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The measurement of technical competencies☆

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Abstract

Technical competencies are operationalized and tested on a census of the international semiconductor industry. This study is an important step in moving competence and capability from a popular topic of trade publications and theorists to a quantifiable management science. A series of questions that can be used for the study of other competencies is developed and tested. Competence is shown to be a single trait measure, with a high reliability. The reliability and validity of technical competencies are also considered. © 2002 Published by Elsevier Science Inc.

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1. Introduction

The study of core competencies has been hampered by the lack of an accepted way of operationalizing this construct. This is unfortunate, since the theoretical roots of core competencies is very old (Coase, 1937; Schumpeter, 1934; Smith, 1776) and is currently of interest to both academe (Morone, 1993; Prahalad & Hamel, 1990; Walsh, Boylan, Paulson, & Morone, 1996) and practitioners (Mitchell, 1992). There is a need for the study of competency to move beyond theory and case study to testing theory in a statistically generalizable fashion. Consequently, this paper addresses the meaning and measurement of technical competence.

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The paper begins with a review of the technical competence literature. The literature review is followed by background information on the industry used to examine the operationalization of technical competence. Next, the method used to identify the competencies to be studied and to collect the competence data is described. Results from the data collected including the reliability and validity are given and discussed. Finally, the conclusions and identification of future research directions are given.

2. Technical competence

The importance of competencies and capabilities is initially proposed indirectly. Firm uniqueness is suggested as the basis of competitive advantage and long-term success (Bitindo & Frohman, 1981; Coase, 1937; Frohman, 1980; O'Brien, 1962; Penrose, 1959; Schumpeter, 1934). Competencies and capabilities are frequently categorized as separate but related constructs (Barney, 1995; Hitt & Ireland, 1985; Marino, 1996). However, confusion results from the different definitions proposed in the literature. Prahalad and Hamel (1990) use the terms competence and capability interchangeably. Whereas, Javidan (1998) suggests that the terms capability, competence, and core competence refer to the span of the advantage within the firm—within a department, within a single SBU or across multiple SBUs. Marino (1996) and others suggest that competencies are firm-specific technologies and production technologies. Whereas, capabilities are firm-specific business practices, processes, and culture. We have based our study on Marino's definition; this decision is based on the use of the terms "technology" and "production skills" in Prahalad and Hamel's (1990, pp. 81–82) discussion of core competencies. To date, research has identified firms that have achieved success by using strategies that focus on a firm's core capabilities and competencies (examples include Hitt & Ireland, 1985; Morone, 1994; Teece, Pisano, & Shuen, 1990).

In this study, only competencies are considered. The most widely used definition for a core competence is that of Prahalad and Hamel (1990, p. 81). They suggest that core competencies are *corporate wide technologies and production skills that empower individual businesses to adapt quickly to changing opportunities*. We suggest that the goal should be to identify competencies that are relevant to a specific industry. To do this, we consider what technical competencies are important to the semiconductor industry. Since core competencies are suggested to lead to competitive advantage (Prahalad & Hamel, 1990), we propose that they will be considered more important. Industry experts, due to their thorough knowledge of firms and competencies present in their industry, will recognize these competencies important if their existence appears to be linked to competitive advantage and their absence appears to be linked to disadvantage. There is minimal value to creating a wish list of important technical competencies for an industry, unless this is an initial step into a further investigation. One also needs to understand which firms possess these competencies, to what extent, and whether there is additional advantage offered by possessing some combination of technical competencies. If we consider a complete set of competencies, any core competencies that are relevant to the industry will be contained within this set. (It is possible that these competencies may be important to a number of industries.) Consequently, an examination of com-

petencies is a logical first step. The literature consistently discusses how core competencies may be resident in firms, but only Walsh and Linton (2001) consider competence from the perspective of an industry. In fact, one can argue that consideration of a specific industry is incorrect, since core competencies frequently offer advantage across multiple industries. However, for a competence to provide a firm with advantage, it must provide value to the customers of one or more industries. Therefore, considering which competencies add value within an industry is a logical starting point. Once these competencies are identified, it is reasonable to ask the questions "Which competencies offer competitive advantage in the industry under consideration?" and "Which competencies have the potential to offer advantage across multiple industries?" Having examined and defined core competencies and competencies, the industry under study is briefly described.

3. Industry under study: semiconductor silicon

The semiconductor silicon industry transforms silica into single crystal silicon wafers. This product is a commodity that is required for the manufacture of integrated circuits. The crystal silicon industry had global sales of over US$6 billion in 1997 (Rose and Sheet, 1998). Since single crystal silicon wafers are required for the manufacture of integrated circuits, which are a building block for almost all electronics products, ability to produce this material is not only important, but is vital to a modern economy.

This strategic and valuable material is made in a four-step process. Silica is reduced to elemental silicon. Next, polysilicon is produced from elemental silicon through a silane-based process. Long cylindrical crystals of silicon are then produced from the polysilicon. These single crystals are sawn into thin slices or wafers. The wafers can be used for semiconductor manufacturing at this time. However, additional manufacturing steps may be taken that give the wafers special characteristics and allow them to be used in different applications. Some examples of the special processes applied to single crystal semiconductor wafers are epitaxial polysilicon growth, nitride and oxide depositions, dopant implantations, and wafer-to-wafer bonding.

The semiconductor silicon industry is ideal for a study of technical competence. Semiconductor silicon is a high value-added commodity product. Since it is a commodity material, the firms that have the greatest ability to perform the small number of required processing steps are most likely to be successful. The commodity nature of the product ensures that the advantages offered by managerial capabilities will be minimized and technical competencies will be maximized. Having briefly examined the semiconductor silicon industry, the method and collection of data are now considered.

