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Demographics of mass customization: a global study of manufacturing plants

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Abstract

This study explores the demographic configuration of mass customization (MC) manufacturing plants. It uses cluster analysis, ANOVA and correspondence analysis to test for differences in business unit size, location, and supply chain structure between MC and non-MC producers across the globe. The analysis uses data from an international survey of manufacturers of metal products, machinery, and instruments from 21 countries. Results indicate no significant differences in size, but significant differences in location and supply chain indicators between MC and non-MC plants. We also find renewed evidence of the positioning of MC plants in Hayes & Wheelwright's (1979) product and process matrix.

Keywords

Mass customization. Cluster analysis. Survey.

1. Introduction

Mass customization (MC) is a phenomenon in evolution. Over the last decades and particularly in manufacturing, MC has evolved from being a niche competitive approach to becoming a widely adopted strategy focused on improved response to customer requirements (Aigbedo, 2009; Matzler et al., 2011). Studies report case applications of MC across a broadening range of industries from traditional, e.g. automotive (Ro et al., 2007), food manufacturing (McIntosh et al., 2010), and apparel (Au & Ma, 2010) to unconventional, e.g. biomedicine (McMains, 2005; Pallari et al., 2010). Such applications have been facilitated by an ever-increasing range of technologies and methods that enable fast delivery of variety at competitive cost. A number of alternatives have become available to industrial managers and engineers, ranging from cutting-edge rapid manufacturing (Atzeni et al., 2010) and 3D computer-aided design technologies (Au & Ma, 2010), to improved product and process configurations such as product modularity (Ro et al., 2007), and time and form postponement (Su et al., 2005).

Formerly limited to companies in close contact with customers and their demands (Da Silveira et al., 2001), MC is currently being adopted by an increasing number of companies with different strategic and technological profiles. Studying common characteristics of such evolving sample of companies becomes paramount to keep the theory and practice of MC in pace. That is the focus of our attention in this paper.

This study explores the demographic configuration of MC manufacturing plants. In particular, it compares the business unit size, location, and supply chain configuration of MC versus non-MC manufacturers of metal parts, machinery and equipment. Previous studies based on single or multiple case studies described specific MC implementations in manufacturers both large (Feitzinger & Lee, 1997) or small (Dean et al., 2009), located in countries as diverse as Canada (Dean et al., 2009) and China (Fan & Huang, 2007). However, no large sample statistics were explored in those studies. In fact, only a few studies such as Liu et al. (2006), Lai et al. (2012), and Trentin et al. (2012) (all using data from the High Performance

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Manufacturing Project) appear to have explored relationships between MC adoption, and manufacturing organizational variables with large international samples.

There are two important contributions in this paper. First, we present an empirical analysis of the demographics of MC and non-MC producers using a multi-national sample of 695 manufacturers of metal parts, machinery, and equipment. The data were collected in the fifth International Manufacturing Strategy Survey (IMSS-V) in 2009, and includes responses from 21 countries in different continents. Our findings point to (i) the prevalence of MC producers in Asian countries, (ii) the emphasis in MC plants on developing coordination with strategic suppliers, and (iii) the homogeneity in company size among MC and non-MC producers.

Second, and following studies such as Safizadeh et al. (1996), Ahmad & Schroeder (2002), Ariss & Zhang (2002), and Olhager & Rudberg (2003), we present new empirical evidence on the positioning of MC plants in Hayes & Wheelwright's (1979) product and process matrix (PPM), based on cluster analysis. A novel clustering variable is proposed for that, considering the amount of mass and customized processes present in the manufacturers surveyed in the study sample. Our findings pointed to the existence of three distinct groups of manufacturers, positioned above, below and along the PPM main diagonal. The groupings enabled the estimation of relevant demographic characteristics of MC and non-MC producers.

In addition to the present introduction there are six sections in this paper. In section 2 we present the study hypotheses, backed by relevant pertinent literature. In section 3 we describe the data used to test the hypotheses, and detail the cluster analysis performed on it. Criterion variables associated with the hypotheses in section 2 are presented in section 4, followed by the results obtained on the hypothesis tests in section 5. In the last two sections we present a discussion on results in previous sections, and general conclusions.

2. Background and hypotheses

2.1. *Mass customization*

Mass customization (MC) is an operations strategy that aims to deliver personalized goods or services at competitive cost (Gilmore & Pine, 1997; Duray, 2002). It provides superior value by allowing customers to choose and often co-design products incorporating unique specifications (Franke & Schreier, 2008; Merle et al., 2008). As pointed out by Safizadeh et al.

