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Aligning manufacturing flexibility with environmental uncertainty: evidence from high-technology component manufacturers in Taiwan

SHIH-CHIA CHANG[†], NENG-PAI LIN[‡] and CHWEN SHEU^{§*}

While flexibility improvement is among the top concerns of manufacturing managers, managers are advised to choose the dimensions of flexibility they want in their plants. This study investigates the strategic choice of aligning flexibility development with the external environment that manufacturing managers face. Considering the nature of the high-technology industry in Taiwan, we measure environmental uncertainty based on the dimensions of customer demand, supply, competitors and product technology. Empirical data were collected from manufacturing firms in Taiwan. We then applied path analysis to examine the effect of aligning three types of flexibility: product mix, new product and volume with specific dimensions of environmental uncertainty. The results indicate that the matching of manufacturing flexibility with environmental uncertainty is necessary to ensure profit and sales performance. When faced with certain environmental stimuli, management should choose to emphasize and develop particular manufacturing flexibility.

1. Introduction

Over the last decade, manufacturing companies have faced both increasing technology innovation and more competitive markets. Constantly changing technology induces product and process innovations, which provide customers with more choices and manufacturers with more ways to compete. All of those changes ultimately increase the complexity and uncertainty of the manufacturing environment and create new challenges to management. For instance, the currently popular supply chain management is mostly motivated by the availability of new information technology, such as enterprise resource planning systems.

The literature has suggested the development of manufacturing flexibility to deal with the constantly changing and increasingly uncertain manufacturing environment. Many believe that high manufacturing flexibility could enable firms to respond to rapid market changes quicker with lower effort and cost. Flexibility has become an effective weapon to gain competitive advantage in an uncertain manufacturing environment (De Meyer *et al.* 1989, Gerwin 1993, Jordan and Graves 1995, Beach *et al.* 2000). In the past, many studies have investigated the impact of external environmental uncertainties on the level of manufacturing flexibility and thus on manufacturing performance. This study examines the relationship between environmental uncertainty and manufacturing flexibility from a different aspect.

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[†]Department of Business Administration, National Taipei College of Business, Taipei, Taiwan, ROC.

[‡]School of Management, National Taiwan University, Taipei, Taiwan, ROC.

[§]Department of Management, Kansas State University, Manhattan, KS 66506, USA.

*To whom correspondence should be addressed. e-mail: csheu@ksu.edu

We take into consideration the multi-dimensional nature of both flexibility and environmental uncertainty and examine the one-to-one relationship between these two factors. The premise is that organizations can be flexible in some ways and less flexible in others (Suarez *et al.* 1996). Specifically, managers may have to choose the dimension in which they want their plants to be flexible. Environmental uncertainty could be the factor that determines this important strategic choice. In other words when faced with certain environmental stimuli, management should choose to emphasize and develop particular sets of manufacturing flexibility. Therefore, the purpose of this study is to map the relationship between the dimensions of manufacturing flexibility and uncertainty. We are interested in how different environmental uncertainty dimensions (demand, supply, competition and technology) link with specific types of manufacturing flexibility such as new products, volume and product mix. Furthermore, this study tests the effectiveness of such mapping on business performance. Theoretically, the alignment of a particular environmental uncertainty dimension with a specific type of manufacturing flexibility should improve business performance.

We first review and summarize the theoretical relationship between manufacturing flexibility and environmental uncertainty with the emphasis on definition and measurement. We then present the research design, including the basic model, hypotheses and statistical methods. Finally, statistical results and discussions are offered.

2. Literature review

This section reviews previous studies on manufacturing flexibility, environmental uncertainties and their relationship.

2.1. Manufacturing flexibility

Manufacturing flexibility was originally defined as the ability of a manufacturing firm to respond to external environmental changes (Mandelbaum 1978). Recent research provides a more specific definition of manufacturing flexibility. For example, Upton (1994) defines manufacturing flexibility as the ability to respond to environmental changes with less time and cost. Other researchers suggest that manufacturing flexibility is a multi-dimensional construct and could be measured in many different ways (Sethi and Sethi 1990, Gerwin 1993). Based on different logics for interpreting its various dimensions, manufacturing flexibility can be classified in many different ways. De Toni and Tonchia (1998) provide a comprehensive review of various classification schemes. For example, one could classify manufacturing flexibility by the variations such as process, product or production volume.

For the purpose of this study we chose to review manufacturing flexibility in a manner relating flexibility to environmental uncertainty. Specifically, several studies have classified manufacturing flexibility into *internal* and *external* flexibility (Lynch and Cross 1991, Chen *et al.* 1992, Upton 1994). External manufacturing flexibility is relative to the need of customer requirements. Examples of external manufacturing flexibility are new product flexibility, product mix flexibility and volume flexibility. It is usually recognized and perceived better since it directly affects a firm's competitiveness. On the other hand, internal manufacturing flexibility is relative to the need to meet customer requirements efficiently, and it is not directly related to market demand and environmental uncertainties. Examples of internal manufacturing flexibility are machine and routing flexibility. Generally, its impact

on a firm's market competitiveness is rather indirect and is usually not recognized by customers.