4. Hypotheses

The measurement of a technical competence provides a challenge, since the discussion of competencies has focussed on case-based and conceptual work. Except Klein, Gee, and

Jones's (1998) finding of the importance of IT support for aligning technical competence and R&D strengths, the consideration of the measurement of technical competence is a void. Consequently, a different, but related literature must be considered for insight into determining the presence or absence of a competence. The management of a firm will know whether or not they possess a competence. This assumption while reasonable, suffers from the possibility that representatives of firms are unrealistic about the competencies that their firm possesses. A measure of the reliability of the opinions of respondents from a firm is whether others associated to the industry agree with the self-assessment from the respondent(s) from a particular firm. Consequently, a series of hypotheses are offered which compare the assessment of respondents within a firm to others outside of the firm.

The innovation literature offers insights into sources that are external to a firm and have depth in a competence and some level of knowledge of other firm's technical competencies. This access to firms and depth of knowledge make them suitable respondents to the question of the presence and the relative strength of a competence at various firms. Suppliers have been indicated to not only have a great depth of knowledge in the competencies related to their products, but an understanding of the technical strengths and gaps of their customers (Ettlie, 1986; Flynn & Cole, 1988; Von Hippel, 1976; Voss, 1985). Consequently, we propose:

Hypothesis 1: Respondents from suppliers and a firm will agree on the presence or absence of a competence at the firm.

Customers are also indicated in the innovation literature as having depth of knowledge in competencies related to their field and an interest in understanding the strengths and gaps in the technical competence of their suppliers (Von Hippel, 1976). Therefore, we propose:

Hypothesis 2: Respondents from customers and a firm will agree on the presence or absence of a competence at the firm.

Other firms within the industry require the same or similar types of technical expertise (Hamel, Doz, & Prahalad, 1989; Khanna, Gulati, & Nohria, 1998; Schrader, 1991; Teece, 1989; Von Hippel & Schrader, 1996). As a consequence of competition, cooperation, and/or movement of technical employees between firms, firms within an industry have knowledge of the presence or absence of technical competence at competing firms (Hamel et al., 1989; Hamel & Prahalad, 1994; Khanna et al., 1998; Kogut, 1988; Teece, 1989; Von Hippel, 1976, 1987). Consequently, we propose:

Hypothesis 3: Respondents from a firm's competitor(s) and the firm will agree on the presence or absence of a competence at the firm.

Consultant and industry experts within an industry have depth of knowledge in the technical competencies that they deal with (Zairi, 1992a, 1992b). Due to their work with firms and their continued exposure, involvement, and monitoring of the industry, they become aware of the strength and weaknesses of firms within not only the competencies that

they specialize in, but other competencies that are important to the industry. Therefore, we propose that:

Hypothesis 4: Responses from industry experts and the firm will agree on the presence or absence of a competence at a firm.

The presence of a core competence offers competitive advantage (Hamel & Prahalad, 1994; Prahalad & Hamel, 1990). And a core competence consists of the combination of more than one technical competence. Recall, the possibility of the existence of core competencies within an industry (Walsh & Linton, 2001). The prior case-based literature identifies core competencies as being resident at certain firms and that these core competencies offer competitive advantage across multiple industries. We propose to extend this by considering the possibility of the existence of core competencies in a specific industry. Therefore, we hypothesize that:

Hypothesis 5: If a core competence exists within the industry, there will be a group of distinct but related technical competencies that are present together within a firm.

4.1. A study to assess technical competence

By considering the above hypotheses, the investigation:

1. Proposes a series of questions that can be used for the measurement of technical competencies.
2. Examines whether competence is a single- or multi-trait measure.
3. Examines the validity and reliability of the measure through operationalization.

Our analysis is based upon data from a variety of sources. Data collection consisted of two phases: identifying the technical competencies and collecting data for each technical competence for each manufacturer. Technical competencies were identified through the examination of forecasts for semiconductor device technology (Carr, 1972; ICE, 1984, 1988, 1994; Mead, 1994; Noyce, 1980; Robinson, 1984) and semiconductor silicon (O'Mara, 1989; Runyan, 1965; Walsh, Boylan, Cook, & Walsh, 1993; Walsh, Boylan, Warrington, & Elders, 1997; Walsh, Cook, & Walsh, 1992) and examination of firms' standard operating procedures (SOPs). The forecasts and SOPs contained 20 different technical competencies as being important to manufacturing. Thirty-five industry experts (company presidents, consultants, and manufacturing managers) were asked to rate the importance of each competence on a five-point Likert scale (where a low score is relatively unimportant and a high score is extremely important for the ability to manufacture silicon). Only competencies that were rated 4 or above by the thirty-five experts were retained for further consideration. Through this method, the list of technical competencies was reduced to 7—the other 13 technologies were not considered by industry experts to be critical. The seven competencies consistently identified

as important are: silane technology, batch processing, crystalline materials, wafering (surfacing), scale intensive, inorganic chemistry, and controlled environment capabilities (the terminology used to describe each competence was provided by the industry forecasts and experts). Having identified the key manufacturing competencies, the study moved to its second phase — the collection of technical competency data specific to manufacturing firms.