(1996), Grover & Malhotra (1999), Ahmad & Schroeder (2002) and Olhager & Rudberg (2003) among others, advanced technologies and methods such as computer-aided design (CAD) and product modularity allow manufacturers to deliver such customized products using linear processes; this combination positions MC manufacturers off the main diagonal of the Hayes & Wheelwright's (1979) PPM.

MC applications evolved significantly since the concept was defined in Davis (1987) and Pine II (1993). The first cases included consumer products such as jeans (Zipkin, 2001), bicycles (Kotha, 1995; Zipkin, 2001), and printers (Feitzinger & Lee, 1997) that were well suited to modular design. Further applications included services such as construction (Barlow et al., 2003) and intermediate parts suppliers (Pine II et al., 1995). More recently, MC has been adopted at the other end of the personalization scale, turning high-end goods such as biomedical components (McMains, 2005; Pallari et al., 2010) more affordable.

Thus, MC has evolved from being a niche approach to become a widely adopted manufacturing strategy (Aigbedo, 2009; Matzler et al., 2011). Its broad dissemination in industry may have various explanations. First, there has been increased consumer demand for personalized goods and services (Ahmad et al., 2010). Second, new information technologies offer new interfaces for user-initiated design (Wind & Rangaswamy, 2001; Dewan et al., 2003; Ong et al., 2006). Third, flexible technologies such as CAD and rapid prototyping are less expensive and more widely applicable (Gould, 2004; McMains, 2005).

Following on Safizadeh et al. (1996), Grover & Malhotra (1999), Ahmad & Schroeder (2002), Ariss & Zhang (2002), and Olhager & Rudberg (2003) among others, there should be a significant number of manufacturers in our sample operating off the main diagonal in Hayes & Wheelwright's (1979) PPM by combining high volume processes such as linear and continuous configurations with high product variation.

- H1. The study sample will include a unique group of MC plants producing high product variety based on high volume process configurations.

Past studies found alternative levels of support to this hypothesis. Safizadeh et al. (1996) found that 13 of 142 U.S. manufacturers offered medium to high levels of customization while operating with linear or continuous processes. Using data from the World Class Manufacturing (WCM) survey, Ahmad & Schroeder (2002) found that two out of four manufacturing clusters provided high levels of customization that did not match their process

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configurations. Ariss & Zhang's (2002) analysis of 31 manufacturers from Michigan, US found that flexibility capability minimized performance gaps between companies operating on and off the PPM main diagonal. Olhager & Rudberg (2003) found that two out of eight Swedish manufacturers in their multiple-case analysis were located in the MC corner of the PPM.

2.2. Size and location

We expect to find no significant differences in size or location between MC and non-MC plants. Effects of firm size, measured by number of employees, are often considered in manufacturing strategy models of adoption; one justification is that larger firms usually have more resources to implement advanced practices or technologies (Boyer et al., 1996; Koufteros et al., 2007; Liu et al., 2006). However, we argue that this rationale is not applicable to MC.

One of the unique features of MC is that it can be supported by methods and technologies having different levels of complexity and cost. Thus, even small and medium enterprises (SMEs) can pursue MC strategies providing they overcome organizational challenges (Svensson & Barfod, 2002) and learn how to apply advanced technologies including IT to their processes (Dean et al., 2009). For example, Bateman & Cheng (2006) discuss at length how a CAD system could be adapted to support "devolved manufacturing" in a small firm. This could explain why Liu et al. (2006) found no significant correlation between "plant size" and MC capability in an international manufacturing survey. This leads to the second study hypothesis:

- H2. There will be no significant differences in size between MC and non-MC plants in the study sample.

Likewise, the broad technological and methodological basis may facilitate MC development across different parts of the world including developed and developing countries. Although we may be witnessing changes in long-established regional advantages (for example, increasing wages in China – see Yang et al. (2010) for a longitudinal analysis), manufacturing in North America and Europe is still more reliant on process technology and less on labor-intensive tasks than manufacturing in Asia and Latin America (see data in Schwab & Sala-i-Martin (2011): 510). However, MC is supported by a mix of labor and technology-embedded capabilities (Kotha, 1995), the balance of which may vary from case to case. Thus, MC processes could be adapted to fit regional advantages such as relying more on technology where labor is more expensive, and vice-versa. For example, Atzeni et al. (2010) suggest that

rapid manufacturing (RM) could substitute injection molding to enable "medium volume" production in Western Europe. These arguments suggest that MC may be indeed a global phenomenon, even though specific configurations of MC may be contingent on local factors. This leads to the third hypothesis:

- H3. There will be no significant differences in location between MC and non-MC plants in the study sample.

