Product and Process Characteristics, Advanced Manufacturing Initiatives, and Supply Chain Management Initiatives: Complementarities and FIT-Performance Consequences

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ABSTRACT

We test two hypotheses reflecting answers to the following questions: (1) Do manufacturing firms adopt *advanced manufacturing initiatives* and *supply chain management initiatives* in a complementary manner, consistent with a given set of *product and process characteristics*? and (2) If the adoptions of various *advanced manufacturing initiatives* and various *supply chain management initiatives* do represent complementary choices, in light of a given set of *product and process characteristics*, what performance consequences can be expected? The two hypotheses are derived based on the logic of complementarities from economics, the structural contingency perspective in organization theory, and the concept of "FIT" from strategic management and are empirically examined with secondary data from durable goods manufacturers. Results from applying the method of simultaneous equations and regression analyses indicate that manufacturing firms appear to make adoption decisions with respect to *advanced manufacturing initiatives* and *supply chain management initiatives* in a complementary manner and that the complementary nature of these choices (i.e., "FIT") improves manufacturing performance. Change decisions should, therefore, not be made in isolation without considering impact on "FIT" and performance. The overall empirical approach, moreover, demonstrates a "systems approach" to defining "FIT" and examining its implications.

1. INTRODUCTION

Improving manufacturing performance for sustainable competitive advantage has been and continues to be an ongoing concern for modern manufacturing. During the past two decades, a plethora of much-heralded *advanced manufacturing initiatives* and *supply chain management initiatives* – all of which claim to improve manufacturing performance for firm survival – has been offered as means for doing so. Taking "value chain" perspective (Porter, 1985), *advanced manufacturing initiatives* refers to policies, practices, and technologies whose primary aim is to impact the performance of the value chain activities within the organizational boundary of a manufacturing firm. A non-exhaustive listing of these *advanced manufacturing initiatives* would include, for example, Total Quality Management, World-Class Manufacturing, Lean Manufacturing, Six Sigma, etc. *Supply chain management initiatives*, on the other hand, correspond to policies, practices, and technologies whose primary aim is to impact the value chain activities outside the organizational boundary of a manufacturing firm. Specifically, they are intended to leverage relational assets and alter the nature of the relationships between the value chain of the manufacturing firm and those of its upstream and downstream entities. A non-exhaustive listing of *supply chain management initiatives* would, for example, include Strategic Sourcing, Supply Base Reduction, Outsourcing, Offshoring, etc.[1]

Manufacturing firms have responded to this bombardment by investing in the adoption of many, if not all, of these initiatives. In many instances, these adoption decisions have followed a sequential trajectory, with one initiative being replaced, within a relatively short timeframe, by another. In other

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[1] The definitions for *advanced manufacturing initiatives* and *supply chain management initiatives* offered here are not intended to connote mutually exclusive constructs or "buckets of activities." Indeed, one could argue, for instance, that Total Quality Management includes elements that belong to both. Rather, *advanced manufacturing initiatives* and *supply chain management initiatives*, as defined, are simply labels intended to encompass any and all initiatives proffered by scholars and practitioners within the two respective disciplines.

instances, these initiatives have been pursued by different functional constituents within the same manufacturing firm, but without widespread awareness of which function is doing what. Motivating these adoption decisions is the presumption that these initiatives, whether adopted sequentially or in parallel, would have complementary and beneficial performance effects.

If one were to survey this landscape, albeit in a somewhat superficial manner, one cannot help but question the logic (or lack of) behind these adoption decisions – not only in terms of the what initiatives to adopt but also in terms of which initiatives to adopt when. In other words, given that manufacturing firms respond to their customer requirements with a set of products and associated means to create these products (i.e., *product and process characteristics*), do they adopt *advanced manufacturing initiatives* and *supply chain management initiatives* in a rational and complementary manner, consistent with their response? An affirmative answer to this question would imply that the various *advanced manufacturing initiatives* and *supply chain management initiatives* have indeed been carefully evaluated and that their adoption decisions are jointly determined contingent upon the unique *product and process characteristics* of the firm and as to their overall effects on performance.

Moreover, one cannot help but question the validity of the presumption that these initiatives, when adopted, would have complementary, beneficial performance effects. In other words, if the adoptions of *advanced manufacturing initiatives* and *supply chain management initiatives* ideally represent rational and complementary choices, in light of a firm's *product and process characteristics*, what performance consequences can be expected? While the performance effects of individual and specific *advanced manufacturing initiatives* or *supply chain management initiatives* are well argued (e.g., Total Quality Management – see Hendricks & Singhal, 1997;Just-in-Time Manufacturing – see Sakakibara et al., 1997; etc.), the performance impact of adopting multiple, with a few exceptions, has rarely been empirically investigated. Yet, many scholars (e.g., Milgrom & Roberts, 1995; Venkatraman & Prescott, 1990) would argue that it is the "FIT" among various adopted initiatives that matters.

In this paper, we seek to provide both theoretical clarity for and empirical insights into these two related issues. Borrowing the logic of complementarities from economics (Milgrom & Roberts, 1988, 1990, 1995), the structural contingency perspective from organization theory (Chandler, 1962; Lawrence & Losch, 1969), and the concept of "FIT" from strategic management (Venkatraman & Camillus, 1984; Venkatraman & Prescott, 1990), we derive and empirically test two hypotheses, with the first hypothesis focusing on identifying empirical profiles reflecting the adoption choices of *advanced manufacturing initiatives* and *supply chain management initiatives*, given a set of *product and process characteristics*, and with the second hypothesis focusing on the "FIT"-performance consequences of these choices.

2. HYPOTHESES DEVELOPMENT

2.1 Complementarities and "FIT"

Manufacturing firms have been engaged in a flurry of activities these past two decades, eagerly embracing many of the latest and often publicly-proclaimed "solutions" for creating and maintaining competitive advantage in the marketplace. No doubt, the constantly evolving emphasis from one initiative to another makes these adoption decisions look rather disorganized, short-term, and, as a result, builds little confidence in the leadership and management of the manufacturing sector.

Recent theoretical developments looking into the economics of modern manufacturing would, however, suggest otherwise. In a series of papers, Milgrom and Roberts (1988, 1990, 1995) developed and formalized the *logic of complementarities* in economic models of modern manufacturing firms that describe their observed characteristics, behavior, and performance. Accordingly, profit-maximizing manufacturing firms do not adopt technologies, methods, and groups of activities (i.e., what we refer to liberally as "initiatives") in an accidental and haphazard fashion that reflect ". . . small adjustments made independently at each of several margins . . ." (Milgrom & Roberts, 1990: 513). Rather, modern manufacturing firms do so in a conscious and coordinated manner in order to exploit complementarities among various initiatives as part of the structuring and re-structuring of their response to customers in the external environment.

In fact, the *logic of complementarities* has already been alluded to, although not formally modeled, in both the manufacturing management and the supply chain management knowledge domains. Empirical evidence reflecting and providing partial support for the logic of complementarities has also surfaced more recently in both literature domains to complement such advice. For example, Das and Narasimhan (2001) found that the pattern of investments in various manufacturing technologies (e.g., CAD, CAM, etc.), manufacturing management systems (e.g., Just-in-Time Kanban), and supply chain coordination technologies (e.g., EDI) differed between jobs shops and assembly lines. Also, Salvador, Forza, and Rungtusanatham (2002) reported that products embedding a component swapping modularity design have manufacturing task allocation decisions and sourcing configurations different from products embedding a combinatorial modularity design.