A search of published data identified 167 companies that either currently or once competed in the semiconductor silicon industry. This list appears to be exhaustive. Representatives from 159 of these firms were contacted during the 4-year interview period. Extensive interviews were conducted with 312 founders, presidents, key corporate personnel, former industry leaders, customers, industry experts, and suppliers (see Appendix A, Table A for a breakdown of the interviewees by role). The selection of interviewees was designed to include the current key upper level managers, owners, and technologists of the firms and those individuals who held key roles in the firms throughout the history of each company. Evaluations of the presence or absence of the seven technical competencies for each firm under examination were obtained from as many as: 20 individuals from within the firm under consideration, representatives of 10 different competitors, representatives of 5 different suppliers, 3 different customers, and 10 different consultants (industry experts). The questions used in the five surveys are listed in Appendix A, Table B. Since there are seven competencies under study, a total of 35 questions was asked (for each firm, 7 questions were asked to respondents in five different roles — firm, competitor, customer, supplier, and consultant) regarding each firm. Competence data were collected for 123 of the 159 firms (77% response rate). Consequently, evaluation of 791 competencies, 7 competencies for each of 123 different firms, is available for analysis. Since 167 firms have been identified in the history of the semiconductor industry, the sample is 74% of the entire population. In addition to the five opinions and four related hypotheses on the presence or absence of a competence, the SIC code was examined to determine if it implied the presence of competence in the technology in question. In many cases, data relating to a competence are missing. There are two ways of addressing missing data. One is to delete the entire case. The other treatment is to state that the absence of data are equivalent to the lack of a competence, since a respondent would not leave a question blank if they knew that the firm possessed the competence under consideration. The measure is examined in this paper using both of the two previously mentioned approaches.

5. Results

Few firms had all seven competencies under consideration. The presence and absence of the competencies are summarized in Appendix A, Table C. Correlation between variables is summarized in Table 1, variable loadings to the competence factor in Table 2, Crohnbach's alpha in Table 3, and factor analysis of competencies in Table 4. After considering the five hypotheses that have been proposed, the results and their implications are discussed.

Hypothesis 1: Respondents from suppliers and a firm will agree on the presence or absence of a competence at the firm. ***Supported***. Both respondent from a firm and

Table 1
Correlation between variables

	Competitor	Customer	Expert	Self-evaluation	SIC code	Supplier
(a) Pairwise, if a competence was missing, it was deemed equivalent to a lack of the competence						
Competitor	1					
Customer	.792	1				
Expert	.47	.45	1			
Self-evaluation	.776	.679	.439	1		
SIC code	.828	.743	.509	.842	1	
Supplier	.611	.644	.834	.545	.611	1
(b) Pairwise, if a competence was missing, the case was deleted						
Competitor	1					
Customer	.855	1				
Expert	.552	.558	1			
Self-evaluation	.846	.836	.542	1		
SIC code	.862	.852	.595	.842	1	
Supplier	.673	.708	.841	.657	.721	1

supplier load strongly onto the same factor (all loadings greater than .82 — see Table 2). Furthermore, there is a significant and substantial correlation between respondents from the firm and the supplier — see Table 1. This correlation is .545 if missing data is assumed to indicate the absence of a competence and .657 if missing data is deleted.

Hypothesis 2: Respondents from customers and a firm will agree on the presence or absence of a competence at the firm. ***Supported***. The respondent from the firm and customer load strongly onto the same factor (all loadings greater than .82 — see Table 2). Furthermore, there is a significant and substantial correlation between respondents from the firm and the supplier — see Table 1. This correlation is .679 if missing data is assumed to indicate the absence of a competence and .836 if missing data is deleted.

Hypothesis 3: Respondents from a firm's competitor(s) and the firm will agree on the presence or absence of a competence at the firm. ***Supported***. The respondent from the firm and firm's competitor load strongly onto the same factor (all loadings greater than

Table 2
Factor analysis of data for deletion of cases with missing data and setting missing data to no technical competence

Variable	Factor loading if missing data is deleted	Factor loading if missing data equals lack of competence
Competitor	.92	.884
Customer	.889	.864
Expert	.782	.759
Self-evaluation	.889	.821
Supplier	.889	.869

.82 — see Table 2). Furthermore, there is a significant and substantial correlation between respondents from the firm and the firm's competitor — see Table 1. This correlation is .776 if missing data is assumed to indicate the absence of a competence and .846 if missing data is deleted.

Hypothesis 4: Responses from industry experts and the firm will agree on the presence or absence of a competence at a firm. ***Supported***. The respondent from the firm and industry experts load strongly onto the same factor (all loadings greater than .76 — see Table 2). Furthermore, there is a significant and substantial correlation between respondents from the firm and the industry experts — see Table 1. This correlation is .470 if missing data is assumed to indicate the absence of a competence and .552 if missing data is deleted.

Hypothesis 5: If a core competence exists within the industry, there will be a group of distinct but related technical competencies that are present together within a firm. ***Supported***. The seven competencies load onto three factors (see Table 4). The first factor explains 35.4% of the variance and strongly represents three of the competencies. The second factor explains 23.4% of the variance and strongly represents two of the competencies. The third factor explains 15.3% of the variance and strongly represents one of the competencies.

Having considered all the proposed hypotheses, we consider the implication of these findings.

6. Discussion

The strong concurrence between different measures of competence suggests that these different measures of the same concept are useful for measuring the presence or absence of a technical competence. Prior to considering use of self-report, supplier, customer, expert, and competitor opinion as a measure of a technical competence, the choice and use of dichotomous data in this study should be explained. The competencies under consideration, in this survey, have been adopted and mastered well over a decade ago in many cases. Consequently, it is not realistic to obtain distinctions of which firm was best-in-the-world, world class, above average, average, or below average. However, it is possible to obtain a distinction between the presence or absence of the competence. Therefore, in this case, dichotomous data have been used. Having clarified the reason for the use of dichotomous data, we now consider the technical competence measure from the perspective of factor analysis, reliability, and validity.