2.3. Supply chain

The design and production of MC products often depends on strong collaboration with a few distinctive suppliers (Galbraith, 1977, reviewed in Trentin et al., 2012). One of the cornerstones of transaction cost theory (TCT) is that maintaining arms-length relationships with external partners may turn outsourcing expensive to producers requiring frequent information exchanges with suppliers (Malone, 1987; Clemons et al., 1993). Therefore, focus on customization calls for more integrated supply chain structures (Mikkola & Skjott-Larsen, 2004; Salvador et al., 2004; Trentin et al., 2012) which, according to TCT, can rely on either straight verticalization or hybrid coordination models such as defined by Williamson (1985). However, as indicated by Lai et al. (2012), the extended resource-based view of the firm (ERBV) suggests that the hybrid form (i.e. supply chain collaboration) is likely to be more prevalent among MC providers, because MC design and production depends on a broad set of capabilities.

Furthermore, MC from a technical view is enabled by a series of capabilities and practices that are more easily implemented through integration with supply chain partners. Frequent and unplanned changes in customer requirements and design specifications demand intensive information exchange across the supply chain to enable product design and process planning (Liao et al., 2011; Peng et al., 2011; Trentin et al., 2012). Such information is often relayed through IT integration (Peng et al., 2011). Moreover, common MC techniques such as form postponement (Mikkola & Skjott-Larsen, 2004; Salvador et al., 2004; Su et al., 2005) and concurrent engineering (Tu et al., 2004; Kincade et al., 2007) rely often on forms of synchronization between supply chain partners (e.g. of strategic goals, design capabilities, process scheduling, logistics, etc. – see, for example Salvador et al. (2004) and Liao et al. (2011)), which are not compatible with market-based relationships and short-term contracts. These arguments lead to the final two study hypotheses:

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- H4. MC plants will maintain more strategic supplier relationships and a smaller supplier base than non-MC plants in the study sample.
- H5. In selecting suppliers, MC plants will give more importance to coordination capability criteria than non-MC plants in the study sample.

Lai et al. (2012) investigated a similar relationship between MC and "supplier integration" in a sample of 287 manufacturers from nine countries. They found no significant support to the hypothesis. However, Trentin et al. (2012) did find a significant higher level of "environmental management" (a construct involving "supplier partnership" together with two other scales) in companies with higher MC capabilities.

3. Data

We use data from the fifth edition of the International Manufacturing Strategy Survey (IMSS-V). The IMSS is designed, conducted, and validated by a network of operations strategy scholars. Some of the information below and further details about the survey can be found in several previous studies that used IMSS data, e.g. Voss & Blackmon (1998), Vecchi & Brennan (2009), and Da Silveira (2011). The following information has been obtained from the start-up package of IMSS-V and from a summary of proceedings in each country after data collection. Both documents were prepared by the survey's central administration at Politecnico di Milano, Italy and distributed to the network.

IMSS is a global periodic survey of the strategies, practices, and performance of manufacturers of metal parts, machinery, and equipment (ISIC 28-35). The survey is carried out every four or five years. Potential respondents include previous survey participants (to allow longitudinal analyses) and new companies identified in national business databases. The target respondent is the Operations or Manufacturing Director, or equivalent in each business unit.

IMSS-V was carried out in 2009 in 21 countries. The unit of analysis was the business unit, with questions about practices and operations performance referring to the "plant's dominant activity". Across the 21 countries, 7277 companies were initially contacted, of which 4457 received questionnaires. Companies were initially contacted by email or phone. Questionnaires were sent by email in most cases, and by regular post or fax if requested by the company. Eight countries used the original questionnaire in English; 13 countries and the Francophone provinces of Canada used local versions that were in most cases double and reverse translated by academics.