As such, one would expect a manufacturer who decides to compete in the market by offering greater product variety to adopt *advanced manufacturing initiatives* (e.g., quick changeover techniques) and *supply chain management initiatives* (e.g., JIT deliveries from suppliers) that are complementary in optimizing flexibility and agility in its chosen production process. Conversely, a manufacturer who offers a standardized product in the market would choose to adopt *advanced manufacturing initiatives* (e.g., quality improvement techniques) and *supply chain management initiatives* (e.g., customer involvement in product design) that are complementary in optimizing a high-volume, defect-free production process. The adoption choices that modern manufacturing firms make with respect to alternative forms of organizational design, *advanced manufacturing initiatives*, and *supply chain management initiatives* are, therefore, rational and, from a systems perspective, reflect an appreciation of how these choices closely interact with and jointly determine one another.

While it may be ideal to specify a priori the exact nature of the joint adoption of *advanced manufacturing initiatives* and *supply chain management initiatives*, contingent on a set of *product and process characteristics*, this could not be undertaken for two specific reasons. First, the multidimensional nature of these constructs, not unlike those in strategic management research (Venkatraman & Prescott, 1990), makes the articulation of a complete and precise configuration of linkages extremely complex. Second, even if the task were not overly complex, there is insufficient domain knowledge within manufacturing management and supply chain management to justify the theoretical and precise nature of any adoption patterns (Cua, McKone, & Schroeder, 2001).

In conclusion, the *logic of complementarities* in the context of modern manufacturing, along with the conceptual and limited empirical results in the manufacturing management and supply chain management domains, suggests the following Hypothesis 1:

> **H1**: For any given set of *product and process characteristics*, the adoption of *advanced manufacturing initiatives* and the adoption of *supply chain management initiatives* would be complementary and be jointly determined.

2.2 Performance Consequences of "FIT"

The *logic of complementarities* also implies that modern manufacturing firms would enhance performance when they can successfully exploit complementarities among the activities adopted in response to the external environment (Milgrom & Roberts, 1995: 186). This performance implication has been more explicitly developed in organization theory and strategic management. Within organization theory, the "structural contingency theory" perspective posits the alignment between organization design and strategy as key to superior organizational effectiveness (Chandler, 1962; Lawrence & Losch, 1969). Strategic management, in turn, has borrowed from the "structural contingency theory" perspective to offer the concept of "FIT" and to argue its performance implications (Venkatraman & Camillus, 1984; Venkatraman & Prescott, 1990). Accordingly, as conditions in the external environment vary, the firm should vary its response by developing, selecting, and adopting different strategies and initiatives so as to maintain both internal and external fit with these external environmental conditions (e.g., Kotha & Nair, 1995) – an argument generally referred to as the "FIT-performance" logic.

In the manufacturing management literature, the "FIT-performance" logic can be found embedded in the Product-Process Matrix (Hayes & Wheelwright, 1979), with the congruencies between product life cycle stages and types of manufacturing process essentially representing ideal configurations (Doty & Glick, 1994) such that mismatches would lead to sub-optimal performance (Safizadeh et al, 1996; Devaraj, Hollingworth, & Schroeder, 2001). Likewise, in the supply chain management literature, there is increasing interest and research looking into the performance impact of integrated supply chains that arise from aligning internal manufacturing decisions with suppliers and customers across the supply chain (e.g., Narasimhan & Jayaram, 1998), as well as the performance consequences of aligning supply chain structural and relationship decisions with given product characteristics (e.g., Randall & Ulrich, 2001; David et al., 2002).

Unfortunately, while insightful, the empirical studies in manufacturing management and supply chain management have tended to focus narrowly on the *manufacturing performance* impact of a single initiative (e.g., Just-in-Time: Sakakibara et al., 1997), as opposed to the impact of different initiatives that may or not be complementary to one another. Even the few notable exceptions (e.g., Cua, McKone, & Schroeder, 2001) examining how multiple initiatives affect *manufacturing performance* were primarily interested in their main effects, prompting the call for research looking explicitly into how the alignment (or lack of) among *advanced manufacturing initiatives* and *supply chain management initiatives* for a given context would affect *manufacturing performance* (Joshi, Kathuria, & Porth, 2003). Moreover, in many prior studies, specific product or process characteristics that may explain *manufacturing performance* variance are often either ignored or simply controlled for during empirical testing.

In conclusion, the "FIT-performance" logic advocated in various disciplines, along with the limited empirical evidence to support this logic, leads to the suggestion of the following Hypothesis 2:

H2: Manufacturing firms, wherein the adoption of *advanced manufacturing initiatives* and the adoption of *supply chain management initiatives* complement one another for a given set of *product and process characteristics* (i.e., where there is "FIT"), would have superior *manufacturing performance* compared to manufacturing firms, wherein the adoption of *advanced manufacturing initiatives* and the adoption of *supply chain management initiatives* do not complement one another for any given set of *product and process characteristics* (i.e., where there is no "FIT").

3. DATA SOURCE

For this study, we used secondary data from durable goods manufacturers, collected by IndustryWeek as part of its Third Annual IndustryWeek Census of Manufacturers. IndustryWeek, working with PricewaterhouseCoopers, administered survey questionnaires to gather information on U.S. manufacturing trends, best practices, and specific *manufacturing performance* metrics. The Third Annual IndustryWeek Census of Manufacturers packages, containing an introductory letter, the questionnaire, and a business-reply envelope, were mailed, mid-April 2000, to plant or manufacturing managers of approximately 28,000 manufacturing industry subscribers of Penton Media, Inc. These informants managed plants belonging to SIC codes ranging from 20 (Food and Kindred Products) to 31 (Leather and Leather Products) to 39 (Miscellaneous Manufacturing Industries) and had estimated employee populations ≥ 100 employees. In early May 2000, a second round of mailing of identical packages of materials was performed, with returned questionnaires being accepted through mid-June 2000. An overall response rate of over 10% was reported, with a total of 3,006 questionnaires being returned from both durable (1748) and nondurable (1245) goods manufacturers.

4. TESTING HYPOTHESIS 1: COMPLEMENTARITIES IN MANUFACTURING

4.1 Measures

As a first and necessary step to test Hypothesis 1, relevant measures have to be derived from the data source for (a) *product and process characteristics*, (b) *advanced manufacturing initiatives*, and (c) *supply chain management initiatives*, as well as empirical proxies for four control variables.

5.1.1 *Product and Process Characteristics*. *Product and process characteristics* describe the nature of the primary products being provided by the plant and the manufacturing process responsible for fulfilling demand for these primary products. We culled four relevant variables from the secondary survey data source to serve as proxy measures for *product and process characteristics*:

1. *Number of SKUs (SKU)* is a proxy for the ***breath*** of the primary product line, with *SKU* defined and measured as the "number of stock-keeping units managed within the plant."
2. *Volume (VOL)* is a proxy for the ***production volume*** of the primary product manufactured by the plant, with *VOL* = 1 when the facility is primarily used for

volume-based production (i.e., high volume) and *VOL* = 0 (i.e., low volume) otherwise.

3. *FORECAST* denotes the ***approach*** by which demand and customer order fulfillment for the primary product is satisfied, with *FORECAST* = 1 for a build-to-forecast approach and *FORECAST* = 0 otherwise.
4. *Process (PROCESS)* denotes the ***type of manufacturing process*** deployed by the plant in manufacturing the primary product, with *PROCESS* = 1 for a line-flow manufacturing process and *PROCESS* = 0 otherwise.