6.1. Factor analysis

Factor analysis requires that variables be measured at least at the interval level (Stevens, 1946). However, if the correlations between dichotomous variables are moderate $-.6$ to

.7 — factor analysis is suitable as a means of finding general clusterings of variables (Kim & Mueller, 1978); also see Kim, Nie, and Verba (1977). In this study, the responses are dichotomous. However, the value that is factored is a value between 0 and 1. In the cases of companies that had 20 separate respondents, there are 20 intervals. Whereas, in the cases of a captive company (one customer), the data are dichotomous. An examination of correlations (Table 1) shows that there is a high correlation between variables. If all missing values are considered to be zero, then the correlation between variables is at least .45 and as high as .83 (Table 1). If all cases with missing values are deleted, then the correlation between variables is at least .54 and as high as .86 (Table 1). Consequently, it is no great surprise that there is a single factor. A factor analysis of the technical competence scale was conducted for the 595 cases that had no missing data (Table 2) and for the 732 cases, in which any missing data were considered to be the same as stating that no competence existed (Table 2). In both cases, there is only one factor. In all cases with missing data deleted, the eigenvalue for the single factor is 3.88 and explains 77.6% of the variance. And in the case in which all missing values are considered to be equivalent to stating that the competence is absent, the single factor has an eigenvalue of 3.55 and explains 70.6% of the variance.

There are no differences between factor analysis and theoretical expectations; the reliability and validity are now considered.

6.2. Reliability

There are three methods of estimating reliability: test–retest, internal consistency, and alternative forms (Peter, 1979). The survey participants are busy practitioners. Consequently, it is not practical to test reliability either using test–retest or alternative forms. Internal consistency is possible to calculate, however, from the data. Therefore, Crohnbach's alpha is used to examine internal consistency of the technical competence scale (Table 3).

The reliability of the technical competence scale is very high (Table 3). This is unsurprising since the eigenvalue of the factor and the correlations between its scale items are both high. In fact, one may argue that the scale reliability is too high. This issue will be addressed in the future by using a 10-point Likert scale, instead of questions that require yes or no as an answer. (Recall, yes or no measures are used since some of the competencies under study were acquired and mastered decades ago.) Having considered reliability, validity is now considered.

Table 3
Crohnbach's alpha for technical competence measure

Case	Crohnbach's alpha
if missing data is deleted ($n = 599$)	.9201
if missing data equals lack of competence ($n = 732$)	.8795

6.3. Content validity

Content validity refers to the representativeness or sampling adequacy of the content. The questions used to gauge technical competence (Appendix A, Table B) are very similar to each other in wording. The questions were asked to respondents as part of an interview process. The interviewer clarified the meaning of the question and answered all queries the respondents had. The questions are consistent with previous work. Earlier studies do not operationalize technical competence, but they do examine the presence of technical strengths within an organization. Fusfeld (1978) proposes a "Technological Audit" to identify synergies throughout an organization. Technology subsets are described as being "distinctive technologies" or "strategic technological assets" (Bitindo & Frohman, 1981; Frohman, 1980). Rosenbloom (1978) categorizes technologies based on differences in their innovation processes. SEST-Euroconsult. (1984) suggests that the success of many Japanese firms is based on their pursuit and competence with specific technological subsets. Having demonstrated that previous literature supports the content validity of the measure, other evidence of content validity is considered.

Internal consistency and correlation of scales with other measures of the construct provide statistical evidence of content validity. Internal consistency has been established and discussed in the previous section (see Table 3). The lack of other measures of the construct prevents using of correlations with similar instruments as a further test of content validity. Content validity is supported through: (1) the consistency of wording of all the questions, (2) consistent with earlier works, and (3) because the scale is internally consistent.

6.4. Predictive validity

Predictive validity is demonstrated by correlating a measure against other measures of the same construct. Since this is the first operationalization of technical competence, development of alternative measures was not feasible at the time of survey development. Predictive validity needs to be pursued in a future study.

6.5. Construct validity

Construct validity is demonstrated by showing the validity of the theory behind the instrument (Kerlinger, 1986). In order to do this, the theory has to demonstrate consistent findings over a number of studies. Two challenges to demonstrating construct validity are operationalization being limited to case studies and different definitions for competence and core competence.

As stated earlier, competency theory has been discussed in great detail, but operationalization has been limited to case studies—examples include Prahalad and Hamel (1990)—Honda, Quinn (1992)—Walmart, Morone (1993)—Corning, Hamel and Prahalad (1994)—Sony. Consequently, more studies are required prior to the establishment of construct validity for the technical competence measure. However, of greater concern are

substantive differences in definition. Recall, Hamel and Prahalad (1994) describe a core competence from the perspective of "technology" and "production skills" and then quite correctly describe Sony as having a core competence in "miniturization." The simplicity of the term miniturization is engaging and is accurate at the time of writing. However, it is incorrect several years later. Sony does have a competence of miniturization of traditional mechanical systems. But technology is dynamic and leaders in miniturization today, firms like Analog Devices and Texas Instruments, have competencies in micro-electromechanical systems an area in which Sony is involved, but not at the forefront (Nexus, 1998). And leaders in miniturization in the future are likely to be firms like Motorola and IBM that are active in the nanotechnology field (Rotman, 1999). Consequently, it is important to be very precise in identifying the basis of a competence or core competence. It is quite likely that subtle, but evidently important, differences in definition have hindered investigations involving operationalization and the establishment of instrument validity.