2.2. *Environmental uncertainties*

Many studies in organizational theory have addressed the issue of external environmental uncertainty. Most of these studies delve into the issues of how firms should predict elements of their environment, such as competitors, customers and suppliers (Burns and Stalker 1961, Duncan 1972, Downey and Slouch 1975). Overall, the literature suggests that firms should adopt a more organic structure to cater to a more complex environment where jobs are less specialized and more complex. On the other hand, firms should apply a mechanistic structure to a more predictable environment with greater subdivision of tasks and simpler job assignments.

Business strategy literature provides various approaches for measuring environmental uncertainty. Some studies suggest the use of objective measures (Dean and Snell 1996, Kotha and Orne 1989, Wernerfelt and Karnai 1987). For example, uncertainty could be measured based on four dimensions: demand, supply, competitive and external. On the other hand, another group of researchers proposes the perceptual measure of environmental uncertainty (Duncan 1972, Bourgeois 1980, Swamidass and Newell 1987). They suggest that the perceptions of the environment are more important than the actual environment. Managers will make decisions based on their perceptions of the degree of environmental uncertainty.

2.3. *Environmental uncertainty and manufacturing flexibility*

While this paper investigates the use of manufacturing flexibility to address environmental uncertainty, there are many other approaches that managers can take. For instance, March and Simon (1958) suggest the use of 'organizational slack' to provide excess resources to cope with environmental uncertainties. Alternatively, managers can invoke some form of environmental control. Sethi and Sethi (1990, p. 294) provide an automated transfer line analogy, suggesting that 'work in progress is presented, by means of transfer mechanisms, to successive machine tools in proper position to be grasped and worked (i.e. environmental control), eliminating the sensory and manipulative functions (i.e. flexibility component) of workers who loaded the machines by hand'. More recently, Pagell and Krause (1999) found that manufacturing firms developed various competitive strategies to reduce the impact of environmental uncertainty.

In general, there are two research issues pertaining to the relationship between uncertainty and manufacturing flexibility (Pagell and Krause 1999). First, what is the specific one-to-one relationship between these two multi-dimensional variables? Second, does the fit between external uncertainty and types of manufacturing flexibility lead to better business performance?

Again, the literature in organizational theory has extensively investigated the issue of aligning internal aspects of the organization with the external environment (Venkatraman 1989, Venkatraman and Prescott 1990, Bluedorn 1993). Many operations management studies also confirmed the notion of aligning internal structure with an uncertain external environment. They suggest that manufacturing companies should develop flexibility for the sake of dealing with short product life cycles and environmental uncertainty more effectively (Mascarenhas 1981, Correa 1994). Swamidass and Newell (1987) and Tombak and De Meyer (1988) find that an increase in manufacturing flexibility resulting from higher environmental uncertainty

would lead to better business performance. Gerwin (1993) and Beach *et al.* (2000) support the effect of environmental uncertainty on manufacturing flexibility. Manufacturing firms should develop a specific type of manufacturing flexibility corresponding to the unique features of the external environments. In other words, a fit between the type of manufacturing flexibility and factors contributing to external environmental uncertainty is necessary. Managers should examine their external environments when making decisions to develop manufacturing flexibility. Braglia and Petroni (2000) empirically confirm the relationship between these two factors but offer no specific one-to-one relationship or comment the effectiveness of such alignment.

Contrary to previous research, Pagell and Krause (1999) study users of advanced manufacturing technologies (AMT) and find no relationship between uncertainty and manufacturing flexibility. The level of manufacturing flexibility (a composite measure of new product introduction, modification and product mix flexibility) is not associated with the level of environmental uncertainty. Moreover, the results of Pagell and Krause (1999) showed that firms do not benefit from the matching of internal manufacturing flexibility with environmental uncertainty. Many manufacturing firms, in response to external environmental uncertainty, chose to focus on other competitive priorities rather than flexibility. Badri *et al.* (2000) observe a strong positive relationship between increased uncertainty and an increased emphasis on flexibility as a manufacturing strategy. Nevertheless, both high and low performers in their sample were responding to increased uncertainty by increasing their level of flexibility, thus making it impossible to determine the true performance benefits, if any, of responding to uncertainty with flexibility.

In summary, the literature holds inconsistent views on the relationship between manufacturing flexibility and environmental uncertainty and the notion of 'alignment'. There are several reasons for this inconsistency. One of the primary reasons is that the levels of uncertainty and manufacturing flexibility are often defined and measured in different ways. For instance, not every study incorporated volume flexibility and/or new product flexibility even though both are recognized as important types of flexibility in manufacturing today. Some studies focus on internal routing and machine flexibility, while others look into external manufacturing flexibility such as mix and new products. In the case of external environmental uncertainty, some studies use managerial perceptions to produce subjective and perceptual measures. On the other hand, many researchers adopt different environmental factors to create objective measures of uncertainty. It is no wonder that the relationship of manufacturing flexibility and uncertainty is not conclusive.