The number of valid responses was 725 (of which 695 were complete for the purposes of this study), i.e. 10.0% of the initial contacts and 16.3% of the questionnaires distributed. The countries involved (and valid responses) were Belgium (36), Brazil (37), Canada (19), China (59), Denmark (18), Estonia (27), Germany (38), Hungary (71), Korea (41), Ireland (6), Italy (56), Japan (28), Mexico (17), the Netherlands (51), Portugal (10), Romania (31), Spain (40), Switzerland (31), Taiwan (31), UK (30), and USA (48). Differences in ISIC and size between respondents and non-respondents were checked in seven countries; all tests yielded non-significant results.

3.1. Cluster formation

We use cluster analysis to verify the existence of a unique group of mass customizers producing high product variety with high volume process configurations. As discussed, this approach has been used by Safizadeh et al. (1996), Grover & Malhotra (1999), Ahmad & Schroeder (2002) and Olhager & Rudberg (2003), among others. Liu et al. (2006) clustered cases based on MC capability strength as opposed to location in the PPM (Hayes & Wheelwright, 1979).

Individuals are classified based on a clustering variable denoted *PPDEV*, comprised of two indicators, *MASS* and *CUSTOM*. Manufacturers informed the percentage of their production obtained through one-of-a-kind, batch, and mass processes. The indicator *MASS* is calculated by adding up percentages of each process type for each respondent, using weights 0, 0.5, and 1, respectively. Manufacturers also informed the percentage of customer orders designed or engineered to order, manufactured to order, assembled to order, or made to stock. The indicator *CUSTOM* is calculated by adding up percentages of each order type for each respondent, using weights 1, 0.67, 0.33, and 0, respectively. *PPDEV* is calculated by *MASS* – (100 – *CUSTOM*).

The cluster formation procedure is based on the work of Menor et al. (2001) and recommendations in Ketchen & Shook (1996), and Hair et al. (2010). Based on the rationale in Punj & Stewart (1983) reviewed by Menor et al. (2001), a two-step method is used. First, hierarchical cluster algorithms are applied to find the best structure for the sample data. Then, *k*-means is used to validate the hierarchical solution. Following recommended practice (e.g. Menor et al., 2001; Tsikriktsis, 2004) we test multiple algorithms in IBM® SPSS® Statistics 19.0.0 (SPSS, 2010) including between-groups linkage (BGL), within-groups (average) linkage (WGL), the centroid method, and Ward's method, all with squared Euclidean distances. Based on

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agglomeration schedules, cluster sizes, and theoretical interpretability (Menor et al., 2001; Hair et al., 2010), the WGL and Ward's three-cluster solutions provide the best initial configurations. Their means are used as initial seed points to the k-means algorithm. The WGL solution has higher stability; thus, the k-means three-cluster solution based on seeds from the WGL algorithm is used in the analyses to follow.

4. Criterion variables

Hypotheses H2 to H4 are tested with objective and perceptual variables. Size (H2) is measured by the number of employees in the plant's respective business unit. Location (H3) is measured by four dummies representing continents where plants are situated.

Supplier base (H4) is assessed by three independent indicators. Respondents were asked to, "Indicate the following supplier figures [relating to the plant' dominant activity]: Total number of suppliers, Average number of suppliers per item, Proportion of suppliers considered as key/strategic suppliers".

Supplier selection criteria (H5) are assessed by perceptual variables. Respondents were asked, "What criteria do you use for selecting your key/strategic suppliers? Specify the level of importance of each criterion." Responses were provided on a five-point Likert scale with endpoints None (1) and High (5). We use exploratory factor analysis (Table 1) to identify latent criteria reflecting the multiple items of the questionnaire. The analysis identifies three criteria named coordination, responsiveness, and efficiency. The KMO estimate (.720) and Bartlett's significance ($p < .001$) suggest the dataset is suitable for factor analysis (Hair et al., 2010). Factor loadings are greater than

.500 and eigenvalues are greater than one. Only one item (logistical costs) loads on more than one factor; the item is retained in Factor 1 for theoretical reasons. The first factor reflects the focus on supply chain integration described in previous studies including the theory leading to H5. The last two factors have straight correspondence to Fisher's (1997) supply chain framework (even though he considered quality a function of both types of supply chains).

Cronbach's alphas of the multi-item scales are .688 and .629; the later estimate is somewhat low but still consistent with two-item scales (see for example Schwartz (2012)). The former estimate is close to the .70 level recommended in the literature (Peterson, 1994).