Two methods, suggested by Kerlinger (1986), for examining construct validity, are factor analysis and correlation between item scores and total scores. Factor analysis supports the construct validity. Correlations between item scores and total scores were conducted after removing the item score from the total score (Cohen & Cohen, 1975). Correlations were high between questions and the modified scales. In the case in which missing values were considered equivalent to the absence of the technical competence, the correlations between the item score and total score (after the item was removed) ranged from .69 to .85. In the case in which cases with missing values were deleted, the correlations between the item score and total score (after the item was removed) ranged from .64 to .81. Further investigation of content validity is required, but initial results are very encouraging. Furthermore, the use of different respondents to identify the absence or presence of a technical competence constitutes triangulation, based on multiple data sources (Denzin, 1978). Future studies of technical competence will be able to use the results presented in this paper to assist in better understanding the construct validity of technical competence.

Table 4
Factor analysis of competencies

	Component		
Competence	1	2	3
crystalline materials	.053	.020	.962
batch process	.832	.174	.001
controlled environment	.838	.132	.157
inorganic chemistry	.838	.424	.043
scale	.342	.803	−.163
silane chemistry	.005	.840	.174
wafering	−.512	.248	.247

6.6. Competency bundles within an industry

A factor analysis was conducted on the seven competencies to determine whether these competencies bundled into a core competency theme, as suggested by Prahalad and Hamel (1990). We see that three factors result (Table 4). *Batch process*, *controlled environment* and *inorganic chemistry* comprise one factor that explains 35.4% of the variation. This factor relates to competencies that offer the benefits of precision and high yield through the reduction of impurities to the level of parts per billion—or even parts per trillion. The technical competencies that comprise this factor are all based on chemistry. *Silane chemistry* and *scale* comprise another factor that explains an additional 23.4% of the variation. This factor relates to size of the operation. Scale relates directly to skills that are important for operating a large operation. Silane chemistry relates to size of operation indirectly, since silane is a competence that has high fixed costs for establishing and maintaining it is most advantageous for a large-scale operation. Both of the technical competencies that comprise this factor are based on chemistry. Finally, *crystalline material* comprises a third factor that represents a further 15.3% of the variation. This factor differs from the other two in that crystallography is a technology competence based on physics, rather than chemistry—like the other two factors.

A more helpful way of describing bundles of competencies that may make up core competencies either in one industry or across industries is considering the knowledge base the competencies relate to. In our study, we identify two clusters of competencies that are based on chemistry and one based on physics. Similarly, referring to the example of Sony (Hamel & Prahalad, 1994) as a firm possessing a core competence of miniturization. We propose that this core competence be described as a competence bundle in the miniturization of traditional mechanical systems (this avoids confusion with knowledge bases in micro-systems and nanotechnologies). Another advantage of using a knowledge-based approach to describing the nature of a competence is that it is more evident whether competencies are sustaining (Abernathy & Clark, 1985) or disruptive (Anderson & Tushman, 1991; Christensen, 1997). Consequently, it is suggested that bundles of competencies and/or core competencies be described so that the knowledge base that the competence represents is clearly stated. Having considered the implications of this work to the identification of core competencies, we consider whether the SIC code assists in understanding the presence or absence of competence.

6.7. SIC codes as an indicator of competence

We attempted using SIC codes as a proxy for identification of competencies. A firm was given a value of 1 for an SIC code, if products related to the technology were being produced. Otherwise, a value of zero was assigned. Correlations between .51 and .86 (Table 1) suggest that SIC code offers a good indication with minimal effort. It appears that the SIC succeeds as an indicator for incremental or continuous innovation (Morone, 1994; Zaltman, Duncan, & Holbek, 1973), but fails for the identification of radical or disruptive innovation (Abernathy & Clark, 1985; Christensen, 1997; Zaltman et al., 1973).

If competencies that rely on incremental innovation are under study, the SIC code is sufficient. However, Leonard-Barton (1995) warns of competency traps that result in firms being blind to the value of new technologies (Christensen, 1997; Foster, 1986) that eventually overthrow the existing technical regime. Consequently, SIC codes should only be used as indicators of competence cautiously and may result in the mis-specification of core competencies.

6.8. Insights for future studies of competence

A tremendous amount of effort was required to conduct this analysis of the technical competencies associated to this one industry. If such an effort is required to identify the technical competencies in an industry, it is understandable why the discussion of competence, capability, and core competence tends to be theoretical and case study based. The experience of collecting and analyzing this massive data set has given us some insights into simpler and easier methods of conducting a competence analysis in other industries. An investigation into the technical competencies that are of importance to firms and industries can be broken down into two parts: identification of competencies and analysis of the presence or absence of competencies. For the identification of technical competencies, two methods are recommended. (1) An examination of industry forecasts, technical roadmaps, and trade publications will identify many of the technical competencies associated with the industry. (2) An examination of either the SOPs or a detailed consideration of the process of a few leading firms identifies additional technical competencies that would be missed if the literature alone is to be considered. Once the technical competencies have been identified, industry experts should be invited to identify additional competencies. (This step may also result in the elimination of some competencies if they are redundant with other competencies on the list.) Having identified the technical competencies, one may either conduct an analysis on all competencies or rate of competencies to eliminate ones of low importance. We will consider how to expedite the analysis of the competencies.