Consistent with the Product-Process Matrix (Hayes & Wheelwright, 1979; Safizadeh et al., 1996) and with standard knowledge in production and operations management textbooks (e.g., Chase, Aquilano, & Jacobs, 1998), we would expect a plant manufacturing only a few *SKUs* to operate using a line-flow manufacturing process (i.e., *PROCESS* = 1) in a volume-based production environment (i.e., *VOL* = 1) to generally fulfill orders using a build-to-forecast approach (i.e., *FORECAST* = 1). Conversely, when a plant has responsibility for manufacturing *many SKUs*, we would expect the plant to produce in relatively lower volumes (i.e., *VOL* = 0), not to use a line-flow manufacturing process (i.e., *PROCESS* = 0), and not to be building to forecast (i.e., *FORECAST* = 0).

4.1.2 *Advanced Manufacturing Initiatives*. In the IndustryWeek survey, subject firms were asked to assess the extent to which each of the twelve *advanced manufacturing initiatives* is implemented within the plant. For each initiative, a survey subject would select responses from one of three categories – No Implementation, Some Implementation, or Extensive Implementation. These twelve *advanced manufacturing initiatives* included (a) Quick Changeover Techniques, (b) Focused-Factory Production Systems, (c) JIT/Continuous-Flow Production, (d) Cellular Manufacturing, (e) Total Quality Management, (f) Cpk Process Capability Measurements, (g) Competitive Benchmarking, (h) Lot-Size Reduction, (i) Preventive Maintenance, (j) Safety Improvement Programs, (k) Pull System/Kanban, and (l) Bottleneck/Constraint Removal.

For the purpose of data reduction, a principal components analysis, using the latent trait approach of categorical factor analysis (see Bartholomew et al., 2002), was applied to the responses for the twelve *advanced manufacturing initiatives*. From this analysis (see Table 1 for factor loadings), we retained two factors – *AG_FLEX: Agility & Flexibility* (eigenvalue > 3.71) and *QUALITY: Quality & Process Improvement* (eigenvalue > 1.48). Whereas the *AG_FLEX* factor appears to be associated with *advanced manufacturing initiatives* that relate to enhancing manufacturing agility and flexibility, the *QUALITY* factor, on the other hand, appears to be associated with *advanced manufacturing initiatives* that relate to ensuring manufacturing process and product quality. To accommodate subsequent analyses, the factor scores for *AG_FLEX* and *QUALITY* were computed using a simple component scoring mechanism.

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<u>4.1.3 *Supply Chain Management Initiatives*</u>. The IndustryWeek Census of Manufacturers also included ten questions about specific *supply chain management initiatives* that build relationships with supply chain partners downstream (i.e., customers) and upstream (i.e., suppliers). The ten questions included (a) Continuous-Replenishment Programs for Customers, (b) Customers Participate in New-Product Development, (c) Customers Interact with Employees, (d) Customer Satisfaction Surveys, (e) Key Suppliers Deliver to Plant on JIT Basis, (f) Suppliers Manage Inventory, (g) Supplier Rationalization, (h) Suppliers Evaluated on Total Cost, Not Unit Price, (i) Supplier Involved Early in New-Product Development, and (j) Suppliers Contractually Committed to Annual Cost Reductions. As with the twelve *advanced manufacturing initiatives*, informants were asked to assess the extent to which each of the ten initiatives had been implemented by choosing responses from one of three categories – No Implementation, Some Implementation, or Extensive Implementation.

Latent trait, categorical factor analysis revealed two factors, one factor pertaining generally to *Supplier-Oriented Initiatives* (*SUPPLIER*, eigenvalue > 3.29) and a second factor pertaining generally to *Customer-Oriented Initiatives* (*CUSTOMER*, eigenvalue > 1.16) – see Table 2. While the *SUPPLIER* factor appears to be associated with *supply chain management initiatives* that acknowledge activities performed by suppliers to support the manufacturer, the *CUSTOMER* factor appears to be associated with activities performed by customers to provide information to the manufacturer. Again, factor scores were then computed for each case in the sample to facilitate subsequent analyses.

----- INSERT TABLE 2 -----

4.1.4 Control Variables. Because other unique factors, besides *product and process characteristics*, may exert influence on the choices of *advanced manufacturing initiatives* and *supply chain management initiatives*, they should, therefore, be controlled for in developing the empirical profiles as part of testing Hypothesis 1. The choices of *advanced manufacturing initiatives* may, for example, be unduly affected by how large and how old the plant is, how complex the plant environment is, whether or not plant employees are unionized, and existing investments in manufacturing-based information technology (e.g., MRP systems). For plant size (*SIZE*), we used the logarithm of the number of employees employed at the plant as a proxy. To measure plant age (*AGE*), we used the number of years since plant startup. For degree of unionization, we used the percentage of production workers belonging to a union as a proxy for the extent of unionization within the plant (*UNION*). Finally, a binary variable (*MFG_INFO*) is created to capture the extent of plant's investments in information technology in supporting manufacturing activities, with *MFG_INFO* = 1 (High) and *MFG_INFO* = 0 (Low).

Similarly, the choices of *supply chain management initiatives* can be affected by the number and values of items sourced from other entities within the supply chain, by negative economic conditions such as plant shutdowns, and by plant investments in information technology to support supply chain management initiatives. To control for these factors when examining the adoption of *supply chain management initiatives*, we used the percentage of cost of materials purchased to the total product cost as a proxy for the relative significance of purchasing spend (*MATERIALS*). Likewise, we used the question of whether or not the plant has experienced significant downsizing in the past five years as a proxy to control for the impact of downsizing (*DOWNSIZE*). Finally, a binary variable, *SCM_INFO*, is used to describe the extent of such supply chain related information technology investments, with *SCM_INFO* = 1 (High) and *SCM_INFO* = 0 (Low).

4.2 Empirical Analyses

4.2.1 Simultaneous Equations Method, Systems Equations, and Estimation. We test Hypothesis 1 via the method of simultaneous equations. This method is appropriate since it is consistent with the systems perspective embedded in the *logic of complementarities* and since it treats the adoption of *advanced manufacturing initiatives* (i.e., AG_*FLEX* and *QUALITY*) and *supply chain management initiatives* (i.e., *SUPPLIER* and *CUSTOMER*) as endogenous and jointly determined decision variables and the four proxies for *product and process characteristics* (i.e., *SKU*, *VOL*, *FORECAST*, and *PROCESS*) as exogenous variables, while controlling for various factors unique to each endogenous variable. The corresponding systems equations can be specified as follows[2]:

$$\begin{aligned} AG\_FLEX_i \quad = \quad & a_0 + a_1 SUPPLIER_i + a_2 CUSTOMER_i && [1a]\\ & + a_3 SKU_i + a_4 VOL_i + a_5 FORECAST_i + a_6 PROCESS_i \\ & + a_7 SIZE_i + a_8 AGE_i + a_9 UNION_i + a_{10} MFG\_INFO_i + \varepsilon_{1i} \\ QUALITY_i \quad = \quad & a_0 + a_1 SUPPLIER_i + a_2 CUSTOMER_i && [1b]\\ & + a_3 SKU_i + a_4 VOL_i + a_5 FORECAST_i + a_6 PROCESS_i \\ & + a_7 SIZE_i + a_8 AGE_i + a_9 UNION_i + a_{10} MFG\_INFO_i + \varepsilon_{2i} \\ SUPPLIER_i \quad = \quad & a_0 + a_1 AG\_FLEX_i + a_2 QUALITY_i && [2a]\\ & + a_3 SKU_i + a_4 VOL_i + a_5 FORECAST_i + a_6 PROCESS_i \\ & + a_7 MATERIALS_i + a_8 DOWNSIZE_i + a_9 SCM\_INFO_i + \varepsilon_{3i} \\ CUSTOMER_i \quad = \quad & a_0 + a_1 AG\_FLEX_i + a_2 QUALITY_i && [2b]\\ & + a_3 SKU_i + a_4 VOL_i + a_5 FORECAST_i + a_6 PROCESS_i \\ & + a_7 MATERIALS_i + a_8 DOWNSIZE_i + a_9 SCM\_INFO_i + \varepsilon_{4i} \end{aligned}$$

where $i \in$ {Plants}

The structural parameters in Equations [1a], [1b], [2a], and [2b] were estimated with the full information–maximum likelihood procedure, which utilizes knowledge about all restrictions in the entire system when determining the magnitude and statistical significance of each structural parameter. The