5. Hypothesis tests

Resulting clusters of individuals are plotted on two-dimensional graphs with *MASS* (mass process) and *CUSTOM* (customized production) in the axes, as seen in Figure 1. Three groups of manufacturers are obtained, and their demographics analyzed using two statistical tests: (*i*) differences between groups in variables 1 to 4 (Table 2) and 9 to 14 (Table 3) are analyzed using Scheffé's method on ANOVA outputs (Sato, 1996; Hair et al., 2010); (*ii*) differences between groups in variables 5 to 8 (Table 4), which are counts, are analyzed through correspondence analysis (Johnson & Wichern, 2007).

Group 1, named *Process Matchers*, is the one best represented in the study sample (49.78% of all valid cases). Its members have corresponding product and process structures as prescribed in Hayes & Wheelwright (1979), being positioned along the main

Table 1. Supplier selection criteria.

	Factor		
	1	2	3
Coordination (*Cronbach's* α = .688)			
Willingness to disclose cost/other information	**.785**	.155	−.054
Physical proximity	**.766**	−.070	.147
Ability to provide innovation and co-design	**.638**	.381	−.262
Logistical costs	**.565**	.266	**.428**
Responsiveness (*Cronbach's* α = .629)			
Quality of products/services	.056	**.869**	−.100
Delivery performance	.199	**.773**	.294
Efficiency			
Lowest price bid	−.017	.029	**.907**
Rotation sum of squared loadings			
Eigenvalue	1.973	1.598	1.195
Cumulative % of Variance	28.179	51.010	68.080

Principal Component Analysis with Varimax rotation. Listwise deletion of cases with missing values ($n = 690$). KMO = .720; Bartlett's test $p < .001$. Factor loadings ≥ .400 in bold.

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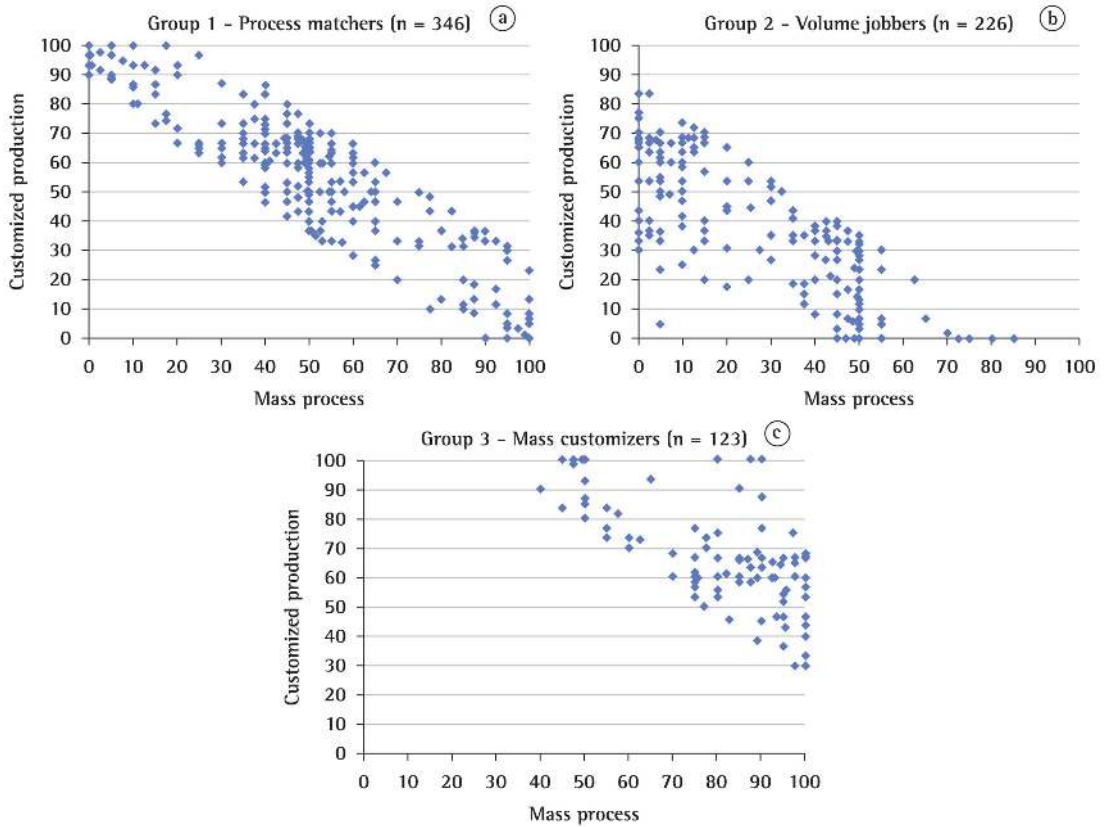PRODUCTION

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Figure 1. Process-product choices in the three clusters.