The analysis of technical competencies in part depends on the purpose of the investigation. For many, the interest will relate to questions like *what technologies, if any, are important for competitive advantage*? For questions such as this, the companies that are leaders in terms of such metrics as growth, market share, reputation, and profitability are identified. Telephone interviews can then be conducted with key personnel at these firms. It is recommended that snowball sampling (Burt & Ronchi, 1994) be used with each respondent spoken to. That is not only is the respondent asked to answer the technical competence questions, but also asked to identify the names of other firms, supplier, customers, and consultants in the industry. In the case of a firm, each firm would be asked about other firm's abilities (competitors). By making inquiries into other industries that the firm is involved in, the transferability of the competencies across industries can be identified. In the case of suppliers, customers, and consultants, they would be asked to rank all the firms that the respondent is familiar with. Sampling stops when interviews have been conducted with every respondent that has been identified by another respondent. And all respondents have had the opportunity to rank all the firms. The proposed method offers the high level of

validity, through triangulation, that our study offers. It requires less time, however, because there is no attempt to identify all the firms that existed and locate their employees. This approach identifies all firms that are active in the industry. Through the use of telephone interviews, interaction with a respondent will be less than an hour. Consequently, it is possible to conduct an analysis of technical competencies for an industry in 1–2 months, as opposed to the 2 years worth of effort required in this study. Having discussed the results and ways to reduce the effort required for the collection of data, suggestions for future study and conclusions are offered.

7. Future study

Based on examination of the effect of the SIC code on Crohnbach's alpha for the technical competence, there is little or no value in including the SIC code as a measure. Furthermore, existing theory does not require the inclusion of the SIC code. Consequently, future studies need not include SIC code as a measure of technical competence.

Future studies should use a Likert scale to measure technical competence. Replacing the current dichotomy with a Likert scale will provide information on the degree to which the technical competence exists. We recommended a 10-point Likert scale with the following category labels: has no; may have some; may have; has some, but weak; has some; has; has strong; has very strong; world class; best in world.

Additional studies must be compared to this work to gain a better understanding of the construct and predictive validity of the technical competence.

8. Conclusions

This study is an important step in moving technical competence research from the realm of trade publications to a quantifiable management science. Consequently, the study of the technical competence scale in some cases provides a first step that must be followed up by further research.

However, this study does make numerous contributions of it own. A series of questions that can be used for the study of technical competence, and possible management capability, has been developed and tested. Technical competence has been show to consist of a single trait. Content validity has been achieved through the use of working that is very similar to previous work. Construct validity is partially addressed by the high correlation between item scores and the scale, excluding the item. A method of conducting an analysis of technical competencies for any industry in under 2 months is described. The existence of bundles of competencies within an industry is shown. And the reliance that these bundles have on a single knowledge base is also illustrated.

The results of this study suggest that technical competence can be measured reliably. However, additional studies are required to further establish the reliability and validity of this scale.

Appendix A.

Table A: Summary description of the interviewees from firms studied

Source of data on learning methods utilized							
Company	President	VP/GM	Director	Manager	Others	Archival data	Number of sources
ALL	2	2	2	2	2	yes	11
AT	1	1			2	yes	5
ASIMI	1	4	2	2	2	yes	12
ATO	1		1		2	yes	5
AMTK			1	1	2	yes	5
CHISSO		1	1		4	yes	7
CENT			1	1	2	yes	5
CS				1	1	yes	3
CM		1	1	1	3	yes	7
DU		1	1	1	2	yes	6
DEL-C			1	1	1	yes	4
DN			1	1	3	yes	6
DYNO	1	2	1	1	2	yes	8
DOW	1	3	1	1	4	yes	11
EP		1	1	1	1	yes	5
EPAGA			1	1	1	yes	4
ELMAT	2		1	1	2	yes	7
EC	1	1	1	1	3	yes	8
FAIR-C		1	1	1	3	yes	7
FU-C				1	2	yes	4
FUJIT-C				1	2	yes	4
FUTURE		1	1	2	2	yes	7
FOOTE					3	yes	4
GIBSS					3	yes	4
GTE-C			1	1	1	yes	4
GRACE		1	1	1	2	yes	6
GE-C			1	1	2	yes	5
GD-C				1	2	yes	4
GALAP		1	1		1	yes	4
GENSIL				1	3	yes	5
GENSD-C				1	3	yes	5
GWAF			1	1	2	yes	5
GWGE			1	1	2	yes	5
GWNK				1	1	yes	3
H	1	1	1	1	4	yes	9
HDS		1	1	1	4	yes	8

HD		1	1	1	4	yes	8
HDMO		1	1	1	4	yes	8
HDMOS		1	1	1	4	yes	8
HU-C		1	4	2	4	yes	12
HOB					3	yes	4
HT		1	1	1	3	yes	7
HLC				1	3	yes	5
HIMO			1	1	1	yes	4
HM			1	1	1	yes	4
HULLS		1	4	4	4	yes	14
IBM-C		1	1	1	3	yes	7
ITT-C			1	1	3	yes	6
KOL		1	1	1	2	yes	6
KAW	1	1	1	1	2	yes	7
KOM	1	2	2	2	2	yes	10
KEV					3	yes	4
LG-C			1	1	2	yes	5
LCMER			1	1	2	yes	5
MCW			1	1	2	yes	5
MA-C				1	1	yes	3
MMS	1	1	1	1	3	yes	8
MSJS		2			1	yes	4
MERK		1		1	2	yes	5
MOTO-C		3	2	1	2	yes	9
MT-C			1	1	1	yes	4
MON	3	5	5	5	3	yes	22
MONTY		2	1	1	3	yes	8
MSNIEL			1	1	1	yes	4
NEC-C				1	2	yes	4
NS		1	1	1	3	yes	7
NB				1	2	yes	4
NKK			1	1	2	yes	5
OTCSS		2	2	2	2	yes	9
OKI		2	2	2	2	yes	9
OTCSM		1	2	2	2	yes	8
P-C						yes	1
PASCO			2		1	yes	4
HUL-CHINA				1	1	yes	3
PENVEN	1	3	1	1	2	yes	9
PHIL-C			2	2	1	yes	6
PTM-C			1	1	2	yes	5
RAY-C			1	1	2	yes	5
RR	2	2	2	2	1	yes	10