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[2] Note that the left-hand side of Equation [1a] (Equation [1b]) does not include the endogenous variables of *AG_FLEX* (*QUALITY*) since they are orthogonal factors for *advanced manufacturing initiatives* and, similarly, the left-hand side of Equation [2a] (Equation [2b]) does not include *SUPPLIER* (*CUSTOMER*).

parameter estimates, therefore, provide empirical evidence about the interrelationships, as opposed to causality, among the jointly determined choices of *advanced manufacturing initiatives* and *supply chain management initiatives*, while controlling for the effects of *product and process characteristics* and other exogenous variables. Such an estimation procedure mitigates the estimation bias when equations are estimated separately and, moreover, allows for the conduct of a formal test of exogeneity (i.e., Hausman test) with respect to the joint determination of these initiatives.

4.2.2 Results. The simultaneous equations method results are tabulated in Table 3.[3] These results do not appear to lead to a rejection of Hypothesis 1 and support the joint determination with respect to the choices of *advanced manufacturing initiatives* and *supply chain management initiatives*. For example, with respect to the adoption of *Agility & Flexibility* (i.e., *AG_FLEX*), the statistical results in Equation [1a] report a positive association between *AG_FLEX* and the adoption of *Supplier-Oriented Initiatives* (i.e., *SUPPLIER*). Moreover, with respect to the three proxies for *product and process characteristics* proxies (i.e., *SKU*, *VOL*, and *PROCESS*), *AG_FLEX* appears to also be positively associated with a large number of *SKU*s, negatively associated with volume-based production, and negatively associated with a line-flow manufacturing process. As to the adoption of *Quality & Process Improvement* (i.e., *QUALITY*), the parameter estimates in Equation [1b] suggest that *QUALITY* is positively associated with *Customer-Oriented Initiatives* (i.e., *CUSTOMER*), a volume-based production, and a line-flow manufacturing process. Regarding Equation [2a], *SUPPLIER* (i.e., *Supplier-Oriented Initiatives*) not only appears to be positively associated with both *advanced manufacturing initiatives* of *AG_FLEX* and *QUALITY*, but, given the statistically non-significant parameter estimates for *SKU*, *VOL*, *FORECAST*, and *PROCESS* in Equation [2a], also appears to not be affected by *product and process*

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[3] The four systems equations – Equations [1a] through [2b] – include a number of cases for which no values were reported for a number of variables, which effectively reduced the sample size from $N = 1389$ used in the latent trait, categorical factor analysis to just $N = 868$ for the simultaneous equations modeling analyses.

characteristics. Lastly, consistent with Equation [1b] results, the adoption of *Customer-Oriented Initiatives* (i.e., *CUSTOMER*) – see the parameter estimates for Equation [2b] – appears to be positively associated with the *Quality & Process Improvement* initiative, while negatively associated with a build-to-forecast fulfillment approach and with a line-flow manufacturing process.

----- INSERT TABLE 3 -----

4.2.3. Discussion and Insights. Besides providing direct support for Hypothesis 1, the simultaneous equations method results represent an initial response to the "call to arms" to ". . . estimate empirically the strength of the complementarities: Just how strongly are various elements . . . linked?" (Milgrom & Roberts, 1995: 205) and, at the same time, highlight three interesting insights. First, these results provide rare empirical evidence for the Product-Process Matrix (Hayes & Wheelwright, 1979), a configuration theory in production and operations management that ". . . has been widely accepted without empirical validation" (Devaraj, Hollingworth, & Schroeder, 2001: 428). Specifically, consistent with the Product-Process Matrix, the results show that a product manufactured in high volumes would likely be paired with a line-flow manufacturing process, while a product with low volume requirements would not be produced using a line-flow manufacturing process.

Second and more importantly, the systems equations results reveal four differentiated profiles that demonstrate and confirm empirically how manufacturing firms differ systematically in their adoption choices as conditioned by market requirements and constraints, which may also reflect differences in their competitive strategies. For example, the results from Equation [1a] show that manufacturing firms facing high product variety requirements would not use a line-flow manufacturing system so as to engage in low-volume production and would emphasize initiatives that enhance flexibility and agility while seeking to integrate tightly with the supply base. Manufacturing firms in such a profile would likely pursue mass customization as a competitive strategy (see Pine, 1993). The results from Equation [1b], on the other hand, identify manufacturing firms that produce a relatively standardized product or set of products using high volume, line-flow manufacturing systems and that, as a consequence, emphasize not only quality improvement initiatives but also initiatives that integrate customers into the firm. Consistent with this profile would likely be contract manufacturing firms like those in the high-technology sector who specialize in meeting customer design requirements and product quality specifications or those who are consciously abiding by any of the many Total Quality Management paradigms that advocate process stability and improvement and customer involvement (see Anderson, Rungtusanatham, & Schroeder, 1994). Manufacturing firms identified by the results of Equation [2a] reveal yet another profile of adoption choices – one that emphasizes leveraging and integrating upstream suppliers while, at the same time, adopting initiatives that improve quality and also enhance flexibility and agility. These manufacturing firms, interestingly, are able to pursue adoption of these three sets of initiatives, irrespective of the characteristics of the products they offer and the processes used to produce these products. Such a profile would, therefore, typify manufacturing firms who have attained world-class or high-performance manufacturing status (Schonberger, 1986; Schroeder & Flynn, 2001). Finally, from the results of Equation [2b], a fourth profile emerges. Manufacturing firms, according to this profile, are similar to those implied by Equation [1b] in that their emphasis on quality improvement initiatives and customer-oriented initiatives but differ in that they subscribe to a build-to-order approach and tend not to use line-flow manufacturing systems to fulfill market orders. Such a profile would typify niche players who are high-end specialty manufacturers (e.g., subsystem suppliers to the automobile industry).

Third, while the logic of complementarities is intuitively appealing in describing and explaining how modern manufacturing firms should operate, there has not been much empirical evidence to validate this logic until now. Each of the four profiles revealed by the empirical analysis above shows a different but coherent pattern of joint adoption decisions with respect to *advanced manufacturing initiatives* and *supply chain initiatives* and how these choices are affected by the *product and process characteristics* of manufacturing firm. For example, because of differences in the values of the two underlying *product and process characteristics* of *VOL* and *PROCESS*, manufacturing firms in the profiles derived from Equations [1a] and [1b] differ systematically in their adoption choices regarding *advanced manufacturing initiatives* and *supply chain initiatives*. Manufacturing firms depicted by the profile from Equation [1a] invest in *Agility & Flexibility* initiatives and complement this choice with investments in *Supplier-*

Oriented Initiatives. In contrast, those depicted by the profile from Equation [1b] seem to make an opposite pattern of adoption choices; they invest heavily in *Quality & Process Improvement* initiatives, complementing this choice with investments in *Customer-Oriented Initiatives*. What differentiates these two sets of manufacturing firms appears to be the differences in *product and process characteristics* in their respective profiles. Whereas manufacturing firms in the Equation [1a] profile are likely to produce customized products using batch manufacturing processes to accommodate the requirements for greater product variety, those in the Equation [1b] profile produce high-volume, relatively standardized products using line-flow manufacturing processes to accommodate high efficiency requirements. As another example, for manufacturing firms that invest in both *Agility & Flexibility* and *Quality & Process Improvement* initiatives and also complement these choices with investment in *Supplier-Oriented Initiatives*, consistent with the profile revealed by Equation [2a], *product and process characteristics* no longer play any role. This suggests that the synergistic effects of these adoption choices enable the manufacturing firms to pursue a much wider range of product and manufacturing process selections. Finally, a high adoption level of *Quality & Process Improvement* is a requisite element in the two profiles derived from Equations [2a] and [2b]. From this, it appears that the activities underlying *Quality & Process Improvement* may be necessary to support or facilitate execution of both upstream and downstream activities within a supply chain and, therefore, can and should be pursued along with the adoption of either upstream or downstream *supply chain management initiatives*.