Table 2. Process configuration, variables 1 to 4.

Group	1 Process Matchers	2 Volume Jobbers	3 Mass Customizers	Total	F-value (p-value)
Valid n[1]	346	226	123	695	
PPDEV					
Mean[2]	6.20 [2,3*]	−34.31 [1,3*]	47.32 [1,2*]	.30	1693.665
S.D.	10.93	14.43	14.38	31.03	(< .001)
MASS					
Mean[2]	47.61 [2,3*]	27.26 [1,3*]	82.60 [1,2*]	47.18	240.716
S.D.	24.42	21.66	17.99	29.28	(< .001)
CUSTOM					
Mean[2]	58.59 [2,3*]	38.43 [1,3*]	64.72 [1,2*]	53.12	77.443
S.D.	23.15	22.05	18.98	24.42	(< .001)
Employees[1]	344	224	121	689	
Mean[2]	1566.49	1848.00	2387.57	1802.20	.411
S.D.	7830.57	10707.57	6017.40	8610.22	(.663)

[1]Casewise deletion of observations with missing values; valid *n* reported next to variable when different from baseline. [2]Highest cluster mean is in bold; numbers in brackets indicate clusters with significant mean differences based on post-hoc Scheffé (*p* < .001).

diagonal of the M×C graph, with indicators *MASS* (mass process) and *CUSTOM* (customized production) in the horizontal and vertical axes, respectively (Figure 1a). Process matchers are distributed evenly across regions with no significant differences, although Asian and North American manufacturers are slightly better represented in the group, in opposition to European and South American companies. The cluster mean with respect to *PPDEV* is 6.20; a zero value would correspond to a perfectly diagonal distribution of individuals in the M×C graph. Indicators *MASS* and *CUSTOM* display averages of 47.61 and 58.59, respectively, resulting in individuals slightly more concentrated above the main diagonal. Average

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Table 3. Supply chain management, variables 9 to 14.

Group	1 Process Matchers	2 Volume Jobbers	3 Mass Customizers	Total	F-value (p-value)
Valid n[1]	346	226	123	695	
No. of suppliers[1]	290	183	96	671	
Mean[2]	270.93[3†]	302.24 [3*]	127.84 [1†,2*]	256.86	3.641
S.D.	614.61	495.16	209.45	530.73	(.027)
Suppliers per item[1]	280	178	94	569	
Mean[2]	9.71	**12.64**	10.14	10.73	.406
S.D.	33.15	40.57	25.56	34.60	(.667)
Strategic suppliers[1]	288	183	91	562	
Mean[2]	32.18 [3*]	27.93 [3*]	39.97 [1*,2*]	.11	6.281
S.D.	26.27	24.94	30.05	.32	(.002)
Efficiency[1]	339	218	119	676	1.469
Mean[2]	**3.57**	3.42	3.50	3.51	(.231)
S.D.	.97	1.01	1.16	1.02	
Responsiveness[1]	340	216	119	675	2.156
Mean[2]	**4.22**	4.14	4.08	4.17	(.117)
S.D.	.68	.67	.75	.69	
Coordination[1]	334	215	118	667	5.012
Mean[2]	3.04 [1†]	2.85 [1†,3*]	3.07 [2*]	2.98	(.007)
S.D.	.81	.71	.79	.78	

[1]Casewise deletion of observations with missing values; valid n reported next to variable. [2]Highest cluster mean is in bold; numbers in brackets indicate clusters with significant mean differences based on post-hoc Scheffé (* $p < .05$; †$p < .10$).

Table 4. Geographic location, variables 5 to 8.

