA}) \\ & + \beta_{33}\mathit{DEPTH} + \beta_{34}\mathit{MACHCOMPL} + \beta_{35}\mathit{DINSPHRS/UNIT} \\ & + \gamma_{31}\mathit{SUPCOST/UNIT} + \gamma_{32}\mathit{TMCOST/UNIT} + \epsilon_3.\end{aligned} \tag{3}$$

$$\begin{aligned}\mathit{SCRAPCOST/UNIT} = {} & \alpha_{41} + \beta_{41}(\mathit{MVGPTS\ COMPL})/\mathit{UNIT} + \beta_{42}(\mathit{MULTCLR}*\mathit{AREA}) \\ & + \beta_{43}\mathit{NUMFUNC} + \beta_{44}\mathit{DEPTH} + \beta_{45}\mathit{MACHCOMPL} \\ & + \gamma_{41}\mathit{SUPCOST/UNIT} + \gamma_{42}\mathit{TMCOST/UNITF} + \epsilon_4.\end{aligned} \tag{4}$$

The exogenous variables are described as follows:

DEPTH = depth of a lens in inches,
$\mathit{DINSHRS/UNIT}$ = measure of the direct labor inspection hours per unit, as determined by the standard operating procedures for the product,
$\mathit{DIRLABHRS/UNIT}$ = measure of the direct labor hours per unit based on process-routing sheets,
$\mathit{MACHCOMPL}$ = machine complexity measured by the replacement cost of each machine,
$\mathit{MULTCLR} \times \mathit{AREA}$ = the area of a multicolor mold,
$\mathit{MVGPTS\ COMPL/UNIT}$ = the complexity of the sweep path of the moving parts in the mold. We divide by production volume since overhead costs are incurred setting up the mold, independently of the volume of production,
$\mathit{NUMFUNC}$ = the number of functions in the lens, and
$\mathit{THERMFAC}$ = the thermal stability factor associated with each lens and is measured as the ratio of the run period to the warm-up period.

The system of equations describes interactions among resources consumed. We expect the sign of the coefficient (β_{ij}) of each exogenous variable (except the thermal stablity factor) in the system of equations to be positive. An increase in complexity factors increases the demand on overhead resources. We elaborate next on the endogenous variables in the system of equations.

The first equation describes the drivers of supervisory resources. Tool maintenance cost per unit is an explanatory variable in equation (1). Fault-free functioning of the tool is a critical element in the smooth and continuous production of lens components. The effective maintenance of tools reduces the need for adjustments and reruns, and thereby reduces supervisory costs. We hypothesize that the coefficient of tool maintenance cost per unit (γ_{11}) will be negative in equation (1).

The second structural equation reflects the expectation that additional resources devoted to supervision have a beneficial effect on tool maintenance costs. Careful monitoring and supervision and better handling of the tool ensure proper alignment and functioning of moving parts. Thus tools remain within tolerance limits for longer periods, reducing the demand for tool maintenance. We hypothesize that the coefficient of supervisory cost per unit (γ_{21}) will be negative in the second structural equation (2), which suggests a substitution effect.

We specify quality control and inspection costs per unit as a derived endogenous variable. That is, the amount of quality control and inspection expenditure on a product depends on the firm's experience with defect rates for that product. If defect rates for a product are high, greater overhead resources of quality control and inspection are expended on that product. Direct inspection hours reflect the intrinsic complexity of line inspection demanded by a product from line operators.

Equation (3) specifies that resources devoted to prevention activities of tool maintenance and supervision decrease quality control costs per unit. We therefore hypothesize that the sign of the coefficient for tool maintenance cost per unit (γ_{32}) and that for supervisory cost per unit (γ_{31}) are negative. Quality control and inspection costs have no influence, however, on supervision and tool maintenance costs. Quality assurance activities at this site are reactive in nature. The major objective of inspection is to identify defective products before faulty components are shipped to assembly plants.