5. TESTING HYPOTHESIS 2: FIT-PERFORMANCE

5.1 Measures

Because Hypothesis 2 effectively conjectures that performance outcomes – more specifically, *manufacturing performance* – would be better off when configurations of adopted *advanced manufacturing initiatives* and *supply chain management initiatives* fit a given set of *product and process characteristics*, testing this hypothesis requires that operational definitions for “FIT” and *manufacturing performance* be articulated.

5.1.1 "FIT" Indices. To operationalize "FIT" (see Table 4), we follow a two-step approach with the simultaneous equations method results in Table 3. The resulting "FIT" indices, in essence, represent and capture succinctly the empirical profiles discussed in Section 4.2.3.

In Step 1, since the four systems equations contain both binary variables (e.g., *VOL*) and continuous variables (e.g., *AG_FLEX*), and in order to maintain consistency across these variables in operationalizing "FIT," we convert the various continuous variables (i.e., *AG_FLEX*, *QUALITY*, *SUPPLIER*, *CUSTOMER*, and *SKU*) into binary [0, 1] variables (i.e., *D_AG_FLEX*, *D_QUALITY*, *D_SUPPLIER*, *D_CUSTOMER*, and *D_SKU*) based on whether their value is below (= 0) or above (= 1) the corresponding median value in the sample. By doing so, the estimates for the four systems equation can now be transcribed and transformed into four corresponding "FIT" indices reflecting different empirical profiles in Step 2 as follows:

$$FIT\_AG\_FLEX_i \equiv 1 \text{ if } D\_AG\_FLEX_i = 1 \text{ and } \begin{bmatrix} D\_SKU_i = 1 \\ VOL_i = 0 \\ PROCESS_i = 0 \\ D\_SUPPLIER_i = 1 \end{bmatrix} \text{; Else} = 0$$

$$FIT\_QUALITY_i \equiv 1 \text{ if } D\_QUALITY_i = 1 \text{ and } \begin{bmatrix} VOL_i = 1 \\ PROCESS_i = 1 \\ D\_CUSTOMER_i = 1 \end{bmatrix} \text{; Else} = 0$$

$$FIT\_SUPPLIER_i \equiv 1 \text{ if } D\_SUPPLIER_i = 1 \text{ and } \begin{bmatrix} D\_AG\_FLEX_i = 1 \\ D\_QUALITY_i = 1 \end{bmatrix} \text{; Else} = 0\text{; and, lastly,}$$

$$FIT\_CUSTOMER_i \equiv 1 \text{ if } D\_CUSTOMER_i = 1 \text{ and } \begin{bmatrix} FORECAST_i = 0 \\ PROCESS_i = 0 \\ D\_QUALITY_i = 1 \end{bmatrix} \text{; Else} = 0$$

This two-step approach is, therefore, consistent in spirit to the "systems approach" for defining "FIT" as a distance measure from a [multidimensional] profile (see Drazin & Van de Ven, 1985).

----- INSERT TABLE 4 -----

5.1.2 Measures of *Manufacturing Performance*. For *manufacturing performance*, metrics pertaining to changes in the last five years in terms of quality (Δ*Pass*), manufacturing cycle time (∇*Cycle_Time*), delivery lead-time (∇*Delivery*), and per unit manufacturing costs (∇*Unit_Cost*) were identified from the Third Annual IndustryWeek Census. These four *manufacturing performance* metrics reflect the four objectives that are frequently used in defining a firm's manufacturing strategy (Hayes & Wheelwright, 1979; Schroeder, Anderson, & Cleveland, 1986). In the census, these *manufacturing performance* metrics were defined as follows:

1. $\Delta \mathit{Pass}$ = Percentage increase in finished product first-pass yield.
2. $\nabla \mathit{Cycle\_Time}$ = Percentage decrease in cycle time.
3. $\nabla \mathit{Delivery}$ = Percentage decrease in delivery lead time from point of customer order to point of customer receipt.
4. $\nabla \mathit{Unit\_Cost}$ = Percentage decrease in per unit manufacturing cost.

For all four metrics, plant informants were asked to select the interval corresponding to the observed % change – e.g., 21-40%. However, for testing Hypothesis 2, each interval value was converted into a single numerical value by taking the median of the interval (i.e., the selected interval of 21-40% would, therefore, be converted into a single numerical value of 30.5%).

<u>5.1.3 Control Variables</u>. Since subsequent analysis with respect to Hypothesis 2 is cross-sectional in nature and since *manufacturing performance* may vary due to unique industry factors (e.g., competition), cross-sectional industry effects should be controlled for. To do so, we used a two-digit SIC code to compute an industry average for each of the four *manufacturing performance* metrics. For example, $\mathit{IND\_}\Delta \mathit{Pass}$ is a control variable whose values denote the respective within-industry average for the percentage increase in finished product first-pass yield. $\mathit{IND\_}\nabla \mathit{Cycle\_Time}$, $\mathit{IND\_}\nabla \mathit{Delivery}$, and $\mathit{IND\_}\nabla \mathit{Unit\_Cost}$, as such, can be interpreted in a similar manner.

5.2 Regression Analyses

<u>5.2.1 Regression Models</u>. To evaluate Hypothesis 2, four regression models (see Equations [3a] – [3d]) are estimated, with each regression model assessing the impact of different "FIT" indices on a particular *manufacturing performance* metric. For $\Delta \mathit{Pass}$, the signs of the various "FIT" coefficients are expected to be positive (signaling improvement); for the remaining three *manufacturing performance*

metrics, the signs for the various “FIT” coefficients are all expected to be negative (signaling improvement). Hypothesis 2 would be supported if the partial regression coefficients for the different “FIT” indices per *manufacturing performance* metric are statistically significant in the expected (positive or negative) directions.

$$\begin{aligned}\Delta Pass_i \quad &= \quad \mathrm{a}_0+\mathrm{a}_1(IND\_\Delta Pass_i)\\ &\quad +\mathrm{a}_2(FIT\_AG\_FLEX_i)+\mathrm{a}_3(FIT\_QUALITY_i)\\ &\quad +\mathrm{a}_4(FIT\_SUPPLIER_i)+\mathrm{a}_5(FIT\_CUSTOMER_i)+\varepsilon_\mathrm{i} \qquad [3a]\end{aligned}$$

$$\begin{aligned}\nabla Cycle\_Time_i \quad &= \quad \mathrm{a}_0+\mathrm{a}_1(IND\_\nabla Cycle\_Time_i)\\ &\quad +\mathrm{a}_2(FIT\_AG\_FLEX_i)+\mathrm{a}_3(FIT\_QUALITY)\\ &\quad +\mathrm{a}_4(FIT\_SUPPLIER_i)+\mathrm{a}_5(FIT\_CUSTOMER_i)+\varepsilon_\mathrm{i} \qquad [3b]\end{aligned}$$

$$\begin{aligned}\nabla Delivery_i \quad &= \quad \mathrm{a}_0+\mathrm{a}_1(IND\_\nabla D\mathrm{elivery}_i)\\ &\quad +\mathrm{a}_2(FIT\_AG\_FLEX_i)+\mathrm{a}_3(FIT\_QUALITY)\\ &\quad +\mathrm{a}_4(FIT\_SUPPLIER_i)+\mathrm{a}_5(FIT\_CUSTOMER_i)+\varepsilon_\mathrm{i} \qquad [3c]\end{aligned}$$

$$\begin{aligned}\nabla Unit\_Cost_i \quad &= \quad \mathrm{a}_0+\mathrm{a}_1(IND\_\nabla U\mathrm{nit\_Cost}_i)\\ &\quad +\mathrm{a}_2(FIT\_AG\_FLEX_i)+\mathrm{a}_3(FIT\_QUALITY)\\ &\quad +\mathrm{a}_4(FIT\_SUPPLIER_i)+\mathrm{a}_5(FIT\_CUSTOMER_i)+\varepsilon_\mathrm{i} \qquad [3d]\end{aligned}$$