Group	1 Process Matchers	2 Volume Jobbers	3 Mass Customizers	Total	χ² value (p-value)
Valid n[1]	346	226	123	695	
Europe					
χ² value	0.03	3.01	4.18	7.2	
Standardized residual[2]	−0.40	**3.29**	**−3.51**		
Asia					
χ² value	0.04	9.61	14.93	24.6	
Standardized residual[2]	0.33	**−4.36**	**4.92**		
N. America					
χ² value	0.04	0.01	0.05	0.1	
Standardized residual[2]	0.28	−0.09	−0.25		
S. America					
χ² value	0.01	1.15	1.65	2.8	
Standardized residual[2]	−0.15	1.34	−1.45		
					34.7 (0.00)

[1]Casewise deletion of observations with missing values. [2]Absolute standardized residuals larger than ±2.0 and ±3.0 (in bold) are significant at 5% and 1%, respectively.

company size in the group is 1566.49 employees, not differing significantly from the other two groups.

Group 2, named *Volume Jobbers*, includes 226 manufacturers of products with medium to low levels of customization, using batch or one-of-a-kind production systems, and positioned below the main diagonal in the M×C graph (Figure 1b). European manufacturers are significantly more present in this group, whereas Asian manufacturers are significantly less present. As expected, individuals are concentrated below but yet close to the main diagonal, with indicators *MASS* and *CUSTOM* presenting averages of

27.26 and 38.43, respectively; only six manufacturers in the group are positioned in the quadrant where indicators are below 25%.

Group 3, named Mass Customizers, includes 123 manufacturers that make products with medium to high levels of customization using mass production processes, being positioned above the main diagonal in the M×C graph (Figure 1c). Asian manufacturers are significantly more present in this group, whereas European manufacturers are significantly less present. Individuals are slightly more concentrated in the lower portion of the triangle above the main diagonal; that

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is reflected in the averages of *MASS* and *CUSTOM* for this group: 82.60 and 64.72, respectively.

We next investigate whether size of the plant's business unit varies with adoption of a MC strategy. Group 1's rounded average size is 1566 employees; for companies in groups 2 and 3 the rounded averages are 1848 and 2388, respectively. Scheffé's test indicates no significant differences in size in the three groups.

The results provide mixed support to our hypotheses. Hypothesis 1 is supported as the cluster analysis clearly separates between MC (Group 3) and non-MC (Groups 1 and 2) manufacturers. Hypothesis 2 is supported as there are no significant differences in business unit size across clusters. Hypothesis 3 is not supported as, based on results in Table 2, MC is more frequently found in Asian companies and less frequently found in European companies.

Finally we test for differences in supply chain configuration between MC and non-MC groups (Table 3). The test of H4 is based on variables 9 to 11. The average number of suppliers (variable 9) in Group 3 (127.84) is significantly smaller than those in Group 1 (270.93) and Group 2 (302.24). The number of suppliers per item (variable 10) is not significantly different across groups. However, the number of strategic suppliers (variable 11) is significantly larger in Group 3 (39.97) than in Group 1 (32.18) and Group 2 (27.93).

The H5 test follows the analysis of variables 12 to 14. There were no significant differences between groups with respect to the importance attributed to efficiency (variable 12) or responsiveness (variable 13) as supplier selection criteria. However, MC plants in Group 3 gave significantly more importance to coordination criteria (variable 14, $\mu = 3.07$) than plants in Group 2 (2.85), even though their mean score was not significantly different from that in Group 1 (3.04).

This analysis provides good support to H4 but partial support to H5. Despite the similar number of suppliers per item, plants in MC group did maintain closer relationships with more suppliers than plants in the other groups, and their supplier base was smaller than in other groups. As a ratio, Group 3 maintained strategic relationships with 31% of their suppliers on average, compared to 11% in Group 1 and 9% in Group 2. On the other hand, results provide only limited support to H5, as MC companies in Group 3 attribute more importance to coordination criteria in supplier selection than companies in Group 2 but not in Group 1.

6. Discussion

One of the study contributions is providing further validation to Hayes & Wheelwright's (1979) PPM. Our analysis identifies manufacturing strategy configurations across a large sample of manufacturers and indicates that about half of the observations fit on the matrix main diagonal.

However, the analysis also identifies several observations operating off the diagonal. In particular, the existence of Group 3 provides evidence to the wide adoption of MC as shown in previous studies (Safizadeh et al., 1996; Grover & Malhotra, 1999; Ahmad & Schroeder, 2002; Olhager & Rudberg, 2003). As stated earlier, manufacturing process innovations in modularity design (Ro et al., 2007), CAD and rapid prototyping (Gould, 2004; McMains, 2005), and rapid manufacturing (Atzeni et al., 2010) enable manufacturing companies to produce high product varieties in high volume process configurations (Svensson & Barfood, 2002).