Also lacking in the literature is empirical verification of the one-to-one relationship between types of manufacturing flexibility and dimensions of environmental uncertainty. Suarez *et al.* (1996) support the need for choosing dimensions along which firms want their systems to be flexible. They suggested that management could make the strategic choice based on the environment. Given the multi-dimensional nature of both manufacturing flexibility and uncertainty, the exact relationship between the two needs to be defined more precisely. For example, constantly changing customer demand would lead to short product life cycles, which creates a great degree of uncertainty in a firm's operations. This type of uncertainty, in turn, drives firms to develop new product flexibility but not volume flexibility. The alignment between manufacturing flexibility and uncertainty must be assessed based on the one-to-one relationship rather than on aggregate level (e.g. a high level of manufac-

turing flexibility versus a high level of uncertainty). It is important that management recognize such an alignment, so that companies can allocate resources to develop the appropriate type of manufacturing flexibility to deal with particular external uncertainty.

3. Model building and hypothesis

This paper intends to map the relationship between types of manufacturing flexibility, various environmental uncertainty dimensions and business performance. Based on our observation from high-technology industries (PCB, personal computers, monitors and motherboard) in Taiwan, we found three types of manufacturing flexibility to be most critical to a firm's competitive advantage. They are *new product flexibility*, *mix flexibility* and *volume flexibility*. Based on Sethi and Sethi (1990) and Suarez *et al.* (1996), new product flexibility is the ability to introduce new products, volume flexibility is the ability to operate profitably at different overall output levels and product mix flexibility is the ability to manufacture a variety of products within a short period of time. These definitions are also adopted by many other studies (e.g. Jaikumar 1986, Boyer and Leong 1996). As an example, almost all customer orders for monitors in Taiwan are from large overseas PC companies such as IBM, Apple and Hewlett Packard. Subject to the overall economy, those large clients frequently change their contract manufacturing orders (in quantity and delivery dates) to absorb demand uncertainties from end users. Such changes have forced their contract manufacturers to develop volume flexibility through outsourcing and overtime.

In the case of environmental uncertainty, we use Wernerfelt and Karani's (1987) definition to measure the level of uncertainty: demand, supply, competitive and technology. We did not include the three uncertainty dimensions (union, public view and government regulations) suggested by Duncan (1972), since they are irrelevant in Taiwanese industry. The procedure for measuring these four dimensions is described in the next section. Overall, our definition of environmental uncertainty is consistent with the environment of the high-technology industry in Taiwan. For example, the PCB industry is known for being highly capital- and technology intensive. Most PCB firms are contract manufacturers, and they all have to compete in the open market subject to a great degree of uncertainty from customers and competitors. Since Taiwan lacks natural resources, the majority of components are imported from overseas, which creates a longer and more uncertain supply lead-time. Finally, the technology used in PCB industry (e.g. surface mount) is highly innovative and programmable and thus offers the opportunity to make a high variety of board designs requested by clients. Overall, this industry faces a very dynamic environment from all four dimensions. The concept of flexibility is definitely nothing new to manufacturers.

Figure 1 describes the research hypothesis relating to the relationship between uncertainty, manufacturing flexibility, and business performance. In the rest of this section we summarize the theoretical relationship in each linkage, based on the observation from a high-technology industry as well as the literature.

3.1. Customer demand uncertainty and manufacturing flexibility

The high-technology industry is known for its highly uncertain customer demand in terms of product options and volume. The level of uncertainty is difficult to handle for original equipment manufacturers (OEM) in Taiwan considering the frequent changes of delivery schedule from overseas PC companies. Theoretically, the litera-

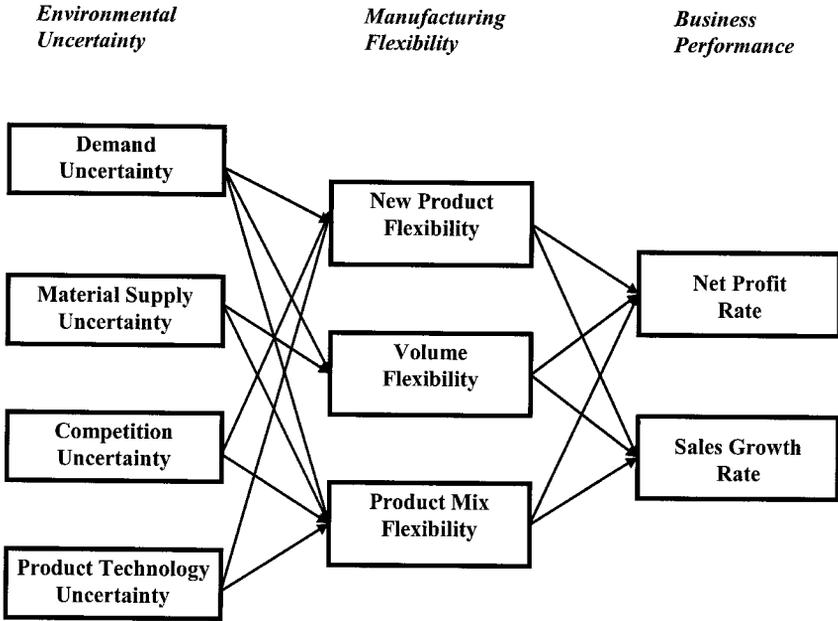


Figure 1. Basic model of relationship between environmental uncertainty, manufacturing flexibility and business performance.