Similarly, the structural equation for scrap specifies the effect of supervision and tool maintenance on scrap costs. The signs of the coefficients of supervisory cost per unit (γ_{41}) and tool maintenance cost per unit (γ_{42}) are anticipated to be negative in equation (4). The equation reflects the widely held perception that increased prevention activities improve quality and mitigate failure. The implication for cost driver analysis is to recognize that costs incurred in prevention (tool maintenance and supervision) are drivers of scrap costs.

Ordinary least squares (OLS) cannot be applied on an equation-by-equation basis in this case because the disturbance term and endogenous explanatory variables are correlated. The direct application of least squares to each equation yields biased and inconsistent estimates of the coefficients. The system of equations are estimated by using the two-stage least squares procedure. The two-stage technique yields unbiased and consistent parameters. The structural form of the system of equations reveals direct effects of complexity and the endogenous relationships among overhead resource categories. The reduced form is easily obtained by solving the system of simultaneous equations for the endogenous variables.

III. Results and Discussion

The results[2] of the two-stage least squares procedure for the structural equations are presented in table 3 and OLS results are reported in table 4. As noted earlier, OLS

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[2] The parameter estimates are very robust. We reestimated the model after dropping 5 percent of the observations at random. All the coefficients and their signficance levels were found to be stable. We also checked for multicollinearity using the Belsey et al. test (1980).

estimates are biased and inconsistent. For example, OLS estimates lead to the erroneous conclusion that moving-parts and machine complexity have a significantly lower effect on unit supervision cost.[3] The results with two-stage least squares show the effect of moving-parts and machine complexity to be significantly greater.[4]

The structural equations characterize two effects. The first is the direct effect of exogenous variables such as moving parts, multicolor molding, thermal stability, number of functions, depth, and machine complexity on supervision, tool maintenance, quality control and inspection, and scrap resources. For example, a unit increase in moving-parts complexity results in expected direct effects of $16.26 on unit supervision cost (see table 3, panel A), $20.33 on unit tool maintenance cost (panel B), $7.97 on unit quality control cost (panel C) and $24.27 on unit scrap cost (panel D). Our results suggest that products and process design features, committed at the design stage, significantly affect manufacturing overhead costs at our site. The cost effects of specific features on subsequent quality-related manufacturing overheads constitute useful information for designing new products and modifying existing ones. For example, managers and designers at our site have begun focusing on designing fewer moving parts into lamps as a means of managing costs.

The second effect is the indirect influence of endogenous variables. The coefficient estimates for the endogenous variables in the structural equations in the second stage of the two-stage procedure (reported in table 3) are all negative and significant.[5] Prevention activities are chosen simultaneously and reduce scrap costs at our site. In particular, increasing supervisory resources, in response to exogenous increases in complexity, by $1 per unit has the effect of decreasing tool maintenance cost by $0.20 per unit (see panel B of table 3), quality control cost by $0.07 per unit (panel C), and scrap cost by $0.30 per unit (panel D).

The net effect can be derived by simultaneously solving the system of equations and describing each overhead cost (endogenous variable) in terms of exogenous factors alone. The derived system of equations are the structural equation in the reduced form. For example, the reduced form coefficients of moving-parts complexity (the effect of a unit increase in moving-parts complexity on each overhead cost category) is as follows:

Supervisory cost per unit	$12.18
Tool maintenance cost per unit	$17.93
Quality control inspection cost per unit	$ 3.24
Scrap cost per unit	$16.91

Note that the corresponding OLS coefficients in table 4 differ substantially (−57 percent to +12 percent) in magnitude as compared to the reduced form results. Also, the net effect of an increase in moving-parts complexity on each category of cost is less than the direct effect of complexity on each cost individually from the results in table 3. The structural equations indicate that this lower net effect is attributable to favorable interaction among cost categories. For example, the direct effects of moving-part com-

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[3] In fact, the OLS estimates suggest that higher machine complexity (−0.025) lowers supervision cost.

[4] We also estimate the system of equations using three-stage least squares. Our results are robust to these estimation procedures.

[5] We confirmed the endogenous nature of *SUPCOST* and *TMCOST* by conducting the test proposed by Spencer and Berk (1981).