Our analysis supports the view in Hayes & Wheelwright (1979) that product and process configuration rather than company size is a determinant of manufacturing strategy. We find that company size does not vary significantly across the three clusters in Figure 1. However, geography may explain MC adoption in manufacturing. The significant prevalence of Asian over European companies in the Mass Customizers group may indicate that environmental factors such as market and industry variables influence MC implementation. In particular, manufacturers located in Asia might pursue MC to cater to a sizeable population with largely diverse values and expectations (see, for example, Kwon's (2012) analysis of cultural differences among employees from different regions of China). Differences in personal cultural profiles within and across Asian countries might lead to higher demand for MC products and services. This proposition might be tested in future studies exploring market antecedents of MC.

Results further indicate that, compared to the other groups, MC providers give more emphasis to developing collaborative relationships with suppliers. Moreover, they have fewer suppliers in total, but more strategic suppliers than any of the two other groups. This is evidence that MC providers give more preference to collaborative (as opposed to arms-length) modes of supply chain governance than any other group in the sample. As indicated in our theoretical framework, these results are consistent with the literature on MC and with basic tenets of transaction cost economics (TCE) (Williamson, 1985) and the extended resource-based view of the firm (ERBV; Lai et al., 2012), as will be discussed.

Two elements in particular may promote the use of collaborative governance by MC providers. Perhaps the more significant is, as indicated by Lai et al. (2012) and Trentin et al. (2012), the inherent uncertainty about the variety and volume of market demand,

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and consequently sourcing requirements of MC firms. As pointed out by Liao et al. (2011) and Peng et al. (2011) among others, MC providers and their suppliers must exchange information more frequently and in higher volume to convey frequent demand changes such as in design specifications, order volumes, and production schedules. As explained by TCE studies such as Malone (1987) and Clemons et al. (1993), such levels of communication might turn coordination costs too expensive under traditional (i.e. arms-length) relationships, and require the development of closer associations with fewer suppliers. Our findings provide clear evidence of such relationships in the case of MC providers.

The second element is based on the ERBV precept of searching for external sources of resources and capabilities to the firm (Lai et al., 2012). Competing on MC requires developing various technologies (Da Silveira et al., 2001) and achieving competitive advantages in multiple performance dimensions (Lai et al., 2012; Trentin et al., 2012). Since individual firms may find it difficult to develop expertise and excellence across many areas simultaneously, they may benefit significantly from partnering with suppliers that are sources of complementary expertise or knowledge. As indicated by Da Silveira (2011), network theory studies such as Jones et al. (1997) suggest that such knowledge exchange between supply chain partners depends on more integrated relationships such as those associated with the MC group in the study findings.

7. Conclusions

The study investigates the demographic configuration of MC providers in an international survey of manufacturers of metal products, equipment and instruments. Results indicate that compared to other manufacturing groups, MC producers (i) are more frequently located in Asia and less in Europe and (ii) have fewer suppliers with whom they developed more collaborative relationships. However, the analysis provides no significant evidence that size of the busines units of MC plants is significantly different from the other groups.

Even though the study focuses on one particular manufacturing sector, its findings may contribute to improve understanding of MC development across the world. Whereas the earlier literature often focused on describing specific cases of implementation, the significant dissemination of MC across the world requires more systematic analyses of MC adopters and their supply chains. This study is aimed at contributing towards that line of research.

The study is based on a parsimonious framework that albeit focusing on key demographic variables does not exhaust the need for further explorations. Future studies should not only replicate our analyses across different industries but also explore additional variables of relevance such as markets and distribution channels of MC providers around the world. Such knowledge will advance our understanding of the nature of MC implementations and subsequently the challenges associated with this production approach.

Our findings have important implications to academics and practitioners. Considering that approximately 50% of the individuals in the study sample appear to operate off the PPM main diagonal, further research is needed to specify the antecedents, particularly technology and practices enabling adoption and success with those configurations. From a management perspective, our findings indicate that the choice of product and process may be aligned to peculiarities of regional markets and industries; for example, in determining the means and extent of MC capability development.

The study has limitations indicating future research opportunities. Since data are obtained from a cross-sectional survey, hypotheses of causality could not be tested. Due to the exploratory nature of the study, further analyses based on confirmatory regression and structural equation modeling might provide further validation to our hypotheses.

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