ture has supported the relationship between demand uncertainty and various types of manufacturing flexibility. Chen *et al.* (1992) indicate that manufacturing firms are speeding up the new product development process to introduce new products to the market in order to satisfy customers' constantly changing desires toward product features. Gerwin (1993) point out that it is important for firms to offer various product options to stay competitive. Sethi and Sethi (1990) suggest the importance of developing the capability of adjusting the level of production, thereby responding to highly uncertain market demands. Overall, demand uncertainty (including volume, options and features) motivates manufacturing firms, which in turn leads to higher levels of new product flexibility, product mix flexibility and volume flexibility. Accordingly, we propose the following research hypotheses.

- H_{D1}: Customer demand uncertainty leads to higher new product flexibility.
- H_{D2}: Customer demand uncertainty leads to higher product mix flexibility.
- H_{D3}: Customer demand uncertainty leads to higher volume flexibility.

3.2. Supply uncertainty and manufacturing flexibility

Since some of the critical components of high-technology products come from other countries, such as Malaysia and Japan, high-technology firms in Taiwan also face a high degree of supply uncertainty. Dixon (1992) observes that the capability of offering various product options enables firms to buffer against a temporary shortage or fluctuations of raw material and component supplies. Krajewski and Ritzman (1999) argue that manufacturing firms should develop capacity cushions to absorb quality problems and delivery inconsistency from vendors. Accordingly, we propose the following research hypotheses.

H_{S1}: Supply uncertainty leads to higher product mix flexibility.

H_{S2}: Supply uncertainty leads to higher volume flexibility.

3.3. *Competitor uncertainty and manufacturing flexibility*

In addition to local competition in the same industry, Taiwan has received increasing competition from nearby Asian countries such as Korea and China in high-technology products. Ward *et al.* (1995) examine the relationship between business strategy and corporate environments from Singapore manufacturers. They suggest developing the capability of offering various product options in different market segments. Such capability can then better respond to competitor's strategy. As the market uncertainty increases due to the addition of new competitors or the exit of existing firms, firms should continue to offer new products to stay ahead of their competitors (Chen *et al.*, 1992, Kerin *et al.* 1992). Accordingly, we propose the following research hypotheses.

H_{C1}: Competitor uncertainty leads to higher new product flexibility.

H_{C2}: Competitor uncertainty leads to higher product mix flexibility.

3.4. *Product technology uncertainty and manufacturing flexibility*

Gerwin (1993) and Lieberman and Montgomery (1988) find that product technology innovation triggers development and introduction of new products. Firms should develop new products to pre-empt the market. Often, new market opportunities come with technological innovation. It is important that firms apply new technology to offer various product options to take advantage of new opportunities (Kekre and Srinivasm 1990, Chen *et al.* 1992). Accordingly, we propose the following research hypotheses.

H_{T1}: Product technology uncertainty leads to higher new product flexibility.

H_{T2}: Product technology uncertainty leads to higher product mix flexibility.

3.5. *Manufacturing flexibility and business performance*

Many studies suggest that manufacturing flexibility contributes to business performance including financial (e.g. return on assets, net profit) and non-financial performance (e.g. market share, sales growth). For example, firms are able to increase their market share by offering various product options (Bolwijn and Kumpe 1990, 1991). Swamidass and Newell (1987), Kekre and Srinivasan (1990) and Gupta and Somers (1996) confirm the positive effect of product mix and new product flexibility on sales growth and net profit rate. Finally, Gerwin (1993), Gupta and Somers (1996) and Tannous (1996) support the positive effect of volume flexibility on sales growth and net profit, while Pagell and Krause (1999) find an insignificant relationship. In this study, we chose net profit and sales growth rate to measure business performance due to data availability and the suggestions from the CEOs interviewed. According to those previous studies, we suggest the following hypotheses.

H_{P1}: New product flexibility leads to higher profit.

H_{P2}: New product flexibility leads to higher sales growth rate.

H_{P3}: Product mix flexibility leads to higher profit.

H_{P4}: Product mix flexibility leads to higher sales growth rate.

H_{P5}: Volume flexibility leads to higher profit.

H_{P6}: Volume flexibility leads to higher sales growth rate.