Table 3
Two-Stage Least Squares Estimates

Panel A. Dependent Variable, Supervision (Cost / Unit):

Independent Variable	*Coefficient*	*Standard Error*	T-*Ratio*
Intercept	0.0016	0.0155	0.109
Moving Parts Complexity / Unit	16.2590	2.1791	7.461
Multicolor × Area	0.0034	0.0009	3.756
Thermal Stability Factor	−0.0011	0.0001	−8.179
Number of Functions	0.0004	0.0074	0.064
Machine Complexity	0.3167	0.0584	5.424
Direct Labor Hours / Unit	0.0314	0.0123	2.548
Tool Maintenance Cost / Unit	−0.2274	0.0845	−2.691

Panel B. Dependent Variable, Tool Maintenance (Cost / Unit):

Independent Variable	*Coefficient*	*Standard Error*	T-*Ratio*
Intercept	0.1190	0.0323	3.673
Moving Parts Complexity / Unit	20.3288	5.0001	4.066
Multicolor × Area	0.0041	0.0025	1.619
Number of Functions	−0.0105	0.0178	−0.591
Depth	0.0796	0.0240	3.309
Machine Complexity	0.1961	0.0970	2.021
Supervision Cost / Unit	−0.1967	0.0540	−3.637

Panel C. Dependent Variable, Quality Control (Cost / Unit):

Independent Variable	*Coefficient*	*Standard Error*	T-*Ratio*
Intercept	0.1518	0.0034	44.226
Moving Parts Complexity / Unit	7.9734	0.7666	10.400
Multicolor × Area	0.0009	0.0003	3.114
Depth	0.0214	0.0029	7.360
Machine Complexity	0.0373	0.0117	3.174
Direct Inspection Hours / Unit	0.2552	0.1040	2.453
Supervision Cost / Unit	−0.0761	0.0239	−3.182
Tool Maintenance Cost / Unit	−0.2120	0.0294	−7.191

Panel D. Dependent Variable, Scrap (Cost / Unit):

Independent Variable	*Coefficient*	*Standard Error*	T-*Ratio*
Intercept	0.4780	0.0333	14.323
Moving Parts Complexity / Unit	24.2689	4.6384	5.232
Multicolor × Area	0.0059	0.0022	2.636
Number of Functions	0.0892	0.0147	6.319
Depth	0.0736	0.0195	3.774
Machine Complexity	0.4497	0.0807	5.571
Supervision Cost / Unit	−0.2994	0.1849	−1.619
Tool Maintenance Cost / Unit	−0.2070	0.1178	−1.758

Table 4
OLS Estimates Using Only Exogenous Variables

Panel A. Dependent Variable, Supervision (Cost / Unit; $R^2=0.84$*):*

Independent Variable	*Coefficient*	*Standard Error*	*T-Ratio*
Intercept	−0.0097	0.0141	−0.690
Moving Parts Complexity / Unit	11.7702	2.0321	5.811
Multicolor × Area	0.0071	0.0005	16.751
Thermal Stability Factor	−0.0008	0.0001	−10.933
Number of Functions	0.0403	0.0534	0.754
Machine Complexity	−0.0251	0.0089	−2.823
Direct Labor Hours / Unit	1.6065	0.8138	1.973

Panel B. Dependent Variable, Tool Maintenance (Cost / Unit; $R^2=0.39$*):*

Independent Variable	*Coefficient*	*Standard Error*	*T-Ratio*
Intercept	0.1141	0.0323	3.523
Moving Parts Complexity / Unit	13.9803	4.6694	2.994
Multicolor × Area	0.0021	0.0019	1.073
Number of Functions	0.0174	0.0119	1.457
Depth	−0.0808	0.0242	−3.341
Machine Complexity	0.3035	0.0922	3.291