RW	1	2	2	2	4	yes	12
RP		1	1	2	4	yes	9
SMGI-C					4	yes	5
SMSIL-GI-M					4	yes	5
SIL	2				4	yes	7
SILTEC	2	2	2	2	4	yes	13
SEHD	2	2	2	2	4	yes	13
SHE	2				4	yes	7
SEC	2				4	yes	7
SD			1	1	2	yes	5
SA			1	1	2	yes	5
SI			1	1	2	yes	5
TATUNG			1	1	2	yes	5
TRAN-C		1	1	1	1	yes	5
TI-C		2	4	4	4	yes	15
TOP	1	1	1	1	1	yes	6
TOS	1	1	1	1	1	yes	6
TRW-C				1	1	yes	3
TS					4	yes	5
TD				1	4	yes	6
TSODA			1	1	4	yes	7
TONE					2	yes	3
TEL-C			1	1	1	yes	4
UC1		1	2		2	yes	6
UC2		1	2		2	yes	6
UI	1			1	1	yes	4
VM-C	1	1	1	1	1	yes	6
WE-C			2	2	1	yes	6
WES-C			2	2	1	yes	6
WACK	2	4	4	2	2	yes	15
WAKF		2	2	2	2	yes	9
PILL		1	1	1	1	yes	5
SS		1	1		1	yes	4
MATPUR		1	1	1	1	yes	5

Table B: Questions used to determine whether a technical competence was present

Questions	Possible replies
As a supplier to _____ please indicate how you perceive that corporation's capabilities in the following areas. Answer yes if you feel that firm possesses this	

capability and no if you feel that firm does not possess it or if you do not know U

1. Does this firm have a traditional silane technology capability?	Yes	No	U
2. Does this firm have traditional batch processing capabilities?	Yes	No	U
3. Does this firm have traditional crystalline materials capabilities?	Yes	No	U
4. Does this firm have traditional wafering (surfacing) capabilities?	Yes	No	U
5. Does this firm have traditional scale intensive capabilities?	Yes	No	U
6. Does this firm have traditional inorganic chemistry capabilities?	Yes	No	U
7. Does this firm have traditional controlled environment capabilities?	Yes	No	U

As a competitor of _____ please indicate how you perceive this corporation's capabilities in the following areas. Answer yes if you feel that firm possesses this capability and no if you feel that firm does not possess it or if you do not know U

1. Does this firm have a traditional silane technology capability?	Yes	No	U
2. Does this firm have traditional batch processing capabilities?	Yes	No	U
3. Does this firm have traditional crystalline materials capabilities?	Yes	No	U
4. Does this firm have traditional wafering (surfacing) capabilities?	Yes	No	U
5. Does this firm have traditional scale intensive capabilities?	Yes	No	U
6. Does this firm have traditional inorganic chemistry capabilities?	Yes	No	U
7. Does this firm have traditional controlled environment capabilities?	Yes	No	U

As an industry expert, please indicate how you perceive _____ corporation's capabilities in the following areas.
Answer yes if you feel that firm possesses this capability and no if you feel that firm does not possess it or if you do not know U

1. Does this firm have a traditional silane technology capability?	Yes	No	U
2. Does this firm have traditional batch processing capabilities?	Yes	No	U
3. Does this firm have traditional crystalline materials capabilities?	Yes	No	U
4. Does this firm have traditional wafering (surfacing) capabilities?	Yes	No	U
5. Does this firm have traditional scale intensive capabilities?	Yes	No	U
6. Does this firm have traditional inorganic chemistry capabilities?	Yes	No	U
7. Does this firm have traditional controlled environment capabilities?	Yes	No	U

As a customer or potential customer of _____ please indicate how you perceive this corporation's capabilities in the following areas. Answer yes if you feel that this firm possesses this capability and no if you feel that firm does not posses it or if you do not know U

1. Does this firm have a traditional silane technology capability?	Yes	No	U
2. Does this firm have traditional batch processing capabilities?	Yes	No	U
3. Does this firm have traditional crystalline materials capabilities?	Yes	No	U

4. Does this firm have traditional wafering (surfacing) capabilities?	Yes	No	U
5. Does this firm have traditional scale intensive capabilities?	Yes	No	U
6. Does this firm have traditional inorganic chemistry capabilities?	Yes	No	U
7. Does this firm have traditional controlled environment capabilities?	Yes	No	U

Please indicate how you perceive your corporation's capabilities in the following areas. Answer yes if you feel that your firm possesses this capability and no if you feel your firm does not possess it or if you do not know U

1. Does your firm have a traditional silane technology capability?	Yes	No	U
2. Does your firm have traditional batch processing capabilities?	Yes	No	U
3. Does your firm have traditional crystalline materials capabilities?	Yes	No	U
4. Does your firm have traditional wafering (surfacing) capabilities?	Yes	No	U
5. Does your firm have traditional scale intensive capabilities?	Yes	No	U
6. Does your firm have traditional inorganic chemistry capabilities?	Yes	No	U
7. Does your firm have traditional controlled environment capabilities?	Yes	No	U

Table C: Summary of the presence or absence of a technical competence for each firm studied