4. Research design

4.1. Survey

A survey methodology was used to collect data pertaining to the research hypothesis. The sample was randomly selected from *1000 Manufacturing Firms in Taiwan 1997–1998*. A field test of the survey instrument was conducted by meeting with manufacturing executives, vice presidents or presidents from four companies. 296 questionnaires were mailed to top executives (Vice President, General Managers or Plant Managers) in selected SBUs in high-technology manufacturing, including firms from personal computers, PCB, monitors and motherboard industries. These four industries have similar market structure, and they are subject to similar environmental uncertainty. Most firms are OEMs of large computer companies in the United States or Europe. The homogeneity of the nature of their operations environment and production processes reduces the possibility of contamination from multiple industry studies (Swamidass and Newell 1987). 103 questionnaires were returned and 87 were valid samples for statistical analysis. Among the 87 questionnaires returned, 25 were from the personal computer industry, 27 from motherboard companies, 18 from monitor manufacturers and 17 from PCB manufacturers.

A copy of the questionnaire is included in the Appendix. The questionnaires included multi-item instruments to measure uncertainty and manufacturing flexibility variables. Questions related to the four dimensions of environmental uncertainty were based on a seven point Likert scale. Managers were asked to rate, on a 16-item instrument, the perceived uncertainty in their environment between the extremes of always predictable and never predictable. Ratings assigned by top executives to the items in the uncertainty instrument were weighted by the average importance assigned to the respective item in a separate instrument (Swamidass and Newell 1987). This subjective measurement of environmental uncertainty is consistent with many previous studies (Lawrence and Lorsch 1969, Duncan 1972, Swamidass and Newell 1987, Miller 1993). The assumption is that only top executives, based on their experience and intuition, are in a position to judge the impact of various dimensions of their environment.

For the three types of manufacturing flexibility, we measured new product flexibility by the total number of new models made in two years (Jaikumar 1986, Dixon 1992). Product mix flexibility is measured as the total number of distinct part/product families (i.e. the number of PCB models and sizes made) made in two years (Dixon 1992). Volume flexibility is measured as the ratio of production volume fluctuation and unit cost while the production volume fluctuation is computed as the variance of monthly production (Suarez *et al.* 1996).

Finally, for business performance, we asked about sales performance and financial performance. Sales performance was measured by sales growth rate. Financial performance was measured in terms of net profit. Similar to the Vickery *et al.* (1993) study, each measure was assessed in three ways.

- (1) The firm's performance relative to its major competitors,
- (2) The firm's performance relative to its historic performance and/or company goals, and
- (3) The actual values.

4.2. Statistical methods

There were two stages of statistical analysis. In the first stage we performed factor analysis on environmental uncertainty items to investigate the dimensions of environmental uncertainty. The results were then used for path analysis, which verified the theoretical relationship presented in figure 1. The path model provides a method for developing explicit relationships within the proposed model and verifying its structure. Several studies have suggested the use of path analysis to analyse the relationship between a precursor variable such as environment and strategic choice (Ward *et al.* 1995). Hair *et al.* (1998) recommend an absolute minimum sample size of 50 or five observations for each estimated parameter. Accordingly, this study has enough samples to conduct the path analysis.

5. Statistical results

5.1. Results of factor analysis

Table 1 presents the results of the varimax factor analysis. The factor rotation yielded four dimensions from a total of 16 variables of environmental uncertainty. Numbers shown in the table are the environmental uncertainty variables' factor loading (relationships) to the four dimensions identified. Highlighted numbers are the individual question's factor loading (relationships) to the four major dimensions of the questionnaire. The Bartlett test of sphericity was used to assess the overall significance of the correlations among the strategy variables. All eigenvalues from the three factors were greater than 1.0. All standardized factor loadings were 0.50 or above, the majority falling above 0.70; thus, the loadings can be considered large

Variable	Factor loading				Significance		Cronbach's α value	Factor (eigenvalue)
	F ₁	F ₂	F ₃	F ₄	Individual	Cumulated		
E ₂	0.8225	0.0447	0.0053	0.0036	12.43%	12.43%	0.6808	Customer demand uncertainty (2.036)
E ₃	0.6844	-0.2673	-0.1526	0.3465				
E ₁₀	0.7701	0.3058	0.0595	-0.1041				
E ₉	0.1540	0.7988	-0.0235	-0.1794	20.75%	33.18%	0.7169	Supply Uncertainty (1.894)
E ₁₁	-0.0697	0.6590	0.0789	0.0047				
E ₁₃	0.1400	0.6468	-0.0867	-0.2914				
E ₁₆	0.3061	0.5790	0.1974	-0.1061				
E ₅	-0.0776	-0.3026	0.7675	0.1225	13.08%	46.26%	0.6025	Competitor Uncertainty (1.783)
E ₈	0.1013	0.1207	0.8108	-0.0579				
E ₁₅	0.2077	0.4997	0.5446	-0.1317				
E ₁	0.0382	0.0437	0.0236	0.7231	11.60%	57.86%	0.6560	Technology Uncertainty (1.885)
E ₁₄	0.0408	-0.0264	0.1236	0.8242				
E ₄	0.0814	-0.6074	-0.0136	-0.3675				
E ₆	0.1852	-0.1507	-0.6668	-0.2988				
E ₇	0.0698	-0.5723	0.0169	-0.1838				
E ₁₂	0.0354	0.4992	0.0911	0.3175				

Table 1. Results of factor analysis.