Panel C. Dependent Variable, Quality Control (Cost / Unit; $R^2=0.62$*):*

Independent Variable	*Coefficient*	*Standard Error*	*T-Ratio*
Intercept	0.0292	0.0045	6.521
Moving Parts Complexity / Unit	1.4002	0.6440	2.174
Multicolor × Area	−0.0001	0.0002	−0.460
Number of Functions	0.0041	0.0025	1.602
Machine Complexity	0.0114	0.0137	0.832
Direct Inspection Hours / Unit	0.4626	0.2637	1.754

Panel D. Dependent Variable, Scrap (Cost / Unit; $R^2=0.76$*):*

Independent Variable	*Coefficient*	*Standard Error*	*T-Ratio*
Intercept	0.4529	0.0285	15.891
Moving Parts Complexity / Unit	18.8597	3.8004	4.963
Multicolor × Area	0.0037	0.0017	2.189
Number of Functions	0.0917	0.0142	6.465
Depth	0.0587	0.0182	3.224
Machine Complexity	0.4365	0.0770	5.669

plexity on quality control and scrap costs are $7.97 (panel C of table 3) and $24.27 (panel D), respectively. The increased prevention expenses on supervision and tool maintenance, however, restrict the net effect of moving part complexity on quality control to $3.24 and to $16.91 on scrap.

Quality improvement programs focus on understanding the causes of scrap and reducing defects generated in the plants. Our two SLS analysis indicates that the scrap costs are significantly influenced by underlying complexity drivers. But the adverse effect of increased complexity on scrap costs is mitigated by prevention activities and better management of complexity through tool maintenance and supervision activities. The two-stage approach offers a better understanding of the underlying structure with respect to the effects of complexity and the payoffs from prevention activities. These insights are not available from OLS or reduced form analysis.

Operations managers at our site handle various types of complexity differently. The reduced form suggests that managers respond to moving-part complexity by investing more in tool maintenance than in supervision.[6] Conversely, they respond to machine complexity by investing in greater supervision rather than tool maintenance.[7]

Note that the above discussion is based on the current operating practices and may not reflect optimal resource allocations. The analysis, however, provides guidance for managing product features to lower costs, and improve profitability. Further insights on managing complexity can be gained by replicating our analysis over time across plants or examining sites that choose different responses to complexity. The effects on failure and scrap can then be compared by using the two-stage method that controls for differences in complexity across the plants.

Our results also provide empirical support for the ABC hypothesis that non-volume drivers (i.e., drivers other than direct labor and machine hours) affect the demand for overhead resources. At our site, for example, direct labor explains only a fraction of supervisory overhead. We find that cost drivers such as moving parts, multicolor molding, and machine complexity significantly affect overhead resources.

IV. Conclusion

The contribution of our analysis in understanding cost structures is two-fold. First, we recognize and incorporate simultaneity among overhead costs in estimating drivers of these costs. Second, we measure the effect of product and process features on overhead costs in the presence of simultaneity. As demonstrated earlier, failure to recognize simultaneity results in inaccurate estimates of the effect of the cost drivers.

The analysis yields information for making design modifications by quantifying the manufacturing cost impact of product features. For example, any design changes that reduce the number of moving parts in the mold substantially lowers the expenditures in supervision, tool maintenance, and quality control. The estimates from the structural equations provides insights into the direct effect of complexity and reveal the interdependencies between cost categories. The reduced form estimates yield the net effect. These estimates may mask the adverse direct effect of complexity due to substitution between cost categories. Operations managers can utilize the information from the estimates of the structural equations to make appropriate resource allocations to manage complexity.

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[6] The net effect, as obtained from the reduced-form equation, of a unit increase in moving-part complexity is $12.18 on supervision cost and $17.93 on tool maintenance cost.

[7] In this case, the reduced-form results indicate that a unit increase in machine complexity affects supervision cost by $0.28 and tool maintenance by $0.14.

We believe that the investigation of simultaneity among cost categories offers scope for future work. Our effort is a first attempt to understand trade-offs among activities. Additional analyses and replication at different sites are required to gain a comprehensive understanding of the choice of cost drivers and the effect on scrap costs of different prevention strategies. Further research is necessary to establish better ways to estimate production functions and manage cost drivers and simultaneous interactions among costs.

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