Company	Crystalline material	Batch process	Controlled environment	Inorganic chemistry	Scale	Silane intensive	Wafering
ALL	0	1	0	1	1	0	0
AT	0	1	NA	NA	NA	0	0
ASIMI	0	1	1	1	1	0	0
ATO	0	1	NA	0	0	0	0
AMTK	NA	NA	NA	NA	NA	0	NA
CHISSO	0	1	NA	1	NA	0	0
CENT	NA	NA	NA	NA	NA	NA	0
CS	NA	1	NA	NA	NA	NA	NA
CM	0	0	0	0	0	0	1
DU	0	1	1	1	1	0	0
DEL-C	0	1	1	1	NA	0	0
DN	0	1	1	1	1	0	0
DYNO	NA	NA	NA	NA	NA	NA	NA
DOW	0	0	1	1	1	1	0
EP	1	1	1	1	1	0	0
EPAGA	1	1	1	1	1	0	0
ELMAT	0	0	0	0	NA	NA	1
EC	0	1	1	1	1	0	0

FAIR-C	0	1	1	1	0	0	0
FU-C	NA	1	NA	1	0	0	0
FUJIT-C	0	1	NA	NA	0	0	0
FUTURE	1	0	NA	0	NA	0	0
FOOTE	0	1	1	1	1	0	0
GIBSS	NA	NA	NA	NA	NA	NA	NA
GTE-C	NA	NA	1	1	0	0	0
GRACE	0	1	1	1	1	0	0
GE-C	0	1	1	1	0	0	0
GD-C	0	1	1	1	0	0	0
GALAP	0	0	0	0	0	0	1
GENSIL	NA	NA	NA	NA	NA	NA	NA
GENSD-C	NA	NA	NA	0	NA	NA	0
GWAF	NA	1	1	0	0	0	0
GWGE	NA	1	1	1	1	1	0
GWNK	0	NA	NA	0	NA	NA	0
H	0	1	1	1	NA	NA	0
HDS	0	1	1	1	1	1	0
HD	0	1	1	1	1	1	0
HDMO	0	1	1	1	1	1	0
HDMOS	0	1	1	1	1	1	0
HU-C	0	1	1	1	0	0	0
HOB	NA	NA	NA	NA	NA	NA	0
HT	NA	0	NA	0	NA	0	0
HLC	NA	NA	NA	NA	NA	NA	0
HIMO	1	1	1	1	1	1	0
HM	NA	1	1	1	1	1	0
HULLS	1	1	1	1	1	1	0
IBM-C	0	1	1	1	0	0	0
ITT-C	0	1	1	1	0	0	0
KOL	0	0	0	0	0	0	0
KAW	1	1	1	1	1	0	0
KOM	1	1	1	1	1	0	0
KEV	NA	NA	NA	NA	NA	NA	NA
LG-C	1	1	1	1	0	0	0
LCMER	NA	1	1	1	0	0	0
MCW	0	1	1	1	1	0	0
MA-C	0	1	1	1	1	0	0
MMS	0	1	1	1	1	0	0
MSJS	0	1	1	1	1	1	0
MERK	0	1	1	1	1	0	0
MOTO-C	0	1	1	1	0	0	0
MT-C	0	1	1	1	0	0	0

MON	0	1	1	1	1	0	0
MONTY	0	1	1	1	1	0	0
MSNIEL	0	1	1	1	1	0	0
NEC-C	1	1	1	1	0	0	0
NS	1	1	1	1	1	0	1
NB	0	1	1	1	1	0	0
NKK	0	1	1	1	1	0	0
OTCSS	1	1	1	1	1	0	0
OKI	1	1	1	1	1	0	1
OTCSM	1	1	1	1	1	0	1
P-C	1	1	1	1	0	0	0
PASCO	1	1	1	1	1	1	1
HUL-CHINA	1	NA	1	1	1	1	0
PENVEN	0	1	1	1	1	1	1
PHIL-C	1	1	1	1	0	0	0
PTM-C	0	1	1	1	0	0	0
RAY-C	0	1	1	1	0	0	0
RR	0	1	1	0	0	0	0
RW	0	1	1	1	0	0	0
RP	0	1	1	1	1	0	0
SMGI-C	0	1	1	1	NA	0	0
SMSIL-GI-M	0	1	1	1	NA	0	NA
SIL	0	1	1	1	1	0	0
SILTEC	0	1	0	0	0	0	1
SEHD	1	1	1	1	1	1	0
SHE	0	1	1	1	1	1	1
SEC	0	1	1	1	1	1	1
SD	0	1	NA	1	NA	0	1
SA	0	0	NA	NA	0	NA	1
SI	0	0	0	0	0	0	0
TATUNG	1	1	1	1	1	0	0
TRAN-C	0	1	1	1	0	0	0
TI-C	NA	1	1	1	0	0	0
TOP	0	1	1	1	0	0	0
TOS	1	1	1	NA	1	0	1
TRW-C	0	1	1	1	0	0	0
TS	0	1	NA	1	1	1	0
TD	NA	NA	NA	NA	NA	1	NA
TSODA	NA	1	NA	1	NA	1	0
TONE	NA	NA	NA	NA	NA	NA	NA
TEL-C	0	1	NA	1	NA	0	0
UC1	1	0	1	1	1	1	0
UC2	1	0	1	1	1	1	0

UI	NA	NA	NA	NA	NA	NA	NA
VM-C	0	1	1	1	NA	0	0
WE-C	1	1	1	1	0	0	0
WES-C	1	1	1	1	0	0	0
WACK	1	1	1	1	1	1	0
WAKF	NA	1	1	1	1	1	0
PILL	0	1	NA	NA	NA	0	NA
SS	0	1	NA	NA	NA	0	NA
MATPUR	NA	1	1	1	1	0	0

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