5.2.2 Regression Results. Panel A in Table 5 reports the regression results. As expected, the industry average means for all four performance metrics are statistically significant, further justifying the need to control for them in testing for Hypothesis 2. More importantly, except for specific exceptions, the “FIT” indices are generally found to exert statistically significant (and sign-correct) effects on *manufacturing performance*. For example, with respect to output quality, or Δ*Pass*, the results indicate that the “FIT” indices representing the empirical profiles consistent with the adoptions of the two *advanced manufacturing initiatives* and of the two *supply chain management initiatives* are associated with improvements in first-pass yield (Δ*Pass*). For the remaining three *manufacturing performance* metrics, at least one “FIT” index appears to have a statistically significant and directionally-appropriate influence. With respect to cycle time and manufacturing cost, “FIT” with respect to the adoption of the *SUPPLIER* initiative appears to lead to significant reduction in cycle time (∇*Cycle_Time*) and in manufacturing cost per unit (∇*Unit_Cost*). Moreover, with the delivery lead time performance, “FIT” with respect to the adoption of the *SUPPLIER* initiative and “FIT” with respect to the *AG_FLEX* initiative both appear to significantly reduce delivery times (∇*Delivery*).

----- INSERT TABLE 5 -----

5.2.3 Discussion and Insights. Beyond support for Hypothesis 2, several additional insights can be gleaned from these regression results. Immediately obvious, based on Table 5 (Panel A), is the statistically significant impact of the different “FIT” indices on each of the four *manufacturing performance* metrics. Furthermore, the “FIT,” indices also, appear to have significant economic value in improving *manufacturing performance*. For example, regarding quality performance (Δ*Pass*), the regression results indicate that all four “FIT” indices have uniformly beneficial impact, with percentage improvement in finished product first-pass yield approximating 4.2%. This empirical observation suggests that quality performance can be improved, irrespective of what profile a manufacturing firm belongs to and as long as the chosen *advanced manufacturing initiatives* and the chosen *supply chain management initiatives* complement one another and are consistent with the corresponding *product and process characteristics* – i.e., as long as *FIT_AG_FLEX* = 1, *FIT_QUALITY* = 1, *FIT_SUPPLIER* = 1, or *FIT_CUSTOMER* = 1.

For the other three *manufacturing performance* metrics, the regression results in Table 5 (Panel A) show that at least one “FIT” index contributes positively to improving each of the three metrics, with economic improvement expected in the range of 3% and 9%. Therefore, if cycle time reduction (∇*Cycle_Time*) is of interest, a manufacturing firm should then pursue the profile corresponding to the adoption of *Supplier-Oriented Initiatives* (i.e., *FIT_SUPPLIER* = 1) since this would yield an improvement of approximately 9.0%. Similarly, for delivery lead time improvement (∇*Delivery*), interpretation of the regression results in Table 5 (Panel A) leads to a similar conclusion about the economic and improvement impact of *FIT_AG_FLEX* and *FIT_SUPPLIER*. Indeed, for delivery lead time performance, no less than 5.8% improvement can be expected, particularly if manufacturing firms were to pursue the profile suggested by *FIT_SUPPLIER* and adopt, as defined, initiatives that would enhance responsiveness (*D_AF_FLEX* = 1), quality (*D_QUALITY* = 1), and integration with upstream suppliers (*D_SUPPLIER* = 1). Similarly, in terms of unit manufacturing cost, Table 5 (Panel A) reveals that only *FIT_SUPPLIER* leads to a significant 3.2% reduction in ∇*Unit_Cost*. In other words, when manufacturing firms adopt the complementary initiatives that would enhance responsiveness (*D_AF_FLEX* = 1), quality (*D_QUALITY* = 1), and integration with upstream suppliers (*D_SUPPLIER* = 1), they can expect to improve their cost structure, and such improvement appears not to be constrained by *product and process characteristics*.

Yet another immediately obvious insight gleaned from Table 5 (Panel A) is the prevalence of the impact of *FIT_SUPPLIER*, the "FIT" index for *Supplier-Oriented Initiatives*, on *manufacturing performance.* Of the four "FIT" indices, only *FIT_SUPPLIER* appears to have statistically significant effects in terms of improving all four *manufacturing performance* metrics uniformly. This empirical finding should not be surprising given that *FIT_SUPPLIER* requires high adoption levels of *advanced manufacturing initiatives* that act both on quality (i.e., *D_QUALITY* = 1) and on timing (i.e., *D_AG_FLEX* = 1) and of *supply chain management initiatives* that also have implications for efficient response from the supply base (i.e., *D_SUPPLIER* = 1). Indeed, this empirical finding bolsters claims that world class manufacturing firms or high performance manufacturing firms can and should be able to avoid traditionally-noted tradeoffs in *manufacturing performance* (see Rosenzweig & Roth, 2004). One can, therefore, conceivably argue that given constrained resources, if a manufacturing firm wishes to maximize *manufacturing performance* in terms of all four metrics, attention should be levied, without a doubt, on pursuing "FIT" with respect to *Supplier-Oriented Initiatives*.

Of the three remaining "FIT" indices, only *FIT_AG_FLEX* also appears to contribute statistically to two of the four *manufacturing performance* metrics – these being Δ*Pass* – 4.2% and ∇*Delivery* – 4.8%. Therefore, along the same reasoning, if quality and delivery lead time performance improvement were desired, manufacturing firms might want to pursue adoption of the initiatives underlying *FIT_AG_FLEX*, particularly if pursuing *FIT_SUPPLIER* is not deemed to be a viable or feasible option.

5.2.4 Sensitivity Analysis. One could, however, argue that the regression results (Table 5, Panel A) are peculiar to the manner by which the "FIT" indices were constructed, raising a concern, therefore, as to the robustness of the regression results. To mitigate this concern, we repeat the regression analyses, after defining the "FIT" indices in a more stringent manner. Rather than converting *AG_FLEX*, *QUALITY*, *SUPPLIER*, *CUSTOMER*, and *SKU* into binary variables, we consider four quartiles such that the redefined variables can take on one of four values in the set {0, 1, 2, or 3}, with 3 denoting "high" and 0 denoting "low" correspondingly. We then set the "FIT" indices so that the values of the underlying profile dimensions are either in the top (= 3) or the bottom (= 0) quartile within the sample. For example,

$$FIT\_AG\_FLEX_i \equiv 1 \text{ if } D\_AG\_FLEX_i = 3 \text{ and } \begin{bmatrix} D\_SKU_i = 3 \\ VOL_i = 0 \\ PROCESS_i = 0 \\ D\_SUPPLIER_i = 3 \end{bmatrix} \text{; Else} = 0$$

The new regression results are shown in Panel B in Table 5. With the exceptions of ∇*Cycle_Time* and ∇*Unit_Cost*, the regression results are generally consistent and appear to be statistically stronger.