(Bollen and Lennox 1991). The reliability of each construct was measured with Cronbach's α . The coefficient alpha values for the three factors are 0.6808, 0.7169, 0.6025 and 0.6560, respectively. In general, all three dimensions are very clear, showing a significant relationship between those dimensions and the factor loading. The four factors found in the results are summarized as follows.

Factor 1 (F1): *Customer uncertainty*

The first factor consists of three variables: E2 (change of customer flavour in product features), E3 (possibility and predictability of customer switching to competitors) and E10 (change of customer demand volume).

Factor 2 (F2): *Supply uncertainty*

The second factor includes four variables: E9 (improvement of vendor quality), E11 (possibility of increasing vendor production capacity), E13 (possibility of changing vendor delivery date) and E16 (possibility of vendor quality variation)

Factor 3 (F3): *Competitor uncertainty*

The third dimension includes three variables: E5 (possibility and predictability of competitors changing their price), E8 (possibility and predictability of competitors changing marketing strategy) and E15 (possibility and predictability of entry/exit of new/current competitors).

Factor 4 (F4): *Product technology uncertainty*

The last factor includes two variables: E1 (change of core production technology) and E14 (change of supporting technology).

5.2. Results of path analysis

Path analysis is used empirically to ascertain the directions and magnitude of the causal relationships proposed in figure 1. Before we ran the path analysis, we examined the correlation matrix for the data set. The correlation matrix is displayed in table 2, which indicates that the correlations between pairs of variables were insignificant.

Path analysis was performed for the entire data set on the model presented in figure 1. Hair *et al.* (1998) note that when testing casual models, researchers who have good theory are able to use more precise tests (one-tail tests as opposed to two-tail tests). For the majority of the links in our model we hypothesize a specific relationship; hence, we used one-tail tests for significance. Table 3 shows the results of this analysis. Additionally we reported three measures of fit: CFI, Normed Fit Index (NFI) and Non-Normed Fit Index (NNFI). The model with all significant paths is presented as figure 2. The rest of this section summarizes the results of the path analysis.

5.2.1. Environmental uncertainty and manufacturing flexibility

According to table 3 and figure 2, demand uncertainty, competition uncertainty and technology uncertainty all present positive relationships with *new product flexibility*. This result supports hypotheses H_{D1} , H_{C1} and H_{T1} . The characteristics of high-technology industry (typified by short product life cycle, severe competition and constant technology innovation) force companies to research and develop new

(a) Manufacturing flexibility

	Demand uncertainty	Supply uncertainty	Competition uncertainty	Technology uncertainty
Demand uncertainty	1.0			
Supply uncertainty	0.186 (0.885)	1.0		
Competition uncertainty	0.182 (0.011)	0.043 (0.694)	1.0	
Technology uncertainty	-0.082 (0.451)	0.109 (0.317)	0.068 (0.534)	1.0

(b) Manufacturing flexibility

	New product flexibility	Volume flexibility	Product mix flexibility
New product flexibility	1.0		
Volume flexibility	0.066 (0.544)	1.0	
Product mix flexibility	0.176 (0.102)	-0.177 (0.101)	1.0