In the case of ∇*Cycle_Time*, the sensitivity analysis reveals that both *FIT_SUPPLIER*, noted earlier in Panel A of Table 5, and *FIT_AG_FLEX* now appear to statistically and economically contribute to improving this metric, with improvement expected to be no less than 9.9%. Moreover, with ∇*Unit_Cost*, it appears from Table 5 (Panel B) that unit manufacturing cost can be improved not only by pursuing the empirical profile defining *FIT_SUPPLIER* but also by pursuing the two empirical profiles defining either *FIT_AG_FLEX* or *FIT_QUALITY*. Therefore, if the profile governing *FIT_SUPPLIER* is not a viable option, then for manufacturing firms characterized by high-volume, line-flow production, adopting *Quality & Process Improvement* and *Customer-Oriented Initiatives* in a complementary manner (i.e., *FIT_QUALITY*) reduces unit manufacturing cost by no less than 4.2%. Conversely, for manufacturing firms characterized by intense market demand for greater product variety and meeting this challenge with small-volume production using job shop or batch processes, unit manufacturing cost can be significantly reduced (~ 6.0%) by complementing the adoption of initiatives that enhance responsiveness, agility, and flexibility with the adoption of initiatives that seek to integrate upstream suppliers.

7. SIGNIFICANCE, LIMITATIONS, AND CONCLUSIONS

The Greek philosopher, Heraclitus (540 BC–480 BC), said quite eloquently that "Nothing endures but change. . . . There is nothing permanent except change." Such is the ultimate constant that all organizational entities, be they for-profit or non-profit firms in the manufacturing or service sectors, face; for survival in the long-run mandates that organizations actively seek to evolve their responses to changing conditions in the environment and not take comfort in the status quo. Failing to do so or the unwillingness to do so (i.e., structural inertia) spells a certain doom (Hannan & Freeman, 1984).

In the case of the for-profit manufacturing firm, to evolve is to offer new and innovative products to viable markets on an ongoing basis and to do so by pursuing efficient and effective processes and supply chains (Rungtusanatham & Forza, 2005) so that above-normal returns could be derived. Indeed, it is the very pursuit of improved processes and supply chains that appears to motivate adoption of various *advanced manufacturing initiatives* and various *supply chain management initiatives* – initiatives often acclaimed by the public media to be the panacea for all ailments.

Set against this context, the first question we ask in this paper is whether or not manufacturing firms actually succumb to and adopt "the initiative of the month" in a manner that defies the logic of complementarities embedded in economic models of modern manufacturing firms. A second question we ask in this paper, one that follows naturally from interest in the first question and that can be juxtaposed against arguments from the logic of complementarities, from structural contingency theory, and from the concept of "FIT," is what performance effects, if any, might there be when adoption decisions of various initiatives are not complementary – i.e., when there is no "FIT" among the adopted initiatives.

What we found in the empirical results to these two related questions are very encouraging. In fact, the empirical results for Hypothesis 1 (i.e., the first question), by affirming the logic of complementarities upon which Hypothesis 1 is based, preserve confidence not only in the sanctity of the extant knowledge in diverse literature streams that have called for increased attention to and highlighted the importance of within-organization and across-organization synergies but also in the leadership ability of modern manufacturing to evolve their respective firms for survival in a rational manner. As for the second question, the empirical results not only validate the arguments from the logic of complementarities, from structural contingency theory, and from the concept of "FIT" but also provide an alternative methodology for operationalizing the system concept of "FIT" and quantify the manufacturing performance improvement impact of "FIT" with respect to different *advanced manufacturing initiatives* and *supply chain management initiatives*. "FIT," simply stated, matters and modern manufacturing firms should embrace this perspective wholeheartedly as they move forward in evaluating new initiatives, regardless of their functional origins, and determining the extent to which an initiative, if adopted, would complement the existing profile of initiatives already in place and yield complementary performance benefits.

While we believe that the reported theoretical and empirical findings are insightful, no research is perfect. The research reported here, despite the attentiveness and rigor in the execution of research activities, is no exception, with the clear source of concerns being the nature of the data. First, since a trade association collected the data via a pen-and-paper questionnaire, the standards of survey design and administration that one would normally expect of scientific research may not have been upheld. A second related concern, albeit not critical, is the fact that the data had been collected for a different initial purpose and, as such, may not be consistent with the objectives of this paper. However, this concern does not mean that secondary data sources cannot be fruitfully used in empirical research, as there is evidence to the contrary in strategic management (e.g., Miller & Chen, 1994) and in operations management (see Rungtusanatham et al., 2003: 481 – Table 5). A third concern is the potential single-source bias that can arise from having the same informant responding to questions corresponding to independent variables and dependent variables (Crampton & Wagner, 1994). How serious this concern may be can, however, be debated (Doty & Glick, 1984).

Moving forward, an obvious research opportunity would be to reexamine and replicate the current study with primary data that would meet the standards of scientific scrutiny. Such reexamination and replication efforts are crucial to the development of scientific knowledge (Lykken, 1968) and, we are convinced, would lend credence to the empirical findings presented herein. In addition, as new initiatives in manufacturing management or in supply chain management become "discovered" and encouraged for adoption, the methodological approaches we followed in this paper can be redeployed to understand in a systematic fashion how these initiatives would (or would not) complement other initiatives as well as the beneficial (or detrimental) effects that adopting these initiatives may have on manufacturing performance. Finally, in this paper, we focused only on manufacturing management and supply chain management initiatives as a consequence of data availability. There are nonetheless many other initiatives across different functional domains whose synergies (or lack of) can be and must be investigated in order to truly help any single organization to adapt and respond effectively to its ever-changing external environment.

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Table 1: Latent Trait Principal Components Analysis – *Advanced Manufacturing Initiatives* [4]

	FACTOR LOADINGS	
	FACTOR 1	**FACTOR 2**
	AG_FLEX	***QUALITY***
Advanced Manufacturing Initiatives	*Agility & Flexibility*	*Quality & Process Improvement*
1. Quick Changeover Techniques	**0.456**	0.333
2. Focused-Factory Production Systems	**0.595**	0.201
3. JIT/Continuous-Flow Production	**0.679**	0.243
4. Cellular Manufacturing	**0.724**	-0.062
5. Total Quality Management	0.260	**0.615**
6. Cpk Process Capability Measurements	0.273	**0.482**
7. Competitive Benchmarking	0.217	**0.603**
8. Lot-Size Reduction	**0.640**	0.098
9. Preventive Maintenance	-0.032	**0.724**
10. Safety Improvement Programs	-0.056	**0.692**
11. Pull System/Kanban	**0.735**	0.070
12. Bottleneck/Constraint Removal	0.451	0.456
EIGENVALUE	**> 2.89**	**> 2.41**
CUMULATIVE VARIANCE EXPLAINED	**0.55**	**0.45**

Table 2: Latent Trait Principal Components Analysis – *Supply Chain Management Initiatives*

	FACTOR LOADINGS	
	FACTOR 1	**FACTOR 2**
	SUPPLIER	***CUSTOMER***
Supply Chain Management Initiatives	*Supplier-Oriented Initiatives*	*Customer-Oriented Initiatives*
1. Continuous-Replenishment Programs for Customers	0.271	0.419
2. Customers Participate in New-Product Development	0.051	**0.779**
3. Customers Interact with Employees	0.064	**0.680**
4. Customer Satisfaction Surveys	0.220	**0.537**
5. Key Suppliers Deliver to Plant on JIT Basis	**0.615**	0.251
6. Suppliers Manage Inventory	**0.728**	0.082
7. Supplier Rationalization	**0.743**	0.100
8. Suppliers Evaluated on Total Cost, Not Unit Price	**0.654**	0.188
9. Supplier Involved Early in New-Product Development	0.387	**0.549**
10. Suppliers Contractually Committed to Annual Cost Reductions	**0.602**	0.243
EIGENVALUE	**> 2.53**	**> 2.00**
CUMULATIVE VARIANCE EXPLAINED	**0.56**	**0.44**

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[4] Due to missing values, the effective sample size for the latent trait, categorical factor analysis is 1389 durable goods manufacturer.

Table 3: Simultaneous Equations – Parameter Estimates (*t*-Statistic) and Statistical Significance [5]

	Equation [1a]	**Equation [1b]**	**Equation [2a]**	**Equation [2b]**
	AG_FLEX	***QUALITY***	***SUPPLIER***	***CUSTOMER***
Intercept	-0.623 (-1.67)***	-0.485 (-1.17)	-0.288 (-1.91)***	0.229 (1.36)
Product and Process Characteristics				
SKU	0.067 (5.09)*	-0.011 (-0.71)	-0.016 (-0.64)	-0.005 (-0.18)
VOL	-0.178 (-2.47)*	0.192 (2.15)**	0.002 (0.02)	-0.067 (-0.56)
FORECAST	0.013 (0.15)	0.133 (1.26)	0.037 (0.63)	-0.172 (-2.56)*
PROCESS	-0.295 (-3.62)*	0.479 (4.75)*	0.039 (0.21)	-0.358 (-1.72)***
Advanced Manufacturing Initiatives <u>or</u> Supply Chain Management Initiatives				
AG_FLEX			0.531 (2.08)**	0.068 (0.24)
QUALITY			0.441 (1.84)***	0.691 (2.57)*
SUPPLIER	0.430 (1.79)***	-0.020 (-0.07)		
CUSTOMER	0.400 (1.44)	0.930 (2.72)*		
Control Variables				
SIZE	0.106 (1.73)***	0.045 (0.65)		
AGE	-0.009 (-2.06)**	0.000 (-0.09)		
UNION	0.001 (1.45)	-0.000 (-0.39)		
MFG_IT	0.051 (0.36)	0.237 (1.37)		
MATERIALS			0.004 (2.75)*	-0.000 (-0.17)
DOWNSIZE			0.072 (1.99)**	-0.018 (-0.50)
SCM_IT			0.035 (0.51)	0.099 (1.30)
WEIGHTED Adjusted R^2 = 0.20				

* $p < 0.01$; ** $p < 0.05$; *** $p < 0.10$

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[5] Formal Hausman tests for exogeneity (Hausman, 1978) failed to reject the hypotheses that *SUPPLIER* (*CUSTOMER*) is endogenous to *AG_FLEX* (*QUALITY*), that *AG_FLEX* and *QUALITY* are endogenous to *SUPPLIER*, and that *QUALITY* is endogenous to *CUSTOMER*.

Table 4: Empirical Profiles of *Product and Process Characteristics*, *Advanced Manufacturing Initiatives*, *Supply Chain Management Initiatives*, and Operational Definition of "FIT" Indices [6]

	FIT* *with respect to* *Agility & Flexibility ***FIT_AG_FLEX* = 1**	***FIT* *with respect to* *Quality & Process Improvement*** ***FIT_QUALITY* = 1**	***FIT* *with respect to* *Supplier-Oriented Initiatives*** ***FIT_SUPPLIER* = 1**	***FIT* *with respect to* *Customer-Oriented Initiatives*** ***FIT_CUSTOMER* = 1**
Product and Process Characteristics				
SKU	Large number (*D_SKU* = 1)	☒	☒	☒
VOL	Not Volume-Based production (*VOL* = 0)	Volume-Based production (*VOL* = 1)	☒	☒
FORECAST	☒	☒	☒	Not following a Build-to-Forecast approach (*FORECAST* = 0)
PROCESS	Not using a Line-Flow Manufacturing Process (*PROCESS* = 0)	Using a Line-Flow Manufacturing Process (*PROCESS* = 1)	☒	Not using a Line-Flow Manufacturing Process (*PROCESS* = 0)
Adoption Level of *Advanced Manufacturing Initiatives*				
AG_FLEX	High adoption level (*D_ AG_FLEX* = 1)	☒	High adoption level (*D_AG_FLEX* = 1)	☒
QUALITY	☒	High adoption level (*D_QUALITY* = 1)	High adoption level (*D_QUALITY* = 1)	High adoption level (*D_QUALITY* = 1)
Adoption Level of *Supply Chain Management Initiatives*				
SUPPLIER	High adoption level (*D_SUPPLIER* = 1)	☒	High adoption level (*D_SUPPLIER=1*)	☒
CUSTOMER	☒	High adoption level (*D_CUSTOMER* = 1)	☒	High adoption level (*D_CUSTOMER* =1)

☒ = Irrelevant

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[6] D_SKU_i = 1 if SKU_i > the corresponding median value in the sample; Else = 0. The same logic applies to *D_AG_FLEX*, *D_QUALITY*, $D\_SUPPLIER_i$, and *D_CUSTOMER*.

Table 5: “FIT”–Performance Effects: Parameter Estimates (*t*-Statistic), Statistical Significance, and Sensitivity Analyses [7]

	PANEL A *Manufacturing Performance* Metrics – % Change				**PANEL B (Sensitivity Analyses)** *Manufacturing Performance* Metrics – % Change			
	ΔPass [3a]	*∇Cycle_Time* [3b]	*∇Delivery* [3c]	*∇Unit_Cost* [3d]	*ΔPass* [3a]	*∇Cycle_Time* [3b]	*∇Delivery* [3c]	*∇Unit_Cost* [3d]
Intercept	-0.234 (-0.09)	1.446 (0.53)	1.700 (0.70)	0.763 (0.84)	-0.247 (-0.08)	1.034 (0.38)	1.148 (0.47)	0.543 (0.58)
IND_ΔPass	0.855 (4.01)*				0.941 (4.40)*			
IND_∇Cycle_Time		0.918 (6.04)*				0.993 (6.57)*		
IND_∇Delivery			0.973 (6.67)*				1.019 (6.96)*	
IND_∇Unit_Cost				0.950 (5.10)*				0.987 (5.30)*
FIT_AG_FLEX	4.198 (2.13)**	-3.262 (-1.27)	-4.820 (-2.06)**	-0.666 (-0.47)	11.025 (2.72)*	-9.804 (-1.84)***	-12.437 (-2.57)*	-5.991 (-2.09)**
FIT_QUALITY	4.390 (2.22)**	-3.216 (-1.22)	-0.831 (-0.35)	-1.230 (-0.87)	10.105 (3.22)*	-5.115 (-1.23)	-3.833 (-1.02)	-4.241 (-1.90)**
FIT_SUPPLIER	4.308 (3.44)*	-8.997 (-5.49)*	-5.841 (-3.93)*	-3.178 (-3.56)*	3.744 (1.86)**	-9.881 (-3.74)*	-4.595 (-1.92)***	-3.993 (-2.81)*
FIT_CUSTOMER	4.130 (3.05)*	-1.559 (-0.88)	-1.860 (-1.15)	-0.499 (-0.52)	6.845 (3.32)*	-2.897 (-1.07)	-3.808 (-1.55)	-2.018 (-1.38)
Adjusted R^2	0.065	0.087	0.074	0.044	0.056	0.065	0.059	0.048

* $p < 0.01$; ** $p < 0.05$; *** $p < 0.10$

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[7] Due to missing values, the sample size was reduced from the $N = 1389$ used in the latent trait, categorical factor analysis to just $N = 953$ for evaluating the performance consequences of “FIT.”