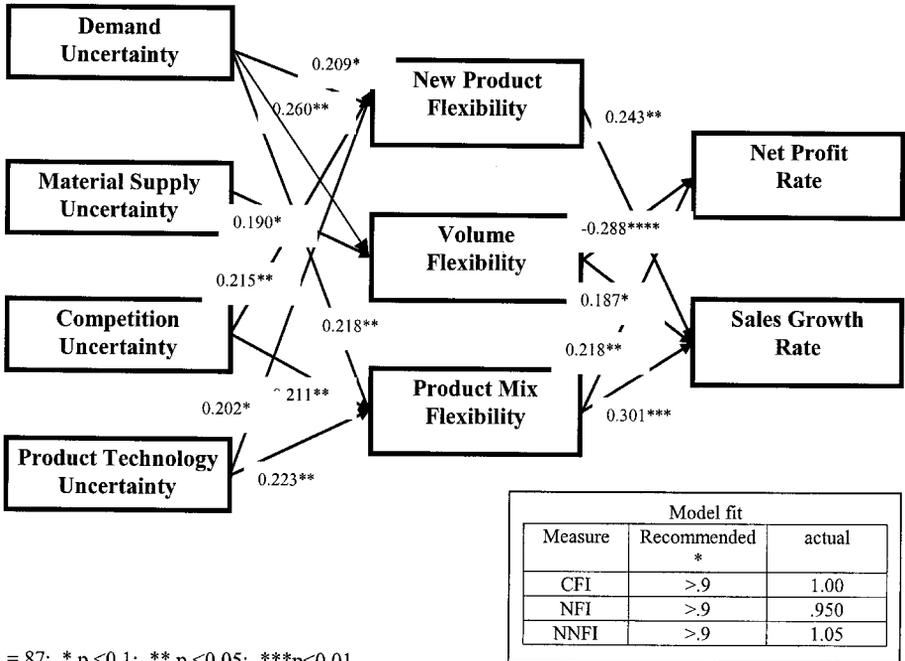
Table 2. Correlation matrix

Dep. Var.	F value	Prob > F	R ² value	Independent Var.	VIF	b	t	Prob > T
New product flex.	4.346	*** 0.0069	0.1401	Customer demand uncertainty	1.027	0.209	1.946	0.0552*
				Competitor uncertainty	0.029	0.215	2.013	0.0475**
				Product technology uncertainty	1.012	0.202	1.920	0.0584*
Volume flex.	3.710	** 0.0149	0.1121	Customer demand uncertainty	1.055	0.260	2.373	0.0201**
				Raw material supply uncertainty	1.060	0.190	1.755	0.0831*
Product mix flex.	3.121	** 0.0194	0.1365	Customer demand uncertainty	1.076	0.218	2.401	0.0453**
				Raw material supply uncertainty	1.060	-0.125	-1.175	0.2437
				Competitor uncertainty	1.029	0.211	1.994	0.0496**
				Product technology uncertainty	1.023	0.223	2.123	0.0369**
Net profit rate	5.058	*** 0.0029	0.1594	New product flexibility	1.041	-0.107	-1.019	0.3112
				Volume flexibility	1.051	-0.288	-2.729	0.0078***
				Product mix flexibility	1.078	0.218	2.010	0.0478**
Sales growth rate	6.699	*** 0.0004	0.2008	New product flexibility	1.041	0.243	2.445	0.0167*
				Volume flexibility	1.051	0.187	1.872	0.0649*
				Product mix flexibility	1.078	0.301	2.933	0.0044***

* P < 0.1; ** P < 0.05; *** P < 0.01

Table 3. Results of path analysis.

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n = 87; * p < 0.1; ** p < 0.05; ****p < 0.01

Figure 2. Model with significant relationships n = 87; * p < 0.1; ** p < 0.05; **** p < 0.01

products to stay competitive. Next, the uncertainty of customer demand drives the development of volume flexibility, which supports hypothesis H_{D3}. Specifically, firms able to adjust production levels are able to respond to demand uncertainty better. As discussed earlier, most OEM firms in Taiwan constantly face the uncertainty of order cancellation or quantity change from overseas customers. Working overtime and outsourcing are very common ways to cope with demand changes without increasing cost or sacrificing quality and delivery. Finally, as vendor delivery becomes unreliable, firms are forced to increase volume flexibility through establishing outsourcing. This finding supports hypothesis H_{S2}.

In the case of *product mix flexibility*, demand uncertainty, competitor uncertainty and technology uncertainty all present significant relationships. This is consistent with Kekre and Srinivasm (1990), stating that the capability of offering various product options is an effective way to take new market opportunities presented by technology innovation. Additionally, Suarez, *et al.* (1996) asserted that the development of product mix flexibility could provide the ‘cushion’ effect to lessen production instability from customer demand and competition. Overall, the statistical results support hypotheses H_{D2}, H_{S1} and H_{C2}.

The only insignificant relationship found was the effect of supply uncertainty on product mix flexibility (H_{S1}) (see table 3). The original rationale of this relationship was that the uncertainty of procuring necessary components from vendors could force firms to offer different product options to meet customer demand (Dixon 1992). In this case, since most firms are contract manufacturers, they must produce to the exact product specifications requested by clients. Having the capability of offering a high variety of product options does not mitigate the negative impact from supply uncertainty.

5.2.2. Manufacturing flexibility and business performance

The results in table 3 show that, with the exceptions of the relationship between new product flexibility and net profit (H_{P1}), all relationships between manufacturing flexibility and two performance measures (H_{P2} – H_{P6}) are significant. New product flexibility is related to sales growth but not to net profit. While new product introduction increases sales, it could not generate enough revenue to offset enormous R&D expenses in the short term. We also suspect that the generally lower profit across the high-technology industries in 1997 and 1998 is attributed to this insignificant relationship.

6. Implications and conclusions

Empirical studies in manufacturing flexibility have not investigated the alignment of specific dimensions of environmental uncertainty with types of manufacturing flexibility. This study examined the relationship between environmental uncertainty, manufacturing flexibility and business performance in high-technology industries. Using the data collected from 87 high-technology manufacturing firms in Taiwan, we analysed the effect of aligning three types of manufacturing flexibility: product mix, new product and volume with specific dimensions of environmental uncertainty. Matching manufacturing flexibility with dimensions of environmental uncertainty is necessary to ensure profit and sales performance. As firms face challenges of various uncertainties from the market, suppliers, competitors and technology, they must invest and develop specific types of manufacturing flexibility to respond.

One thing we learned from this study worth noting by managers and researchers was that the relationship between uncertainty and manufacturing flexibility may be industry dependent. Pagell and Krause (1999) studied users of advanced manufacturing technologies (AMT) and found no relationship between the two issues. Unlike the high-technology firms sampled in this study, AMT users might develop manufacturing flexibility for the sake of either reducing lead-time or improving quality. The effect of environmental uncertainty on manufacturing flexibility is thus inconsistent between the two different industries.

Practically, even firms in the same industry may experience different levels and types of environmental uncertainty and thus choose to develop different manufacturing flexibility strategies. For example, there are two types of plant in the PCB industry. One is a captive plant that produces for downstream plants or divisions of the same company, and one is a contract manufacturer (which we studied) that produces for various companies. Captive plants are likely to be more insulated from market pressure than contract manufacturers. Suarez *et al.* (1996) studied captive plants and found a slightly different relationship between suppliers and product mix flexibility. The implication is that since uncertainty and manufacturing flexibility are complicated issues, no universal conclusions can be drawn without first considering the factors of industry and/or even the positions of firms in supply chain system.

In summary, manufacturing flexibility has been suggested as an important concern as firms develop their business strategy and, thereby, their organizational capabilities. It is clear that firms should consider specific environmental variables in developing the necessary manufacturing flexibility. The environment should be built into designing competitive strategy. Furthermore, this study chose to investigate the fit between environmental uncertainty and manufacturing flexibility in high-technology component manufacturers in Taiwan. Those firms sampled operate in a rather dynamic and hostile environment, which reinforces the effect of 'fit' on sales and

profit performance. Hamlin (1999) observes similar business behaviours from the OEMs in many Asian countries. Generally, high-technology contract manufacturers in Asian countries face similar demand, supply, technology and competition uncertainties. Therefore, we believe that the results of this study provide valuable insights to managers in other Asian countries (e.g. China, South Korea and Malaysia). On the other hand, we are more uncertain about the application to other, more traditional, manufacturing environments, such as the textiles or machine tool industries. Companies in a more stable environment are likely to define environmental uncertainty differently and thus address manufacturing flexibility in a different way.

While our results indicate the importance of 'fit' between manufacturing flexibility and environmental uncertainty, we do not suggest that firms continuously and blindly invest in various types of manufacturing flexibility. It is important that manufacturing managers distinguish between required (the amount needed), potential (the amount designed into a system) and actual (the amount obtained in practice) manufacturing flexibility for the previously identified dimensions (Dixon 1992, Gerwin 1993). Specifically, once the type of manufacturing flexibility is identified given the environmental uncertainty, managers should perform some sort of discrepancy performance to examine the three levels of flexibility before any investment is made. After all, developing more flexibility, even with the alignment of environmental uncertainty, is not always better if the actual flexibility is equal to the required flexibility.

Another limitation of this study is related to the measures of manufacturing flexibility and uncertainty. The use of single item indicators for the manufacturing flexibility measure could limit the generalizability of the statistical results, although there is no one right way to combine multiple indicators underlying a multidimensional concept (Flynn *et al.* 1999, Noble 1995). On the other hand, there are researchers who advocate the use of single item indicators for better efficiency in social science studies (e.g. Drolet and Morrison, 2001). In any case, the statistical results are mostly consistent with previous studies and our observations from the field. Research in this area should try to establish operationally useful measurement criteria across different industries to facilitate empirical study.

Appendix: Survey items and scales

I. Environmental Uncertainty

Over the past three years, please indicate the degree of predictability of the changes of each of the following environmental factors.

	Highly predictable				Not predictable			
1. Change of current core production technology (E1)	1	2	3	4	5	6	7	
2. Change of customer preference in product features (E2)	1	2	3	4	5	6	7	
3. Customers switch to competitors (E3)	1	2	3	4	5	6	7	
4. Change of current customer profile (E4)	1	2	3	4	5	6	7	
5. Change of competitors' price (E5)	1	2	3	4	5	6	7	
6. Change of the length of product life cycle (E6)	1	2	3	4	5	6	7	
7. Change of acceptable quality level in the current market (E7)	1	2	3	4	5	6	7	
8. Change of competitors' marketing strategy (E8)	1	2	3	4	5	6	7	
9. Improvement of vendor quality as requested (E9)	1	2	3	4	5	6	7	
10. Change of customer demand (volume) on current products (E10)	1	2	3	4	5	6	7	
11. Increase of vendor production capacity as requested (E11)	1	2	3	4	5	6	7	
12. Change of current market share of major products (E12)	1	2	3	4	5	6	7	
13. Change of delivery reliability of material and parts (E13)	1	2	3	4	5	6	7	
14. Change of non-core production technology (E14)	1	2	3	4	5	6	7	

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15. entry of new competitors and exit of current competitors (E15)	1	2	3	4	5	6	7
16. Change of the current level of vendor quality (E16)	1	2	3	4	5	6	7

II. Manufacturing flexibility

1. How many distinct products/parts made in the last two years?
2. How many new models introduced in the last two years?
3. What are the highest and lowest monthly production volumes in the last two years?
4. What is the total annual production volume (in unit) in the last three years?
5. What is the average labour cost per unit of product?

III. Business performance

IV. Company background information

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